THE 12TH INTERNATIONAL CONFERENCE ON ENGINEERING, PROJECT, AND PRODUCTION MANAGEMENT

EPPM2022

CONFERENCE PROCEEDINGS

EDITED BY:

Kriengsak Panuwatwanich

Chien-Ho Ko

John-Paris Pantouvakis

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Edited by:
Kriengsak Panuwatwanich, Thammasat University, Thailand
Chien-Ho Ko, University of Kansas, United States
John-Paris Pantouvakis, National Technical University of Athens, Greece

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Correspondence:
All correspondence pertaining to the EPPM2022 Conference should be sent to:
John-Paris Pantouvakis
National Technical University of Athens, Greece
Email: jpp@central.ntua.gr

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EDITORIAL

The 12th International Conference on Engineering, Project, and Production Management (EPPM2022) is the first onsite event of the EPPM conference series after the COVID-19 global pandemic that began in the first half of 2020. Although the previous conference experienced some set back due to this pandemic, the presence of delegates in this year's conference demonstrates the resilience of our community of researchers, scholars, and practitioners in the fields of engineering, project, and production management across the globe. The authors of the EPPM2022 conference continue to shed light on the recent advancement in the fields - many have also paved the way for post-pandemic directions for research and development. Undoubtedly, the EPPM2022 conference continues to serve as a platform for researchers, scholars, and practitioners to share and exchange ideas and knowledge that are applicable across multiple industries. We believe that the conference participants will benefit greatly by building upon each other's experiences and lessons learnt gained from fresh and emerging perspectives after the pandemic.

The EPPM2022 conference features 47 quality papers selected through a double-blind peer-review process by the members of our International Scientific Committee of experts in the fields. These 47 papers constitute eight main themes: smart manufacturing and logistics; project management; modern technology in architecture, engineering, and construction (AEC); smart and sustainable building; legal and contracts; simulation, prediction and foresight; and productivity and safety. Among these 47 papers, 23 papers have been nominated for further editorial review for publication in a special issue of the Journal of Engineering, Project, and Production Management. In total, 28 papers are finally included in this book of proceedings.

As Editors, we would like to express our sincere gratitude to all authors for their valuable contributions to the conference. We would like to especially thank the members of the International Scientific Committee for taking their valuable time and effort to review the papers to assure their quality. We sincerely hope that this proceedings will be of interest and valuable to researchers and practitioners across multiple industries who are seeking to update their knowledge in engineering, project, and production management.

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Kriengsak Panuwatwanich
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ORGANIZING COMMITTEE'S DECLARATION

All the papers in these conference proceedings were double-blind reviewed by members of the International Scientific Committee. This process entailed detailed reading of the papers, reporting of comments to authors, modification of papers by authors, and re-evaluation of revised papers to ensure quality of the content.

PEER REVIEW PROCESS

A rigorous two-stage peer review process was applied to this conference to maintain and assure the quality of the conference proceedings. In the first stage, submitted abstracts were evaluated by the Scientific Committee Chairs in terms of:

- Relevance to conference theme and objectives;
- Originality of material;
- Academic rigour;
- Contribution to knowledge; and
- Research methodology.

Authors, whose abstracts were tentatively accepted in the first stage, were requested to submit full papers for further review. Each paper was reviewed by acknowledged experts in the field with unidentified reviewers' comments. Authors were requested to submit their revised papers noting and addressing reviewers' comments. Evidence was required relative to the action taken by authors regarding the comments received. These resubmitted and revised papers were re-reviewed again in terms of:

- Relevance to conference theme and objectives;
- Originality of material;
- Academic rigour;
- Contribution to knowledge;
- Research methodology and robustness of analysis of findings;
- Empirical research findings; and
- Critical current literature review.

In the second review stage, authors were provided with additional comments and requested to submit their revisions. The final accepted decision was rendered when Scientific Chairs confirmed that all reviewers' comments were appropriately responded to, having been double peer-reviewed for publication. At no stage was any member of the Scientific Chairs and International Scientific Committee involved in the review process related to their own authored or co-authored papers.

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KEYNOTE SPEAKERS

Leonidas Phoebus KOSKOS

Leonidas Phoebus Koskos is an attorney-at-law and member of the Athens Bar Association. He has served as the Executive Vice President, Deputy Chairman, and President of various Greek industries. He was the Chairman and Governor of the National Welfare Organization, Chairman and President of the Confederation of Greek Food Industries, President of Confederation of Agro-food Industries of the European Union in Brussels, and member of the Board of Directors of the Hellenic Federation of Enterprises. He co-founded the National Council for Free Enterprise Greece, which he served as Secretary General and President. He taught philosophy of law and jurisprudence at the University of Athens Law School and gave lectures at the Economic University of Athens. He has delivered talks at chambers of commerce and professionals associations and organized and spoke at conferences in Greece and abroad. He is a member of the Board of Directors of the Center for Liberal Studies- Markos Dragoumis, Chairman of the Board of Directors of Hellenic American Union, and President of Hellenic American University.

Prof David CHUA KIM HUAT

Prof DAVID CHUA KIM HUAT graduated from Adelaide University with BEng (1st class) in 1980 on a Colombo Plan Scholarship. In 1986 he obtained his MEng National University of Singapore. In 1986 he obtained his MSc and subsequently completed his PhD dissertation on a network pavement management system using reliability-based mechanistic pavement distress models in 1989. He now serves as Professor & Deputy Head at the Department of Civil and Environmental Engineering, National University of Singapore. His research is mainly in areas relating to transportation and construction management with emphasis on lean construction, information technology applications, systems modelling and risk management. He has been involved in many consulting projects for the Mass Rapid Transit Corporation of Singapore, the Land Transport Authority, the Maritime Port Authority, Chartered Systems Manufacturing and other companies and joint ventures.

Michail D. DAKTYLIDIS

Michail D. DAKTYLIDIS graduated from the Aristotle University of Thessaloniki (AUTH) in 1975. Up to 1985 he has been head of Construction sites at EDOK-ETER, a large construction company working in public works in Greece and in Libya.

He is currently Chairman of "MENTOR S.A." working in construction of Public and Private Works. Mr. Daktylidis is PEDMEDE (Panhellenic Association of Engineers Contractors of Public Works) President since 2017, while he was holding the position of Vice President since 2005.

He also holds the position of FIEC (European Construction Industry Federation) Vice President from 2014 up to 2022. He is also EDA (European Demolition Association) Vice President.

Mr. Daktylidis is also the legal representative of PEDMEDE ECO a Collective Waste Management System of Excavations, Demolition and Construction Waste organization founded recently by PEDMEDE.

National Technical University of Athens (NTUA) - School of Civil Engineering, Laboratory of Construction Equipment & Project Management

The National Technical University of Athens (NTUA) was founded in 1837 and today is the most prestigious among engineering schools in Greece with global reputation (*among the 500 best Universities worldwide*). It is also a symbol of democracy due to the student uprising of November 1973 against the then ruling dictatorship which is celebrated yearly nationwide on November 17. NTUA's emblem portrays *Prometheus* the mythical Titan god of fire who defied the gods by stealing fire from them and giving it to humanity in the form of technology, knowledge, and more generally, civilization.

The university comprises about 409 of academic staff, 200 scientific assistants, 118 technical staff, 525 administrative staff, 1,500 Ph.D. students and 250 researchers. Around 22,000 undergraduate students attend 9 academic schools and 150 laboratories in engineering disciplines, architecture and applied sciences. Undergraduate studies last for 5 years and lead to a combined Master's degree. Around 1,500 postgraduate students attend 20 interdisciplinary postgraduate taught programmes. NTUA participates in more than 1,500 research programmes and it is ranked first in Greece and among the top 10 in the European Union in attracting research funding. NTUA enjoys more than 550 international academic collaborations with Institutions around the globe.

Admission to NTUA is highly selective and can only be accomplished through achieving exceptional grades in the annual entry examinations.

The School of Civil Engineering, ranked 4th worldwide and 2nd in Europe (*Shanghai rankings*, 2021), comprises of 4 departments (Structural Engineering, Water Resources and Environmental Engineering, Transportation Planning and Engineering and Geotechnical Engineering) and 14 laboratories.

The Laboratory of Construction Equipment & Project Management is one of the 5 laboratories of the Structural Engineering department. Its origins go back to mid 1950s when Professor Garbotz of the University of Aachen, Germany (nicknamed the "*Pope of Construction Machinery*") was invited to give lectures on construction equipment to NTUA Civil Engineering students. The laboratory was formally established in 1960 and it has been renamed in 2002. Today is ISO9001 certified and is the only laboratory in Greece equipped with fully fledged construction equipment simulators. Since 2007 it incorporates the Centre for Construction Innovation (CCI), the first organization in Greece to certify project management competencies with international recognition.

Association of Engineering, Project, and Production Management

Call for members

Purpose

The Association is an academic organization dedicated to encouraging the exchange of ideas, research, and other professional activities that are of an interdisciplinary nature relating to the engineering, project, and production management, while being dedicated to freedom of discussion and research, and undertakes to avoid a prejudiced attitude with respect to any individual, group, political philosophy, or research method.

Activities

The Association conducts the following activities:

- to organize academic meetings, lectures, and conferences
- to issue academic journals, scholarly books, and newsletters
- to conduct researches and surveys in its area of interest
- to promote the professional activities of its members
- to conduct commissioned researches and surveys
- to engage in other activities necessary for the achievement of its purpose.

Membership

- Honorary Member
- Regular Member
- Student Member
- Organizational Member

Registration forms can be downloaded at http://www.ppml.url.tw/EPPM/association.htm. Applicants should fill out the registration form and e-mail it to eppm.association1@gmail.com for approval. Registration is FREE.

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Paper no. 9

Social-psychological Insights into Energy-saving Behaviours: An Occupant Survey in New Zealand

Achini Shanika Weerasinghe[1], Eziaku Onyeizu Rasheed[2] and James Olabode Bamidele Rotimi[3]
[1]PhD Student, School of Built Environment, Massey University, Private Bag 102904, North Shore, Auckland 0745, New Zealand, E-mail: A.Weerasinghe@massey.ac.nz (corresponding author).
[2]Senior Lecturer, School of Built Environment, Massey University, Private Bag 102904, North Shore, Auckland 0745, New Zealand, E-mail: E.O.Rasheed@massey.ac.nz
[3]Associate Professor, School of Built Environment, Massey University, Private Bag 102904, North Shore, Auckland 0745, New Zealand, E-mail: J.Rotimi@massey.ac.nz

Abstract: There is a great potential for reducing energy consumption in office buildings through occupant energy-saving behaviours. While various factors influence these behaviours, previous studies emphasise environmental and contextual factors with little consideration of social-psychological factors. Therefore, this study investigates the social-psychological insights into energy-saving behaviours based on the general occupancy survey data collected from 294 office occupants in New Zealand. One-way ANOVA and descriptive analysis is used to provide insights into user control availability, occupants' energy-saving behaviours, and social-psychological effects across different demographic groups. ANOVA results indicated significant differences (P value < 0.05) exist in the availability of user control, occupants' energy-saving behaviours, and social-psychological effects across the demographic groups, primarily visible across the ethnicity and region groups. The results further revealed an increasing trend (more than 60% of the respondents agreed) of adjusting to the indoor environment and occupants' social-psychological effects such as attitude, personal norms, perceived control in terms of comfort needs and preferences, and actual and perceived knowledge to save energy. In addition, there was a lack of organisational support (40% or more than 40% agreed) and behavioural intervention (60% or more than 60% responses received), which is necessary for encouraging occupants to save energy while giving them more responsibility for their energy consumption. This study contributes decision-makers such as building owners, energy modellers, facilities managers, and policymakers to tailor energy-saving implications based on these social-psychological effects. Furthermore, the current study could be extended by applying more advanced statistical analysis methods to develop a comprehensive framework that evaluates occupant energy behaviours in office buildings.

Keywords: Demographics, energy-saving behaviours, occupants, office buildings, social-psychological insights.

1. Introduction

Considerable attention has been given to the influence of occupant behaviours on building energy consumption. The studies have focused on understanding different occupant behaviours and analysing their impact on energy for certain behaviours. For instance, empirical studies define and classify the occupant energy behaviours in buildings as adaptive and non-adaptive behaviours (O'Brien and Gunay, 2014; Hong et al., 2017). Furthermore, studies pinpoint that adaptive occupant actions directly depend on occupants' comfort requirements and influence overall building performance in building energy consumption (Wang et al., 2016; Bavaresco et al., 2021). For example, Masoso and Grobler (2010) reported that more than 50% of total energy consumption was consumed after regular working hours in commercial buildings in South Africa due to occupants failing to turn off the lights and heating, ventilation, and air conditioning (HVAC) system when leaving the buildings. A study by Staats et al. (2004) estimated a modest 6% savings in energy by providing energy usage feedback in terms of thermostat use and diffuser covering. In another study, Dietz et al. (2009) highlighted that a 7.4% of US emissions reduction can be expected through occupant energy savings.

Furthermore, many pieces of research have been developed around understanding occupant behaviours for energy use predictions at the design stage. However, it has been observed that accurate forecasts of occupant behaviour have rarely been achieved due to the complex nature of occupant behaviours arising from multiple factors (Rupp et al., 2021; Uddin et al., 2021). For example, it is frequent to treat occupant behaviours as static and deterministic in energy performance simulation, although they are stochastic, diversified, and dynamic

(Hong et al., 2018). Another set of studies estimated the building operation costs based on the building characteristics or energy-efficient technologies (Weerasinghe et al., 2020a; Weerasinghe et al., 2021). However, a more realistic and robust representation and modelling of occupant behaviours could help to improve building simulation accuracy and understand the building design-operation performance gap (Wang et al., 2019). Similarly, there is a lack of collective agreement on occupant behaviour modelling and simulation approaches (Hong et al., 2017). Enriching knowledge about the effect of multiple factors may improve occupant behaviour models for Building Performance Simulations (Carlucci et al., 2020).

Recently, social-psychological perspectives of building occupants received increasing attention, emphasising the implication of behavioural theories and frameworks. Mainstream theories and frameworks are namely the theory of planned behaviour (TPB), norm activation model (NAM), social cognitive theory (SCT), drivers, needs, actions, and systems (DNAS), and motivation-opportunity-ability (MOA) (D'Oca et al., 2017; Fu et al., 2021; Hong et al., 2015; Li et al., 2019; Liu et al., 2021). Within the occupants' energy-saving behaviour research, the majority emphasise the influence of attitude, personal norms, subjective norms, perceived behavioural control (PBC), perceived awareness, and knowledge on the energy consumption of both residential and commercial buildings (Deme Bélafi & Reith, 2018; Li et al., 2019; Liu et al., 2021; Rissetto et al., 2022). Other aspects such as individual's personality traits, emotions, beliefs, and motivations are mainly relevant to residential buildings (Hewitt et al., 2015; Mack et al., 2019; Murtagh et al., 2019; Shen et al., 2022).

However, Heydarian et al. (2020) found that social-psychological perspectives/constructs should be further evaluated to identify the best fit for implementing energy-saving practices in office buildings. Specifically, understanding occupants' mentality on energy-saving is significant as commercial buildings open to flexible working solutions but complex energy operations in the post-pandemic situation (Mantesi et al. 2022). Additionally, despite the highlighted need to understand the influence of various driving factors and integrate them into occupant behaviour modelling and simulation approaches, the literature lacks identification of social-psychological insights of occupants towards energy-saving behaviours (Shi et al., 2017; D'Oca et al., 2018; Li et al., 2019).

Furthermore, research in different climate zones or countries to identify the variations of behaviours in a different context, culture, climate, and socio-economical background is recommended to provide new insights into occupant adaptive behaviours (D'Oca et al., 2018; D'Oca et al., 2019; Rupp et al., 2021). Although empirical studies have developed various frameworks that include social-psychological factors (D'Oca et al., 2018; Li et al., 2019; Bavaresco et al., 2021), the applicability of these frameworks are not evaluated for most countries. Specially, in New Zealand, studies focused on occupant energy behaviours are limited (Azizi et al., 2019; Weerasinghe et al., 2020b) and focused on the behaviours in response to thermal comforts (Azizi et al., 2015a), and the computer usage behaviour of occupants (Azizi et al., 2015b). In contrast, these studies ignored the occupant lighting on/off behaviour, fan usage, clothing adjustment, moving through spaces, and occupants' non-adaptive behaviours such as reporting discomfort and taking no action. Furthermore, the studies do not represent the social-psychological effects on energy-saving behaviours.

Therefore, the current study aims to evaluate and identify the social-psychological insights relating to energy-saving behaviours across the general office building occupants in New Zealand. The specific objectives of the study include: (1) assess the availability of user control; (2) identify the occupants' energy-saving behaviours and practices; and (3) highlight the social-psychological insights based on the socio-demographic characteristics of the general office building occupants in New Zealand.

The study contributes to the researchers in this field by highlighting the insights associated with social-psychological effects on adaptive and non-adaptive occupant behaviours in offices. It also helps building owners, energy modellers, facilities managers, and policymakers to promote energy-saving behaviours among office building occupants.

2. Literature Review

Experimental studies have demonstrated that occupants vary in comfort preferences, satisfaction, and indoor environment perceptions due to many factors confirming the stochastic, diverse and complex nature of occupant behaviours in buildings (Schakib-Ekbatan et al., 2015; Schweiker et al., 2015). In addition, the availability and the accessibility of user controls in the buildings are critical as it links humans and the building through their interactions with these building controls and systems (O'Brien and Gunay, 2014). For instance, Onyeizu (2014) identified that occupants who control the temperature were highly satisfied with the thermal comfort of the space. Similarly, a lack of user control leads to a potential lack of motivation to save energy (Papadopoulos and Azar, 2016).

Furthermore, previous studies also considered social-psychological constructs such as attitudes, social norms, PBC, knowledge, organisational support, and behavioural intervention (energy feedback, messages) (Vellei et al., 2016; D'Oca et al., 2019; Li et al., 2019). For example, the occupants with a more positive attitude toward saving energy are the ones who have the most intentions to conduct energy-saving behaviours (Obaidellah et al., 2019). On the other hand, Gao et al. (2017) stated that if occupants are aware of the significance of energy-saving behaviour, they hold a positive attitude and intend to save more energy.

Moreover, Nie et al. (2019) investigated the careful-use behaviours regarding appliance usage and lighting and found that the subjective norm variable had the most significant effect on behavioural intention. On the contrary, Chen et al. (2017) found that subjective norms were no longer significant in predicting intentions when additional factors were added to the regression model. While subjective norms highlight the perceived social pressure, personal norm indicates occupants' self-obligation to save energy by directly impacting environmental intention and behaviour (Kim & Seock 2019).

Another aspect, PBC was deemed positive, significantly affecting adaptive behaviour choices related

to HVAC control, windows, and shades/blinds (Bavaresco et al., 2020). However, the higher degree of control and relevant knowledge and skills on energy-saving influence occupants' intention to practice a particular behaviour and save energy (Gao et al., 2017). For instance, occupants with higher perceived and actual knowledge of energy consumption and related savings are more likely to save energy than occupants without much knowledge (Abrahamse and Steg, 2009).

Organisational support and behavioural intervention positively drives pro-environmental behaviours of the employees to promote energy-saving (Xu et al., 2017). Vellei et al. (2016) discovered that feedback intervention and occupants' perceived control promote energy-saving adaptive behaviours, such as wearing more clothes when they feel cold and controlling the windows more effectively. Behavioural intervention in terms of providing energy feedback and report is usually analysed outside the social-psychological domain. Intergating this variable would facilitate the constraining factors identified with the previous social-psychological frameworks. When energy-saving behaviours are considered individually, physiological and social-psychological factors are mainly related to adjusting thermostats and plug-ins behaviours. However, the studies that adopted social-psychological theories (D'Oca et al., 2019; Li et al., 2019; Bavaresco et al., 2020) focused on mixed behaviours.

The above highlighted social-psychological constructs influence the occupants' energy-saving behaviours. However, the influence of these factors may vary significantly depending on the different contexts or the demographic factors. Therefore, identifying social-psychological constructs influencing occupant behaviours should be carefully done by considering the effect of demographic factors (Hong et al., 2017). Notwithstanding the importance of demographic variables such as age, gender, population, culture, and location, the commercial buildings received limited attention. At the same time, the literature has widely covered residential building-related contexts such as household income, household size, number of children, age, and income (Hong et al., 2017). However, the specific results in residential buildings cannot be applied to office buildings due to the diverse and unique characteristics of those who live in residential buildings (Putra et al., 2021). In addition, many studies in the office building context showed the direct impact of socio-demographics on dependent variables (energy-saving intentions and occupant behaviours), while they failed to show how the influence of social-psychological constructs varies due to demographics (Azar and Al Ansari, 2017; Park and Nagy, 2020; Xie et al., 2021).

Along these lines, the current study investigates the context specific social-psychological insights on energy-saving behaviours in New Zealand office buildings.

3. Methods

This study explored the occupant perceptions on accessibility to user control, occupants' energy-saving behaviours, and social-psychological effects on office building occupants in New Zealand. The study used a survey approach to capture the occupants' perspectives on user control, occupants' energy-saving behaviours, and social-psychological effects. In the past, quantitative methods such as questionnaire surveys were used to study occupants' energy-related behaviours and develop occupant energy models (Day and O'brien, 2017), which provide more insights than experiments and field observations in this research field (Hong et al., 2017).

3.1. Survey structure and measures

The questionnaire consists of four (04) sections: background-related questions (gender, age, ethnicity, employment status, work duration, and region), user control and occupant behaviours related questions, and the social-psychological factors of building occupants. The survey questions included in Table 1 were adapted from previous literature. The questions relating to attitude, subjective norms, and PBC were adapted from Abrahamse and Steg (2009), personal norms from Zhang et al. (2013), perceived and actual knowledge, organisation support, behavioural interventions, and accessibility to control were adapted from Li et al. (2019), while OB related questions were adapted from (Hong et al. 2018). The questionnaire included multiple-choice questions for background-related questions, whereas all the other aspects were measured using a 5-point Likert scale representing 1- strongly disagree, and 5-strongly agree.

Table 1. Survey questions and constructs

#		Questions	Social-psychological constructs
1		Demographic Information	
		Availability of user control	
2	A	I have personal control over most of the appliances	
		Occupants' energy-saving behaviours	
3	A	I often report discomforts related to indoor environmental quality	
	B	I am willing to accept and do nothing about the existing indoor environmental conditions	
	C	I often adjust building appliances to satisfy my comfort preferences	
	D	I often adjust myself to the environmental conditions by adjusting clothing, drinking hot/cold beverages, and moving through spaces	
		Social-psychological effects	
4	A	Saving energy at work is important to me	Attitude
	B	I feel responsible at to save energy	Personal norms
	C	My co-workers expect me to save energy at work	
	D	Most of my co-workers expect me to turn off electrical appliances	Subjective norms
	E	Sharing control over building systems with my co-workers is easy	
	F	Saving energy during work is	Perceived

	entirely within my control	behavioural control
G	Actions I take to save energy depending on my comfort preferences	
H	I am aware that reducing energy use will reduce cost	
I	I am aware that reducing energy use will reduce emissions	Actual knowledge
J	I am aware that reducing energy use will improve my organization's image/reputation	
K	I often close windows, turn off the lights, heaters, fans, computers, etc., whenever I leave the office, and unplug appliances when not in use	
L	If I feel slightly cold at the workplace, I would put on another layer of clothing instead of using the heater	Perceived knowledge
M	If I feel slightly warm at the workplace, I would adjust my clothing level instead of using the air conditioner	
N	My company encourages employees to save energy	Organisational support
O	My company rewards employees for saving energy	
P	The feedback on individual energy use by our building management team is important for me to change my energy-driven behaviour	Behavioural interventions
Q	Our building management team often sends energy use reports	

3.2. Data collection and Analysis

A questionnaire was disseminated in-person and online through the Qualtrics survey platform from July to November 2021. The participants for the study were conveniently selected from the general population of employees who work full-time and part-time in any office space in New Zealand. The total workforce of New Zealand who employed full-time and part-time as managers, professionals, community and personal service workers, and clerical and administrative workers equals 1,869,481, according to 2018 Census data (Stats NZ, 2022). A recent survey conducted in New Zealand concluded that only 22% (out of 2,560 respondents) would like to work from home daily, and the majority (67%) prefer a mix of working remotely a few times a week or month during COVID19 and post lockdown situation (O'Kane et al., 2020). Accordingly, assuming a population proportion of 0.75 who work in an office space from the population selected, a minimum sample size of 289 with 95% confidence and a margin of error of 5% was considered for the current study (Calculator.net 2022; Saunders et al., 2019). Accordingly, 294 valid responses were received from the survey distribution and continued for the analysis.

A most commonly used statistical method in the social sciences, one-way analysis of variance (ANOVA) was used to analyse the variance of energy-saving behaviours and social-psychological perspectives in different demographic groups (i.e., age, gender, ethnicity, and location). After identifying any significant variance, the social-psychological perspectives were illustrated against those demographic variables. Statistical Package for Social Sciences (SPSS) version 27 and Minitab 19 software were used for the data analysis.

4. Results

4.1. Participants

The survey was conducted across the general office building occupants who work full-time and part-time in any office space in New Zealand. 294 respondents who filled out the questionnaire survey were used for the analysis. Table 2 summarises the demographics of the participants. As seen in Table 2, respondents consist of most males (61.2%) and building occupants aged 30 or older (85%). Ethnicity-wise, most respondents were New Zealand Europeans (53.7%). Amongst the respondents, 90.8% are working full-time, and 70.1% have been working in the current workplace for a year or more. These higher percentages on employment status and work duration provide insights into that most occupants are familiar with their surroundings. Most of the respondents (41.5%) are based in Auckland. Based on the demographic characteristics of the selected sample, gender, age, ethnicity, and region-related data were further utilised to identify the social-psychological insights.

Table 2. Demographics of the participants

Background	Responses	Percentage
Gender		
Male	180	61.2
Female	112	38.1
Prefer not to answer	2	0.7
Age		
30 or older	250	85.0
Under 30	44	15.0
Ethnicity		
NZ European	158	53.7
Other	73	24.8
Asian	54	18.4
Māori/Pacific peoples	9	3.1
Employment status		
Full-time	267	90.8
Part-time	15	5.1
Other	12	4.1
Work Duration		
A year or more	206	70.1

Less than a year	88	29.9
Region		
Auckland	122	41.5
Manawatu-Whanganui	106	36.1
Other	66	22.4

4.2. Demographic group analysis

One-way ANOVA was conducted to identify if any significant differences exist in the availability of user control, occupants' energy-saving behaviours, and social-psychological effects across the demographic groups. In ANOVA, if P-value (significance level) is less than the α value of 0.05, there are significant differences across the groups. Table 3 includes the ANOVA results. As highlighted in Table 3 in green colour, significant differences (P value < 0.05) exist for most of the selected variables and are primarily visible across the ethnicity and region groups. To visualise these differences in occupants' viewpoint on user control, energy-saving behaviours, and social-psychological effects, stacked-bar graphs are illustrated in the forthcoming section by descriptively analysing the occupants' responses.

Table 3. The ANOVA results of the demographic groups

#	Gender		Age		Ethnicity		Region	
	F	P	F	P	F	P	F	P
2A	1.673	0.189	6.044	0.014	11.659	<.001	43.376	<.001
3A	1.066	0.345	2.751	0.098	6.94	<.001	19.024	<.001
3B	2.177	0.114	8.12	0.005	1.727	0.160	1.758	0.173
3C	2.902	0.056	0.355	0.552	2.47	0.061	25.448	<.001
3D	2.466	0.086	2.074	0.150	2.099	0.099	5.825	0.003
4A	9.782	<.001	12.17	<.001	1.443	0.229	0.823	0.440
4B	10.416	<.001	6.695	0.010	5.99	<.001	2.556	0.078
4C	1.932	0.146	1.281	0.258	2.111	0.098	8.197	<.001
4D	0.498	0.608	6.795	0.009	1.088	0.353	5.334	0.005
4E	0.46	0.631	3.414	0.065	11.175	<.001	0.2	0.818
4F	0.309	0.734	3.348	0.068	4.739	0.003	4.226	0.015
4G	0.408	0.665	3.543	0.060	4.114	0.007	18.092	<.001
4H	1.084	0.339	1.723	0.190	0.892	0.445	2.256	0.106
4I	1.42	0.243	0.082	0.775	1.261	0.287	2.355	0.096
4J	1.749	0.175	0.077	0.782	3.415	0.017	2.651	0.071
4K	2.601	0.075	0.894	0.345	8.618	<.001	36.61	<.001
4L	0.891	0.411	0.212	0.645	6.562	<.001	8.749	<.001
4M	0.854	0.426	1.364	0.243	6.242	<.001	7.863	<.001
4N	2.378	0.094	1.034	0.310	5.363	0.001	5.495	0.004
4O	4.141	0.016	13.059	<.001	10.174	<.001	2.006	0.136
4P	4.791	0.009	1.313	0.252	6.215	<.001	9.552	<.001
4Q	2.232	0.108	19.461	<.001	9.666	<.001	10.186	<.001

4.3. Perceptions of user control, energy-saving behaviours, and social-psychological effects

The following graphs in Fig. 1–10 highlight insights observed when analysing responses.

4.3.1. Availability of user control

First, when asked if occupants have personal control over most of the appliances (windows, doors, blinds, thermostat, lights, heaters, fans, computers) in their workspace, more than 50% or more than 50% responded "somewhat agree" or "strongly agree" in most demographic measures (Fig.1). Which is slightly different in the samples from under 30, other ethnicities, and Auckland categories. Results indicate that user controls are available in most respondents' workplaces, and most respondents have access to these controls, which might increase their ability to save energy.

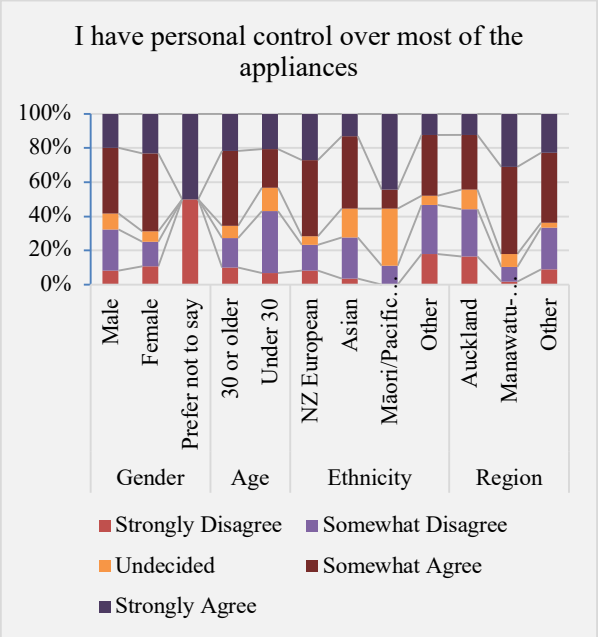

Fig. 1. Personal control over office appliances

4.3.2. Occupants' energy-saving behaviours

Fig.2 illustrates the occupants' viewpoint on adaptive and non-adaptive behaviours. Adaptive behaviours include adapting the indoor environment to their preferences and adapting themselves to their environment. Non-adaptive behaviours include reporting discomfort, doing nothing, or accepting existing environmental conditions. As shown in Fig.2, when asked if they often adjust building appliances to satisfy their comfort preferences (**3C**), the majority (50% or more than 50%) indicated "somewhat agree" or "strongly agree", with a similar but increased trend (more than 60%) when asked if they often adjust themselves to the environmental conditions at their workspace by adjusting clothing, drinking hot/cold beverages, and moving through spaces (**3D**). In parallel, when asked if they often report discomforts related to indoor environmental quality (IEQ) to the building management (**3A**), the vast majority (more than 50%) either "somewhat disagree" or "strongly disagree". However, when asked if they were willing to accept and do nothing about the existing indoor environmental conditions in their workspace, similar agreement and disagreement (30%–40%) were observed because a considerable number of occupants responded "undecided" (**3B**). These trends in Fig.2 highlight that office occupants practice adaptive behaviours rather than non-adaptive behaviours. There is an increased motivation to adjust themselves to the indoor environment and interact with building systems.

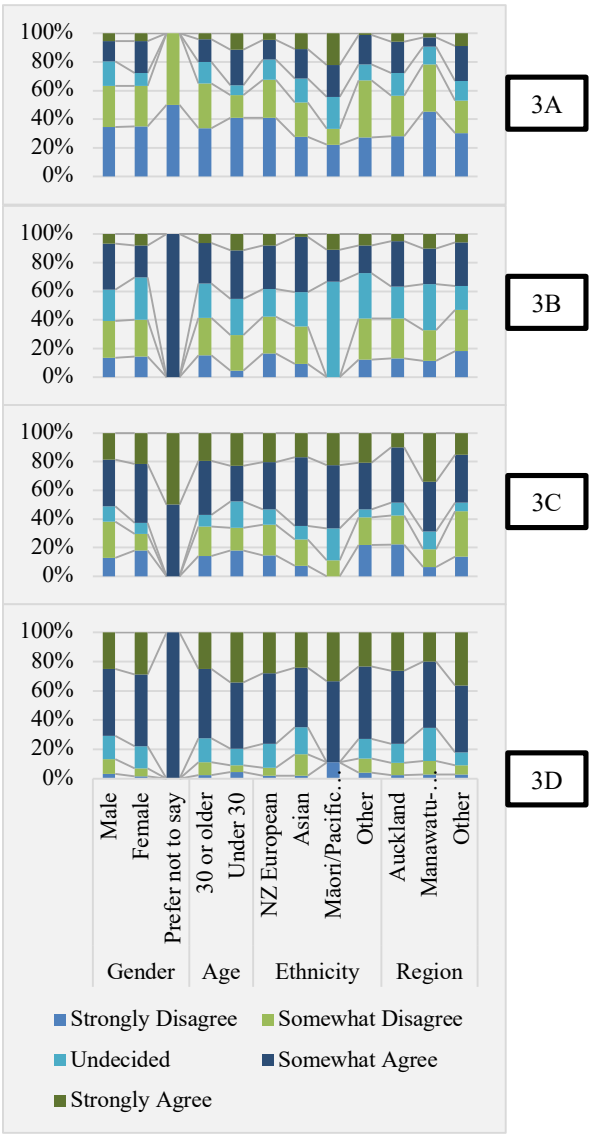

Fig. 2. Occupants' energy-saving behaviours

4.3.3. Social-psychological effects

Social-psychology effects were investigated based on eight variables adopted from Li et al. (2019). Those variables are from both occupants and the organisation. Attitudes, personal norms, subjective norms, actual knowledge, perceived knowledge, and perceived behavioural control relate to the occupants, while organisation support and behavioural intervention relate to the organisational energy/building management.

4.3.3.1. Attitude

When asked if saving energy at work is important to respondents, most respondents (more than 60%) answered "somewhat agree" or "strongly agree" except in one ethnic category, "prefer not to say". However, only two responses were received in this category; therefore, the response is insignificant (Fig. 3). Results highlight the positive feelings of most respondents about performing energy-saving behaviours.

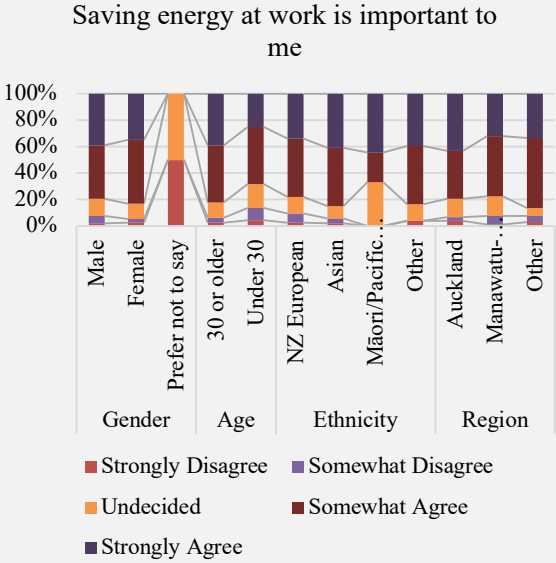

Fig. 3. Attitude to save energy

4.3.3.2. Personal norms

The respondents were also asked if they feel responsible/obliged to save energy at work. A majority of respondents (more than 60%) either somewhat agree" or "strongly agree" (Fig.4), which indicates there is a self-obligation among respondents to commit energy-saving behaviours. This finding justifies the respondents' positive attitude toward saving energy.

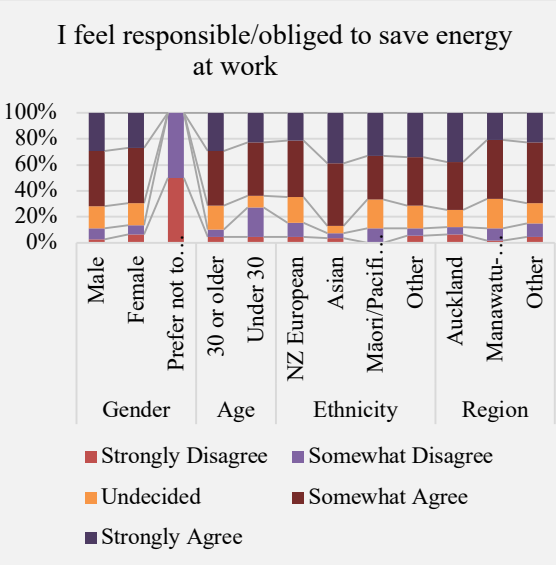

Fig. 4. Personal norms to save energy

4.3.3.3. Subjective norms

Next, the respondents were asked if social pressure exists to engage or when engaging in energy-saving behaviours (Fig.5). When asked if their co-workers expect them to save energy (**4C**), similar agreement and disagreement (30%–40%) was observed because a considerable number of occupants responded "undecided". In contrast, when asked if the co-workers expect them to turn off electrical appliances when leaving (**4D**), 40% or more than 40% answered "somewhat agree" or "strongly agree" except in one region category, "Manawatu-Whanganui", which has

a significant number of responses. This indicates that the respondents are more familiar with the specific actions/behaviours and believe some social pressure exists when taking such actions. However, they are unsure if social pressure exists to save energy. Similarly, 40% or more than 40% answered "somewhat agree" or "strongly agree" when asked if sharing control over building systems with co-workers is easy (**4E**). A slight change was observed in ethnicity group "Māori/Pacific peoples" and the region group "Manawatu-Whanganui".

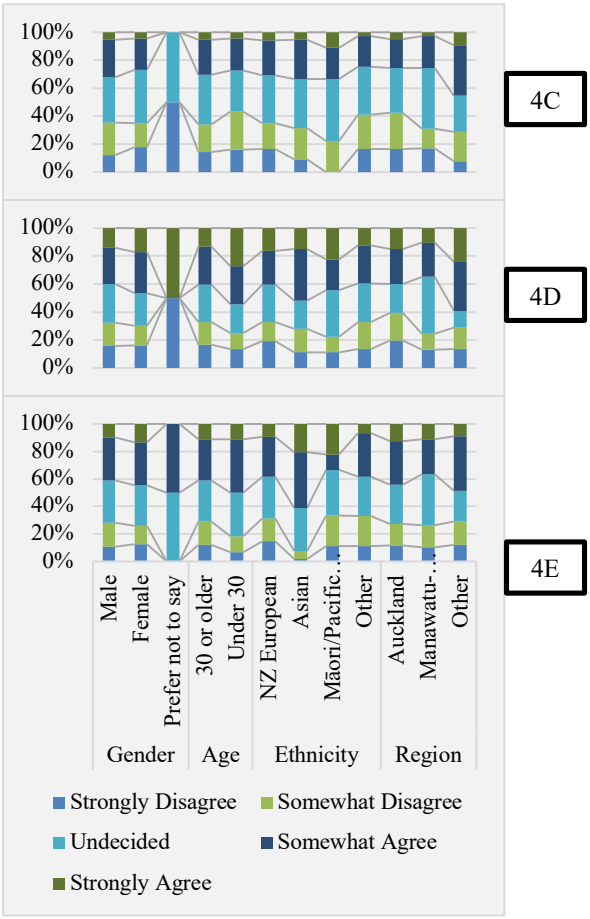

Fig. 5. Subjective norms to save energy

4.3.3.4. Perceived behavioural control

Subsequently, the respondents were asked about perceived ease or difficulty in saving energy at the workplace. As seen in Fig.6, when asked if saving energy during work is entirely within their control (**4F**), 40% or more than 40% responded "somewhat disagree" or "strongly disagree", however in some categories similar agreement also observed. Such categories include female, under 30, NZ European, and the regio groups "Manawatu-Whanganui" and "other". In these samples, similar number of participants showed either agree or disagree. In contrast, 60% or more than 60% answered "somewhat agree" or "strongly agree" when asked if their actions to save energy depend on their comfort needs and preferences (**4G**). This further justifies the respondents' positive attitude toward saving energy while ensuring their needs and preferences are satisfied.

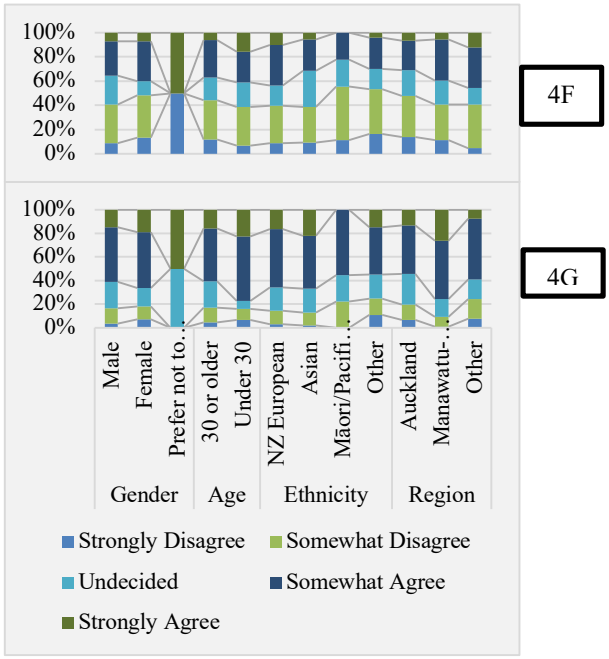

Fig. 6. Perceived behavioural control to save energy

4.3.3.5. Actual knowledge

Fig. 7 illustrates the respondents' psychological abilities to perform energy-saving behaviours. According to Fig.7, the respondents were first asked if they were aware that reducing energy use would reduce energy costs (4H).

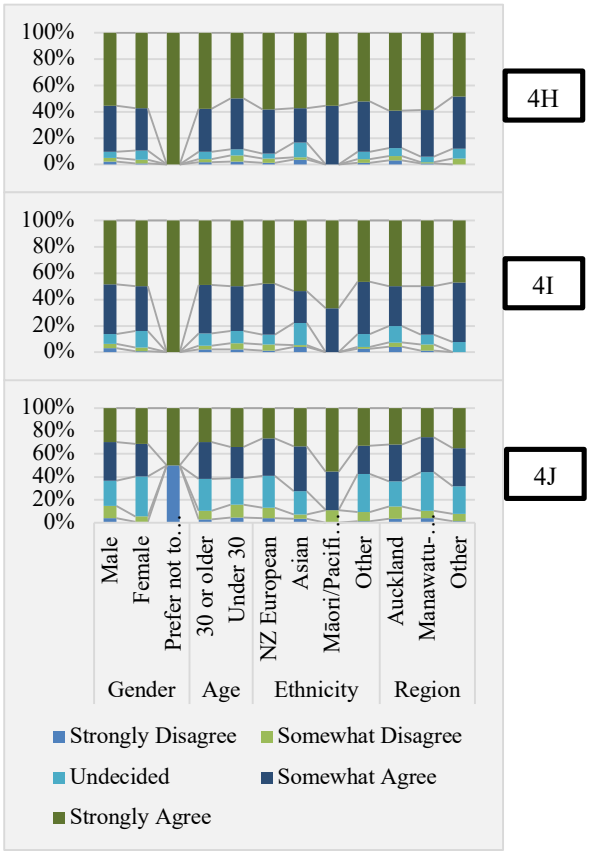

Fig. 7. Actual knowledge to save energy

When asked if they were aware that reducing energy use would reduce carbon emissions (**4I**), and if they were

aware that reducing energy use would improve their organization's image/reputation (**4J**) (60% or more than 60%). In general, results indicate the respondents' relatively strong mental ability to save energy and perform energy-saving behaviours.

4.3.3.6. Perceived knowledge

Subsequently, the perception of respondents' knowledge about saving energy was investigated, and Fig.8 summarises the results. When asked if respondents often close windows, turn off the lights, heaters, fans, computers, etc., whenever they leave the office, and unplug appliances when not in use (**4K**), the vast majority (60% or more than 60%) either "somewhat agree" or "strongly agree", with similar insight when asked if they feel slightly cold at the workplace, they would put on another layer of clothing instead of using the heater (**4L**). If slightly warm, they would adjust their clothing level instead of using the air conditioner (**4M**) (60% or more than 60%). With these results, it is highlighted that most respondents are aware of how to save energy by practicing the right behaviours.

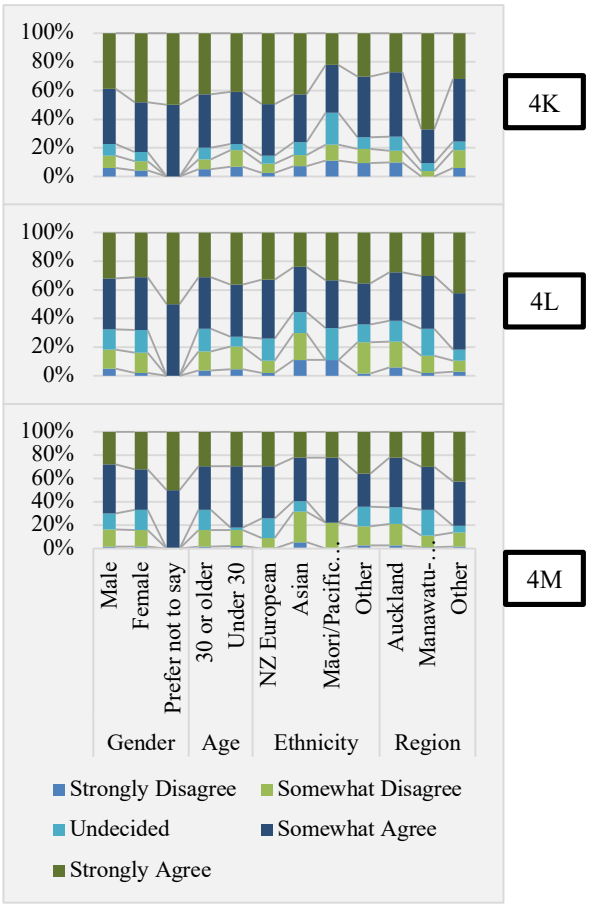

Fig. 8. Perceived knowledge to save energy

4.3.3.7. Organisational support

While the above sum up the social-psychological insights relating to occupants, the respondents were asked about the organisation's support and intervention toward saving energy (Fig.9). When asked if their companies encourage employees to save energy (**4N**), most respondents (40% or more than 40%) answered "somewhat agree" or "strongly agree". In contrast, 60% or more than 60% answered "somewhat disagree" or "strongly disagree" when asked if the company rewards employees for saving energy (**4O**). The findings highlight that the occupants believe their organisations only partly provide energy-saving opportunities.

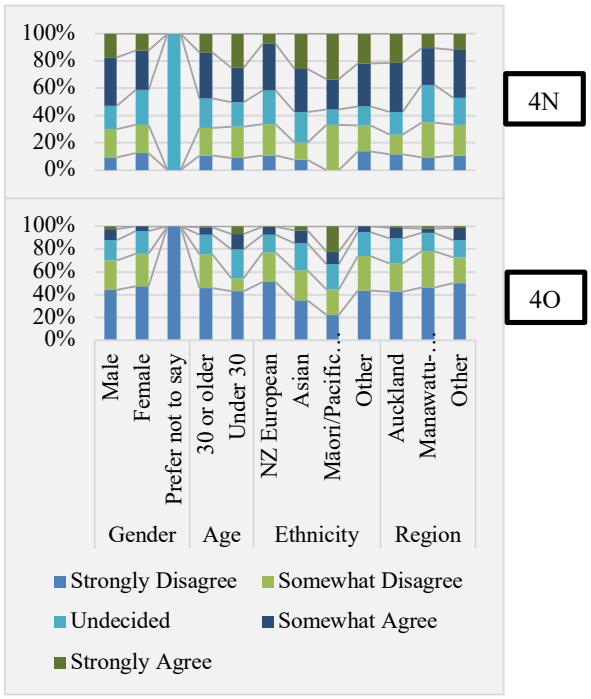

Fig. 9. Organisational support to save energy

4.3.3.8. Behavioural interventions

Finally, the respondents were asked about the extent of organisational interventions to energy-saving behaviours (Fig.10). When asked if the feedback on individual energy use by the building management team is important for them to change energy-driven behaviours (**4P**), most respondents (40% or more than 40%) answered

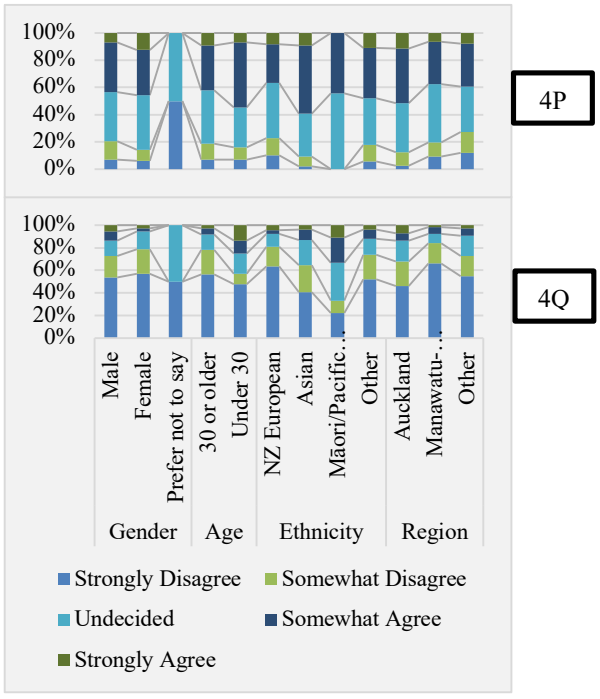

Fig. 10. Behavioural interventions to save energy

"somewhat agree" or "strongly agree", while a similar percentage of respondents unable to make a decision. However, when asked if building management teams often send energy use reports to employees (**4Q**), the vast majority either "somewhat disagree" or "strongly disagree" indicating 60% or more than 60% in most groups. The findings indicate a lack of behavioural intervention from the organisations, thus a lack of opportunity for occupants to practice energy-saving behaviours.

5. Discussion

The following discussion of results is expressed in terms of insights into access to user control, energy-saving behaviours, and social-psychological effects, along with specific recommendations.

Starting with user control, results indicate the availability and accessibility of user controls within New Zealand office workplaces as an enabler of saving energy. The findings confirm the results of previous studies (O'Brien and Gunay, 2014; Papadopoulos and Azar, 2016) that have observed a direct relationship between building user controls and energy reduction or energy-saving behaviours.

Regarding occupant energy behaviours, the study found that the occupants mainly adjust themselves to the indoor environment than adjust the building environment to their preferences interacting with building systems and appliances. However, the previous studies primarily focused on energy use due to the occupants' interaction with building systems and appliances (Weerasinghe et al., 2020b). For instance, significant energy use was highlighted in behaviour choices related to HVAC control, windows, shades/blinds, and lighting (Bavaresco et al., 2020).

The current study identified social-psychological effects in eight factors representing attitudes, social norms, PBC, occupants' knowledge, organisational support, and behavioural intervention. Accordingly, results highlighted the positive attitude of occupants toward saving energy. Furthermore, occupants in New Zealand office buildings believe that they are self-obligated to commit energy-saving behaviours. Additionally, the occupants are more likely to save energy if those actions satisfy their needs and preferences. These personal norms and the PBC of occupants also justify their positive attitude toward saving energy. Similarly, previous studies highlighted that these occupants with a positive attitude have the most intentions to conduct energy-saving behaviours (Gao et al., 2017; Obaidellah et al., 2019). Individuals are more likely to save energy when they have a positive attitude, high PBC, and strong personal norms (Gao et al., 2017).

Regarding subjective norms, the occupants in the current study believe the existence of some social pressure when taking specific actions such as turning off electrical appliances and sharing control over building systems at the workplace. However, they are unsure if social pressure exists to save energy. As Chen et al. (2017) found, subjective norms were no longer significant in predicting occupants' intentions when there are other strong factors.

Considering occupants' actual and perceived knowledge, a higher agreement was received that highlighted their relatively strong mental ability and awareness to save energy and perform energy-saving behaviours. The findings confirm the results of previous studies (Gao et al., 2017) that emphasised relevant knowledge on how to save energy influences occupants' energy-saving behaviours.

However, the findings highlighted that the occupants believe that they do not get enough support and intervention from their organisations to save energy, thus a lack of opportunity to practice energy-saving behaviours. Although organisational support and behavioural interventions positively drive employees' pro-environmental behaviours (Vellei et al., 2016; Xu et al., 2017).

Based on the above discussion, an increasing trend of agreement is visible with social-psychological effects such as attitude, personal norms, and actual and perceived knowledge entirely within their control. However, subjective norms such as social pressure and PBC to save energy follow a trend of majority disagreement. A similar trend was observed in terms of organisational support and interventions. These trends are mostly similar across different demographic groups.

Therefore, the authors recommend providing more organisational support (e.g., rewards to those who save energy, awareness on energy) and behavioural interventions (e.g., energy use report, feedback) to encourage occupants to save energy and practice energy-saving behaviours while providing some levels of responsibility or control to save energy, thereby to increase occupants' satisfaction with their comfort conditions.

6. Conclusions

This study presents social-psychological insights relating to energy-saving behaviours across the general office building occupants in New Zealand. The study includes insights into (1) user control availability, (2) occupants' energy-saving behaviours, and (3) relevant social-psychological effects. The study focused on general building occupants in office buildings in New Zealand, where the data were collected from 294 participants. The data were analysed using one way ANOVA to identify the differences across the demographic groups and then stacked-bar charts were used to illustrate relevant insights.

The empirical results revealed an increased trend of adjusting themselves to the indoor environment and occupants' social-psychological effects such as attitude, personal norms, and actual and perceived knowledge to save energy. In addition, according to occupants' perspectives there was a lack of organisational support and behavioural intervention, which is necessary for encouraging occupants to save energy while giving them more responsibility for their energy consumption.

A key contribution of the study is that decision-makers such as building owners, energy modellers, facilities managers, and policy makers can consider these social-psychological effects to promote energy-saving behaviours among office building occupants. Academic researchers can also benefit by extending the current study to occupant energy modelling and building performance simulation. Finally, knowing how occupants' decision-making or behaviours is influenced by social-psychological constructs will facilitate the choice of advanced building design and technologies to achieve energy reduction goals.

As the current study is limited to identifying basic social-psychological insights, future studies can focus on applying more advanced statistical analysis methods to develop a comprehensive framework that evaluates the occupant energy behaviours in office buildings. Furthermore, the study could be extended to enable other social-psychological dimensions such as occupants' motivations, beliefs, and personal traits, while also considering the influence of socio-demographic factors like educational background, workplace characteristics, occupancy schedule patterns, etc.

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Author Contributions

Achini Shanika Weerasinghe contributes to conceptualization, methodology, software, analysis, data collection, draft preparation, manuscript editing, and visualization. Eziaku Onyeizu Rasheed contributes to manuscript editing, supervision, and project administration. James Olabode Bamidele Rotimi contributes to manuscript editing, supervision, project administration, and funding acquisition. All authors have read and agreed with the manuscript before its submission and publication.

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Institutional Review Board Statement

This project has been evaluated by peer review and judged as low risk. The Ethics notification number for this project is 4000022597, and the low-risk notification is valid for a maximum of three years, effective from May 2020.

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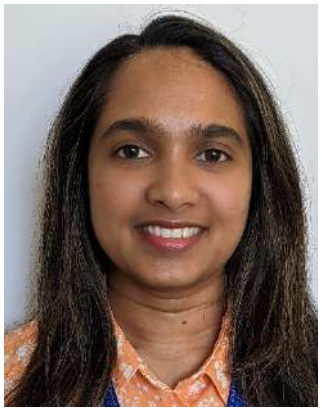

Achini Shanika Weerasinghe is a PhD student/Tutor in Facilities Management at the School of Built Environment, Massey University, New Zealand. She is a member of the Institute of Facilities Management Sri Lanka (MIFMSL). Her research works contribute to enlight sustainability, green buildings, energy efficiency, occupant behaviours, and life cycle costs (LCC) implications in the built environment.

Dr. Eziaku Onyeizu Rasheed is a Senior Lecturer in Sustainable Built Environment at the School of Built Environment, Massey University, New Zealand. Her research is focused on the interface between sustainability and building performance. She investigates the relationship(s) between building users' interaction, comfort and productivity with building performance (energy use/efficiency, facilities, systems, and Indoor Environment Quality (IEQ)) in residential and commercial buildings.

Dr James Olabode Bamidele Rotimi is an Associate Professor of Construction Project Management at the School of Built Environment, Massey University. James has qualifications in Building, Construction Management, Civil Engineering, Commerce and Education. His research has a focus on improving performance of the construction industry, integrating its supply chain and optimising the achievement of construction and project deliverables. James publishes extensively and is the Founding Editor of the International Journal of Construction Supply Chain Management IJCSCM.

Paper no. 10

Investigating Labour Productivity Factors Affecting the Constrction Industry in Oman

Ghassan Al Farsi[1] , Abdullahi A. Umar[1] and Nuhu Braimah [2]
[1]Assistan Lecturer, Department of Civil Engineering and Quantity Surveying, Military Technological College, Al Matar Street, Muscat 111, Sultanate of Oman, E-mail: ghassan.ibrahim@mtc.edu.om (corresponding author).
[2]Lecturer, Department of Civil and Environmental Engineering, Brunel University London, Kingston Lane, Uxbridge, Middlesex UB8 3PH, United Kingdom, E-mail: nuhu.braimah@brunel.ac.uk

Abstract: In the Sultanate of Oman, the construction industry contributes to the national economy mainly through infrastructure construction. This sector is highly labour intensive. There are several challenges that construction projects face in Oman but one of the most fundamental is low labour productivity. The purpose of this paper is to investigate, identify and rank the relative importance of the factors that impact labour productivity in the Oman construction industry. The study utilised a structured questionnaire survey containing 22 productivity factors which were classified into three main group: (1) cultural factors (2) environmental factors (3) economic factors. Data was gathered from 25 Contractors and 10 government organisations. Using the relative importance index (RII) method, the study found that the top 5 factors affecting labour productivity in Oman include: (1) collectivism, (2) financial motivation, (3) environmental training, (4) communicating in English, and (5) high temperatures. The outcomes obtained from this study fill a gap in knowledge about productivity factors that have an impact on construction labour in Oman. These results can be used by policy makers, academics and industry practitioners as a guidance to develop efficient and cost effective labour policies.

Keywords: labour productivity, the sultanate of Oman, cultural factors, environmental factors, economical factors.

1. Introduction

In construction, projects teams transform inputs like labour and materials into output such as a complete project. However, project teams performance is effected by the productivity of labour in dealing with complex operations (Tsehayae and Fayek, 2014). Productivity can be defined as the physical progress achieved per hour of work (Dozzi & AbouRizk, 1993). Therefore, Managing labour force through proper hiring, training and retraining can significantly raise personnel productivity (Kucharčíková, *et al.,* 2015).

However, organisations in the MENA region are facing constraints in the labour market which creates difficulties for their businesses (Fakih and Ghazalian, 2015). Moreover, there are more expatriates workers in construction than Omanis. The efficiency of labours rely upon skill level of labours and working situations such as atmospheric situation which combines location of the site and the thermal condition (Mohamed and Srinavin, 2002). Additionally, weather is mostly hot during the day time which can reach 50°C particularly in the summer. Zivin and Neidell (2012) suggested that, officials should integrate environmental protection and invest on human capital to enhance the productivity of the organisation. Although the government is investing heavily in infrastructure within Oman, but the projects are often delayed resulting in deffered benefit realisation. Hence, it is crucial to enhance the productivity of the construction sector (Jarkas, *et al.,*2014) to deliver project on time. Therefore, the purpose of this study is to investigate the current condition of the Omani construction industry and identify, rank and analyse the factors that impact labour productivity.

2. Literature Review on Causes of cost overruns

Yi and Chan (2014) mentioned that, productivity in construction is perceived as a gauge of the outputs which are acquired by an integration of inputs during production operation. Furthermore, productivity in construction is closely related to workers' efforts such as elements of work performed or arranged per man hour. Therefore, the success of projects depend essentially upon the productivity of employees and their management (Hanna et al., 2005). The productivity of the labour in construction is an essential sign of project progress. As a result, low productivity leads to redundant costs resulting from factors and conditions of the site which influence workers productivity negatively and hence the contractor has to compensate and pay additional cost to finish the work (Odesola, 2015). Numerous case studies have been conducted to examine the factors which might affect labour productivity on construction projects. One study found that inefficient project planning, design mistakes and variations,

communication approach and environment for work were the highest ranked ones respectively among 46 factors (Naoum, 2016). In India, material shortage, material delay, strikes, design or drawing revisions were the most crucial factors that could decrease the productivity Thomas and Sudhakumar (2014). In Oman, Jarkas, *et al.,*(2015) found that productivity was impacted by management, technological, labour and exogenous factors. Hence, an understanding of the factors that affect construction labour productivity could assist to enhance the performance of projects in Oman and elsewhere. However, there are other factors such as cultural, environmental, and economic which can impact the productivity of an individual.

2.1 Cultural Factors:

The high impact of Islam on the daily life of the followers which is anticipated to effect significantly on the system of human resource management in establishments (Rajasekar and Simpson, 2014). It has been shown that religion factor has a positive impact on labours productivity (Hiyassat, *et al.,* 2016). However, in the workplace especially in construction sector in Oman, there are a mix of labours from different religious, social, cultural and ethnic persuasions, some could be collectivist and others individualist. Hence, understanding the different types of norms might help them cooperate and increase the work production.

According to National Centre for Statistics and Information (2016), the total expatriates labour working on the construction sector represent 37.34% of the total expatriates in the country with a number of 640,211 labour. Parrotta, *et al.,*(2011) argued that, the diverse ethnic groups and demography in construction has no impact on productivity but the negative influences comes from the communication processes. A study of Dutch and Indian workers on a large IT project found that, there were issues with communication and understanding each other's language. Emuze and James (2013), have examined the impacts of culture and language in the place of work in the construction sector and found that there was confusion for workers to understand the managers, although site workers were considered to comprehend the orders effectively.

2.2 Environmental Factors:

The Climate in Oman is tremendously hot and humid during the summer months similar to other Gulf Cooperation Council (GCC) nations where temperatures often cross the 50°C degree mark. In their study of factors affecting construction productit=vity, they found that weather condition was ranked in eight and ninth place respectively (Jarkas, et al., 2015;Thomas & Sudhakumar, 2014). Langkulsen, et al., (2010), found that 60% of construction employees reported loss of productivity between 10% to 66.7% per worker due to weather issues. Another study in Iran found that heat stress resulted in a 16.35% of productivity loss among construction workers. Consequently, protection against environmental harm is counted as investing into individuals and can contribute to productivity enhancement (Zivin and Neidell, 2012). Employers can increase their workers' productivity by simply enhancing the indoor environment (Al-Omari and Okasheh, 2017). It has been established that a small productivity increase of 0.1-2% could significantly impact on a company's profits (Sehgal, 2012).

2.3 Economic Factors:

Recently the construction industry in Oman has been suffering from major delays and financial issues due to the decline in oil prices. Kazaz and Ulubeyli (2007) studied the factors that influence labours productivity in Turkey, among the top seven factors, five of them were economic ones such as time for payment, quantity of payment and financial Incentives. In state of Qatar, Jarkas, et al., (2014), revealed that lack of financial incentive scheme is the most prominent demotivation factor that could influence the productivity of the project managers. Furthermore, shortage of materials can have a crucial impact on workers productivity (Mahamid, 2013). Son, *et al.,* (2014), found that economic recessions negatively impacted workers productivity as actual salaries were reduced. in Macedonia, Trpeski, et al., (2016), found that, after the crises appeared in 2012, productivity decreased by 1.63%, while wages rose by 5.45. As a result, economic factors are seen as a vital consideration that might affect production level and productivity of employees among different job levels.

3. Methodology

This study was mainly quantitative and was conducted through the use of a survey questionnaire. The factors that impact productivity from literature were summarised into the questionnaire. The factors that have an impact on productivity among construction labours in Oman were specified after analysing previous literature. After identifying the factors, this was discussed with some industry experts to make sure the factors were relevant. Therefore, the analysis revealed 22 factors which were categorised among three groups cultural, environmental, and economic. Before administering the survey, a pilot study was conducted using 5 industry practitioners who have experience in the construction industry of Oman. Feedback from the pilot study resulted in changes to the questionnaire. A closed ended questionnaire survey was conducted to collect the data. The questionnaire is designed by starting with a cover letter which explain the approach of the survey and purpose of the study to respondents. Moreover, it was divided into two main parts. Part 1 consist of demographic questions to categorise the respondents. Part 2 include the factors that impact labour productivity in the construction sector. The respondents were asked to rank each of the determinants on a Likert-type scale from 1 to 5. The population which has been targeted in this study are labours who are working in the construction industry either in private or public sectors. Also, a non-probability sampling has been used to target the right population. The population on this research was selected by choosing 25 excellent grade contractors from the Omani Tenders Board from the private sector and 10 governmental sector organisations that work in the construction field. It was a self-administrated questionnaire which has to be completed by the respondents through the internet. The relative importance index has been used to rank the factors, where this method was used by authors like Jarkas and Bitar (2012) and Jarkas, et al., (2015) to rank construction labour productivity factors. The following equation shows the formula:

$$RII = \frac{5(n5) + 4(n4) + 3(n3) + 2(n2) + n1}{5(n1 + n2 + n3 + n4 + n5)}$$

EQ 1. Relative Importance Index

Where n1, n2, n3, n4, and n5 are the respondents number who selected: 1, for No effect at all; 2, for little effect; 3, for moderate effect; 4, for strong effect; and 5, for very strong effect, respectively. Also, the ranking for every group, was determined by quantifying the average value of the relative importance indices for all the factors which is categorised under the group.

4. results and discussions

By the end of the survey period, data had been collected from 41 individuals, 35 of whom were male and 6 were female. Also, the age of the respondents varied, 5 of them were between 18-24, the majority 22 person were between 25-34, 10 of them aged from 35 to 44 years, 2 were between 45-55 and 1 was above 55, while 1 preferred not to say.

Regarding their nationality, 23 of the participants were Omani, while 18 of them were non-Omani. Additionally, governmental sector respondents representing 46.34%, whereas private sector individuals represented 51.22% and 2.44% decided not to say which sector they belonged. In terms of education level of the respondents, the majority have undergraduate degree (diploma & Bachelor).

Respondents were working in various sectors of the construction industry such as mainly in contracting, infrastructure, services, repair and maintenance and manufacturing. Moreover, participants were from different level of job and majority were from mid-level as shown in the Pie chart below

Respondents were asked from 22 questions of different factors to indicate the effect in a scale ranging from 1 which is no effect to 5 very strong effect. The factors were divided into three groups which is cultural, environmental, and economical. Moreover, an importance index which explained previously was used to measure and rank the factors. The following are the obtained results for each group factors.

Cultural Group:

Table (4.1) presents the ordering of the factor under cultural group. This group has 8 identified factors which the top was collectivism followed by communication in English, individualism, equal treatment, difficulty in dealing with worker not the same nationality, working during the holy month (Ramadhan), working with the other gender and cultural differences respectively.

Table 4.1 : Cultural factors group ranking

Factors	RII	**Rank**
Collectivism	0.834	**1**
Communicating in English	0.771	**2**
Individualism	0.673	**3**
Equal Treatment	0.643	**4**
Difficulty in dealing with difference nationality	0.497	**5**
Working during the holy month (Ramadhan)	0.489	**6**
Working with the other Gender	0.483	**7**
Cultural Differences	0.458	**8**

Environmental Group:

Table (4.2) illustrates the ranking of factors for environmental group. Seven factors are specified and the ranking resulted the following, training, high temperatures, place of work, working on office is desirable, working on site is desirable, difficult working conditions and following standards respectively.

Table 4.2 Environmental factors group ranking

Factors	RII	**Rank**
Environmental Training	0.78	**1**
High temperatures	0.683	**2**
Place of work	0.658	**3**
Working on office is desirable	0.658	**4**
Working on site is desirable	0.651	**5**
Difficult working conditions	0.629	**6**
Following standards	0.619	**7**

Economical Group:

Table (4.3) shows the ordering of factors related to economical group. The result revealed 7 identified factors are ordered respectively, financial motivation, national economy affected the salary, reducing in materials and equipment, financial cuts, worried about losing job, satisfied with the salary, payment delay.

Table 4.3 Economical factors group ranking

Factors	RII	Rank
Financial motivation	0.785	1

National Economy affected the salary	0.644	2
Reducing in materials and equipments	0.585	3
Financial cuts	0.535	4
Worried about losing job	0.522	5
Satisfied with the salary	0.507	6
Payment Delay	0.351	7

Top 5 Factors Affecting Labor Productivity:

By using the relative importance indices to rank and examine the factors which are illustrated, discussed and compared with other studies findings. Also, the importance indices for groups are computed, compared and ranked. The table 4.4 below presents the ranking for the whole productivity factors.

As it can be seen from table 4.4 that, the descending order of the 10 highest ranked factors that affect construction labour productivity in Oman are, collectivism, financial motivation, training, communicating in English, high temperatures, individualism, place of work, working on office is desirable, working on site is desirable and national economy affected the salary respectively. The top 10 ranked factors will be discussed as it has been conducted by Jarkas and Bitar (2012) and Jarkas, *et al.,*(2015) to examine the overall factors that has an impact among construction labour productivity. In addition, the factors that has a common or related characteristics will be discussed collectively to avert redundancy regardless the ranking of it.

Collectivism and Individualism:

In the overall ranking, collectivism became the top ranked factor with relative importance index of 0.834, while individualism is on the 6th rank with relative importance index of 0.673. As these two factors related to the cultural group, it is vital to identify the difference between local and expatriate labour. In one hand, both Omanis males and females have ranked collectivism as the top factor, while individualism came in the 12th order. On the other hand, non-Omani individuals chose to work with others in the second rank, whereas chose to work individually in third place where the difference was little in the relative importance indices. Consequently, this indicates that Omanis are more collectivist and this result is coherent with Mujtaba, *et al.,*(2010) which they mentioned that the Omani society is a collectivist as it is an Arabic nation. Also, the results point out that expatriate labours are more individualistic than the locals. As a result, identifying the most suitable leadership style which suit Omanis and expatriates and it is function could rise the commitment of the labours (Mujtaba, *et al.,*, 2010).

Financial Motivation:

The second highest factor is financial motivation with RII of 0.785. Interestingly, this factor was observed to be ranked as the highest one according to non-Omani labour. This result is consistent with data obtained by Jarkas and Bitar (2012) in Kuwait, which Lack of incentive has RII of 0.786 where this is very close with our findings. In Kazaz and Ulubeyli (2007) case study, incentive payments was the 5th ranked among 18 factors in Turkey. Moreover, they suggested that, using financial incentives as a program to motivate the labours is vital and effective which could rise their satisfaction and hence increase the productivity. Furthermore, the level of payment should be factual and equally distributed where the best way is by adapting group based incentive programs. However, incentive programs should be investigated before the implementation of the project and adapted properly to avert any negative effects.

Environmental Training:

Based on all factors, training is ranked 3rd with RII of 0.78 which means it is on top of the environmental group. Lannelongue, *et al.,*(2015), Neitzel and Seixas (2005), Delmas and Pekovic (2013), whose indicated that training the workers could improve the productivity and enhance interpersonal communication, but it can be expensive to the organisation. Additionally, the real environment of the workplace might differ from training and hence it should be tested initially. Consequently, the top management should plan for this properly and incorporate it in the organisation strategy. According to Tabassi, *et al.,*(2012), organisations utilising training as an essential strategy to assist workers to obtain the appropriate knowledge and skills to face environmental impacts. Moreover, the availability of career motivation and training schemes is vital to keep employee productive and support them during the stages where training programs must contribute directly to project execution and directed by managers and leaders. Therefore, construction organisations gaining work efficiency and enhance teamwork activity by applying training strategies and motivating the workforce.

Communicating in English:

Communication in English language comes as the 4th factor that influence labours among all the factors with RII of 0.771. Among all the job levels, low level labours has the highest ranking for this factor which is ranked second according to the low level ranking. This result is not surprising, although the spoken language inside most of the organisations particularly the private sector in Oman is English, low-level labour might work with no degree or school education and English is not used outside workplace. Okoro and Washington (2012) suggested that, sufficient communication and interaction of individuals play an essential part in the productivity of a diverse manpower.

Parrotta, *et al.,* (2011) proposes that, conducting diversity management and integration activities could help to create a homogeneity between the labours and minimise the cost that related to communication of workforce diversity.

High Temperatures:

The temperature plays a significant role in construction labour as some of them work outside regularly.

Table 4.4 Ranking of all productivity factors

Productivity determinant	RII	Group	Rank
Collectivism	0.834	Cultural	1
Financial motivation	0.785	Economical	2
Environmental Training	0.780	Environmental	3
Communicating in English	0.771	Cultural	4
High temperatures	0.683	Environmental	5
Individualism	0.673	Cultural	6
Place of work	0.658	Environmental	7
Working on office is desirable	0.658	Environmental	8
Working on site is desirable	0.651	Environmental	9
National Economy affected the salary	0.644	Economical	10
Equal Treatment	0.643	Cultural	11
Difficult working conditions	0.629	Environmental	12
Following standards	0.619	Environmental	13
Reducing in materials and equipment	0.585	Economical	14
Financial cuts	0.535	Economical	15
Worried about losing job	0.522	Economical	16
Satisfied with the salary	0.507	Economical	17
Difficulty in dealing with worker not the same nationality	0.497	Cultural	18
Working during the holy month (Ramadhan)	0.489	Cultural	19
Working with the other gender	0.483	Cultural	20
Cultural Differences	0.458	Cultural	21
Payment Delay	0.351	Economical	22

High temperature factor was ranked in the 5th order which influence labour performance with RII of 0.683. Supporting the findings of Jarkas, *et al.,* (2015), Thomas and Sudhakumar (2014), harsh weather which includes high temperatures ranked 9th and 8th respectively. Furthermore, to monitor the harmful impact of heat and sun exposure in workplace, it is suggested to install barriers, provide a break zone with proper ventilation and scheduling fluid drink (Hajizadeh *et al.,* 2015). Langkulsen, *et al.,* (2010) mentioned that, both private and public sectors should treat heat and other industrial contaminants in a serious way as it is considered as a health danger which could decrease labour productivity as well. In china a case study conducted by Li *et al.* (2016), to measure the effect of high weather degrees on construction employee productivity who is working outdoors. The study revealed that, working from 07:00 to 09:00 in the morning was the best time for personnel with less danger, whereas the time between 14:00 to 15:00 in the afternoon is most hazardous period to work.

Therefore, identifying the highest degrees during work time and minimise the work at this period might assist to decrease the harm impacts. As a result, with proper regulations from responsible parties and identifying the best time for working could help to minimise the effect on labour productivity.

Factor Group Ranking:

A comparison of the three groups results reveals that, environmental group factors become the first with total RII of 0.668, while cultural group comes the second with RII of 0.606 and lastly economical group scored RII of 0.561. This has been done by taking the average of total factors for each group and this procedure done by researchers like Jarkas and Bitar (2012) and Jarkas, et al., (2015). Table (4.5) illustrates the order of the set of group factors which ranked according to the relative importance indices.

Table 4.5 Overall average RII

Productivity Group	Group factors average RII	Group Rank
Environmental	0.668	1
Cultural	0.606	2
Economical	0.561	3

5. Conclusions

The present study was designed to determine the effect of cultural, environmental, and economic factors on labour productivity in the Omani construction industry. Previous literature on the subject matter was the basis for identifying the factors and group categorisation. The data collected through questionnaires and analysed revealed the following findings:

The construction industry in Oman is highly dependent on expatriate workforce and has suffered from the current post-pandemic economic situation which has affected projects execution, workers' wages and progress of work. The relative importance index (RII) showed that the factors which affect labour productivity in the Sultanate of Oman were: collectivism, financial motivation, environmental training, communicating in English, and high temperatures. Further analysis revealed that environmental group scored the highest average RII followed by cultural and economic group factors respectively.

Practical Implications:

Project managers and industry practitioners should pay attention to the cultural determinants like collectivism and communicating in English. A reasonable approach to tackle this issue is by proper diversity management and interaction activities to reduce the cultural differences or communication problems. Additionally, leadership style could play a significant role to control the interaction between the labours.

The findings of this study suggest that contractors should pay attention to financial motivation factor as it has been ranked highly by labours particularly by expatriate workers. Therefore, contractors must have planned incentive program, as this may result in labour satisfaction which can reflect an increase in labour productivity. In addition, the recent national economy issues have affected construction labour by lowering wages and material shortages, but the impact is seen more on expatriate labours than locals. As a result, contractors must consider financial incentives and stability of wages particularly for non-Omani workers.

Limitation and Future Recommendation:

Few limitations should be considered in this research. Firstly, due to the time constraint, research has conducted a survey data instead of interviews, but conducting both methods could lead to a better and more reliable analysis of the results. Secondly, the contractors have been selected from the excellent group of contractors.

It is recommended that future research to be undertaken to investigate the impact of the different group factors from previous studies with this study and compare different construction professionals' perspectives with those of contractors, project managers and staff.

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Eng. Ghassan Ibrahim Al Farsi (MSc, BSc) is Assistant Lecturer in the department of Civil Engineering and Quantity Sureveying at the Military Technological College Muscat. His research interests include labour productivity factors, constrction project management and infrastructure management.

Dr. Abdullahi Ahmed Umar (MRICS, PMP) is a Lecturer in the department of Civil Engineering and Quantity Surveying at the Military Technological College Muscat. His research interests include Construction project management, Ethics in the construction industry, Public Private Partnerships (PPP) procurement, and Project finance with particular interests in developing countries.

Dr. Nuhu Braimah (BSc, PhD, MAPM, FHEA) is a Lecturer in the Civil and Environmental Engineering department at Brunel University London. His research interests include Project Planning and Programming, Risk and Contract Management, Project Change and Claims Management, Delay and Disruption Analysis, Project Procurement.

Paper no. 17

Factors Causing Cost Overrun in Projects: A Case from Pakistan's Construction Industry

Ahsen Maqsoom[1], Usman Ali[2], Muhammad Rafique Ahmed[3], Muhammad Irfan[4], Hassan Ashraf[5] and Maria Ghufran[6]

[1] Associate Professor, Department of Civil Engineering, COMSATS University Islamabad Wah Campus, Wah Cantt, E-mail: ahsen.maqsoom@ciitwah.edu.pk (corresponding author).

[2] Graduate Student, Department of Management Schiences, COMSATS University Islamabad Wah Campus, Wah Cantt, E-mail: FA20-RPM-007@cuiwah.edu.pk

[3] Graduate Student, Department of Management Sciences, University of Wah, Wah Cantt, E-mail: UW-21-MGT-MS-004@student.uow.edu.pk

[4] Lecturer, Department of Civil Engineering, HITEC University, Taxila, E-mail: irfan7235@yahoo.com

[5] Assistant Professor, Department of Civil Engineering, COMSATS University Islamabad Wah Campus, Wah Cantt, E-mail: drhassanashraf@ciitwah.edu.pk

[6] PhD Student, Department of Construction Engineering Management, National University of Science and Technology, Islamabad, E-mail: mghufran.cem17nit@student.nust.edu.pk

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Abstract: The construction sector has a significant role in the socio-economic development of any country. As the construction sector involves diverse stakeholders with complex processes and communication channels, it faces numerous challenges. Among most of the critical challenges encountered, the issue of cost overrun is very concerning in the construction sector of Pakistan. The factors that result in cost overruns include poor communication and coordination between teams, inefficient contract management, inadequate financial management, and procurement management. The current research investigates the priority of these specific factors on cost overruns. To achieve the objectives of the study, a survey was conducted on 113 construction projects supervised by the respective companies. According to the findings of the study, the lack of coordination and communication at the design stage and coordination and information flow between the parties resulted in cost overruns for the companies involved. Moreover, contract management factors have highlighted that poor project management and lack of experience is a major factor in causing a cost-related disaster. In a similar context, procurement-related factors attributed that high cost in the purchase of construction machinery during construction indicated it as an important circumstance leading to cost overrun. In the perspective of financial management, the factors have shown the inaccurate estimation of time and cost, and poor site management assistance of site engineers leads to cost escalation in construction projects at the national level. The current study can play a crucial role in minimizing the cost overruns as the results of this study will provide some guidance to the key stakeholders in construction organizations and policymakers at the national level to adopt a proactive approach to ascertain an optimum utilization of resources and minimize cost overrun in the construction projects.

Keywords: cost overrun, coomunication and coordination, contract management, procurement, financial management.

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1. Introduction

The construction industry is the most important asset for any nation and it has a great contribution in boosting its economy along with the development and growth of social benefits. Construction projects usually take months or years and include many different phases or parts. It can be difficult to separate these parts and measure what contributes to operational efficiency and what leads to cost overruns in construction projects (Okonkwo et al., 2022). In implementing these types of long-term projects, the initial plan is inevitably a guideline rather than a plan. Therefore, changes happen along the way, and these variations considerably affect the project cost estimates and lead to cost escalations (Plebankiewicz, 2018). A cost overrun occurs when the contractual amount for a project is exceeded by experienced costs.

Understanding the root causes of cost overruns is crucial for addressing and minimising them. While certain circumstances, like as extreme weather, might cause delays or damages, resulting in cost overruns, this is frequently the result of more complicated project management issues that are complex to tackle. The highest cost overruns are usually due to changes in requirements or poor contract management (Irfan et al., 2020). Therefore, it is very significant to make certain that the project is concise and that all stakeholders in the project embrace and consent on the specific scope of work and performance necessities. Pre-construction cost determinations and comprehensive project planning are essential to confirm the accuracy and reliability of project budgets, especially when the project is perplex and subject to change (Plebankiewicz, 2018). In most of the cases, design and implementation problems can be eliminated by utilizing effective project management strategies, cost administration and control software, or utilization of building information modelling (BIM), so that all stakeholders and project team members utilize similar latest design information and have the potential to change it in real-time when deemed necessary. Frequent change or variation orders can also cause cost overruns as a consequence of inadequate communication and coordination between team members (Maqsoom, et al., 2018). A change order is a new job added or deleted in the original contract that results in a change in the original amount and/or the duration of the contract. Failure by a party to enter into a contract is inconsistent with the contract and incurs significant costs that could result in the breach of contract. A non-compliance of contract may give rights to the claimant to a claim for incurred damages. Construction contracts generally stipulate that the contractor incurs direct losses and/or costs as a result of work that is significantly affected by the client's liability (Shaikh, 2020). Furthermore, the factors related to contract management, procurement, communication and coordination at the design phase, and financial management of the projects play a key role in efficiently controlling the cost of the construction projects (Irfan et al., 2020).

The contribution of Pakistan's construction sector to GDP is about 2.4%. Transport infrastructure is the fourth largest sector that constitutes 10% to GDP and more than 17% to Gross Capital Formation and the sector acquires 20-25% of yearly federal Public Sector Development Program and 2.3 million people (6% of the total recruited labour force of Pakistan) earn through this sector and support their families. (Nasir et al., 2011). As per a report published in Business Recorder by Amin, (2017), official resources revealed that the majority of important road projects had a cost overrun of 200% in Pakistan and are still not functional despite the passage of over 10 years. Cost overruns are global issues and Pakistan is no exception to it. Therefore, the current study determines the (1) communication and coordination; (2) contract management; (3) procurement; and (4) finance-oriented factors causing cost overruns in the Pakistani construction sector. Therefore the current research examines the following research questions:

RQ1: What are the communication and coordination related factors that cause the cost overrun in Pakistani construction projects?

RQ2: What are the contract management related factors that cause the cost overrun in Pakistani construction projects?

RQ1: What are the procurement related factors that cause the cost overrun in Pakistani construction projects?

RQ1: What are the finance related factors that cause the cost overrun in Pakistani construction projects?

The current research will investigate the impact of these indicators on project performance regarding cost escalation. Consequently, the findings of this study will provide some guidance to the top management in construction organizations and policymakers at the national level to adopt a proactive approach to ascertain an optimum utilization of resources and minimize cost overrun in construction projects. The money recovered from such overruns can be utilized for many other development projects.

2. Literature Review

Cost overruns are common in construction, and they emerge when real expenses surpass projected costs or budgeted quantities (Plebankiewicz, 2018). Many researchers have identified the causes and factors of cost escalation in construction projects globally and Pakistan. Sohu et al. (2018); Soomro et al. (2019); Shaikh, (2020) concluded from their studies that price escalation on major construction material and delay in progress payments are the key factors that influence the cost escalations in construction projects in Pakistan.

According to previous studies, frequent reasons of cost escalation include inaccurate and faulty project estimates, unclear project scope definition, project design omissions, unforeseeable project variations, management errors, weak communication among teams, underestimating the time needed to finish the projects (Asiedu and Ameyaw, 2020; Heravi and Mohammadian, 2020; Irfan et al., 2020). Similarly, Sohu et al. (2018) highlighted that midway project revisions typically arise as a result of design defects or inadequate scope in the initial project assessment, raising the total budget as well

as the delivery schedule, according to their findings. If the schedule is underestimated, additional projects may be put on hold till the current one is completed. Within major projects, it can also generate issues with project sequencing and phasing. Moreover, lack of proper communication, poor contract management, procurement-related issues, and financial management-related issues give rise to cost overruns in construction projects (Plebankiewicz, 2018). Irfan et al. (2020) stressed the significance of effective and strong communication channels between different project teams because it will reduce lots of other problems that might increase the probability of cost runs. Apart from these factors, poor contract management, inefficient procurement, inadequate communication and collaboration among project teams, and poor financial management can significantly lead to cost escalations in construction projects (Plebankiewicz, 2018; Vu et al., 2020).

Moreover, as a result of all these cost overrun factors, the history of Pakistan's infrastructure projects has witnessed huge cost overruns in the past and continues to struggle with controlling this enigma at present as well (Irfan et al., 2020). Some of these projects' data have been included in the current study. For instance, the 193km Gwadar-Hoshab section of Rattodero-Gwadar Motorway (M-8) was completed in February 2016 against the initial deadline of 2006 at Rs 13 billion, revised several times. The cost of Lyari Expressway increased to 154% from Rs.5.9 billion to Rs.12.99 billion originally accepted by the Executive committee of the National Economic Council (ECNEC). Karachi Hyderabad Motorway (M9) which was approved at a cost of Rs.24.93 billion has increased to Rs.36 billion. Similarly, the construction cost of the Lawari tunnel was revised from Rs.7 billion to Rs.27 billion. Due to continuous delays and design revisions, the construction cost of the Takht Bai Over-head Bridge escalated from Rs.582.12 million to Rs.836.47 million. Lahore Orange Train Line has resulted in an additional cost overrun of Rs.50 billion apart from 22 months delay. In a similar report published in Express Tribune, it was stated that the cost of the Bus Rapid Transit System in Peshawar has increased 54% from Rs37 billion to Rs.57 billion due to delays. Furthermore, the cost of the Jalkhad-Chilas section escalated to Rs 7.8 billion against the initial cost of Rs 2.3 billion due to an inordinate delay of over six years in project completion. The Jalkhad-Chilas section (68km) is the last section of Mansehra-Naran-Jalkha-Chilas Road (N-15). China is currently working on a revolutionary idea of One Belt One Road (OBOR), in which CPEC is a subsidiary part. A big portion of projects in CPEC with an investment of $10.63 billion is in transport and infrastructure through governments funding including $6.1 billion investments in road projects (Butt, 2015).

These issues of cost overrun are huge and can be minimized as highlighted by include: developing the core stakeholder group for the project as soon as possible, engaging them in decisions that impact them, enquiring from them if the project impacts anyone else, and engaging those people also, and ensure the right approval method is in place and implemented (Irfan et al., 2020). In conclusion, project cost overruns can be avoided by following a rational approach to design and monitoring the progress. A strong, practical starting point is provided by good planning. Proper monitoring identifies which areas are likely to deviate from the plan, providing the project team adequate time to make modifications to the project management method and put the work back in line with expectations. Being able to precisely track time is one of the most important aspects of preventing cost increase.

3. Methodology

All of the studies cited previously covered four primary factors that contributed to project budget overruns. These contain communication and collaboration factors; procurement factors; financial management factors; and contract management related issues (Irfan et al., 2020). To attain the pre-defined objectives of the current research, the authors developed a structured questionnaire that took into account the identified communication, contract, procurement and finance related cost overrun-related factors in construction projects. The questionnaire was pilot tested with nine construction representatives, of whom three were general managers, three were project managers, two were site engineers, and last one was CEO (chief executive officer). Subsequently, modifications were made in the questionnaire as a result of the respondents' recommendations.

The author tried to compile a simple and easy to apprehend questionnaire. All the chosen factors were grouped in such a way that the respondents would understand the question easily and without hesitation. Furthermore, rather than using set numbers or figures, some of the responses were structured in ratios, making the questionnaire simple to comprehend and respond to without reluctance. Proper options for some questions were also given so that the respondents could answer the questionnaire conveniently.

Following a trial survey and proposed changes, the final survey was conducted using a created questionnaire and was directed towards the contractor enterprises across Pakistan. To collect the most responses from the questionnaire, many methods were tried. The questionnaire was endorsed by a cover letter from the University's Head of Administration and the Chairman of Pakistan Engineering Council (PEC), giving the questionnaire the legal authorization to be distributed among the Pakistan Engineering Council's recognized contractors' firms (PEC). The questionnaire was disseminated to about 180 companies in total. The respondents were asked to rate the listed factors through a Likert scale (where "1" depicts the least important; "5" shows the most important). There were 130 filled responses in all. Because 17 of the responses were unsatisfactory, they were eliminated. As a result, the total number of successful questionnaires was 113, with thirty nine from the building sector, forty thee belonged to civil works, twenty six responses were received from electrical and mechanical, and five responses from rest of the specializations. All of the companies that answered to the survey were PEC members and worked in the construction industry; they specialized in a variety of

disciplines such as building and civil, petroleum, electronic, and mechanical construction.

4. Results andAnalysis

In the current study, the first phase of the investigation is regarding the communication and coordination related factors that cause cost escalation in the construction industry of Pakistan (Table 1). Insufficient coordination at the design phase was ranked as highest in the communication and coordination-related factors in Pakistani construction projects with the mean importance rating (MIR) 3.74 and standard deviation (SD) 0.905.

Table 1. Communication and Coordination factors causing cost overrun

Related Variables	N	Min	Max	MIR	Standard Deviation	Ranking	Remark
Insufficient coordination at design stage	110	1	5	3.74	0.905	1	Imp
The slow response by the consultant engineers regarding testing and inspection	110	1	5	3.68	1.013	2	Imp
Inadequate coordination between designers	110	2	5	3.63	0.917	3	Imp
Inadequate information flow between stakeholders	110	2	5	3.63	0.937	4	Imp
Delay in informing contractor	110	2	5	3.55	0.884	5	Imp
Unstable interest rate, fluctuation of currency/exchange rate	110	1	5	3.49	0.974	6	Mod. Imp
Information availability at implementation stages	110	1	5	3.42	0.806	7	Mod. Imp

Note: means<1.49=unimportant; 1.5-2.49= less Important; 2.5-3.49= moderately important; 3.5-4.49= Important; 4.5-5.0= very important.

and SD 1.013. Subsequently, the remaining factors as the findings of Table 1 include insufficient coordination between designers (MIR= 3.63, SD= 0.917), lack of information flows between parties (MIR= 3.63, SD= 0.937), delay in informing contractor (MIR= 3.55, SD= 0.884), unstable interest rate in projects, fluctuation of currency/exchange rate in projects (MIR= 3.49, SD= 0.974), and information availability at execution stages (MIR= 3.42, SD= 0.806).

Delays in obtaining design documents, delays in the preparation method leading to a shortage of resources, expertise, and governance, unpredicted conditions, poor decisions or adjustments in the design documents given by the employer, and delays in replying to contractor's enquires are all examples of poor coordination at the designing phase. According to Irfan et al. (2020), receiving the design document is on top of the list because the best project performance needs good coordination. In Pakistan, the coordination between owner, consultant, and contractor is a big challenge. For successful project execution, it is important to hire competent consultants to efficiently undertake testing and inspection at sites. The faster the response of inspection and testing, the more economical will be the project. In Pakistan, the consultant engineers who are only hired for testing and inspections are too slow in giving a timely response that causes cost overrun in the construction projects.

Similarly, an absence of mechanisms to incorporate client needs, an excessive amount of rework caused by design revisions, a lack of suitable quality control methods, and the absence of a project representative during the design phase all contribute to a high level of rework, and lack of coordination between designers. As the design is the most basic part of the construction therefore it needs the best coordination between designers and other key stakeholders. To have fewer cost overruns, the management must make effective coordination between designers. Apart from this, the contractor is the contract winner, is the one who leads the project on-site, and for leading a good project, the contractor must complete cost and time plans for activities, bar charts and graphs for enhance project performance assessment. According to Asiedu and Ameyaw (2020), as part of the contractor's role and responsibilities, owners may demand for more advanced and modern scheduling methods, such as the Critical Path Analysis, Program Evaluation and Review Technique, or Precedence Diagramming Technique. Delays in information release can lead to cost overruns in construction projects.

The second phase of the investigation is related to the contract management-related factors that result in cost overruns in the construction sector of Pakistan (Table 2). Insufficient project management and inadequate experience was ranked as highest in the contract management-related factors in Pakistani construction projects with the mean importance rating (MIR) 3.92 and standard deviation (SD) 0.898. Followed by mistake during constructions from mason was ranked as the second-highest and most significant factor with MIR 3.87

and SD 0.931. Subsequently, the remaining factors as the findings of Table 2 include management dearth in planning/ scheduling (MIR= 3.75, SD= 0.902), poor contact management by contractor (MIR= 3.72, SD= 0.901), project complexity (MIR= 3.68, SD= 0.947), lack of monitoring and control by project management and contract administration group (MIR= 3.65, SD= 0.874), non-synchronization of planning with execution (MIR= 3.63, SD= 0.758), contractor lack of project type experience (MIR= 3.49, SD= 0.917), , and inaccurate and faulty assessment of project's time by contractor (MIR= 3.48, SD= 0.907).

Table 2. Contract management-related factors causing cost overrun

Related Variables	N	Min	Max	MIR	Standard Deviation	Ranking	Remark
Poor project management and lack of experience	113	1	5	3.92	0.898	1	Imp
Mistake during constructions from mason	113	2	5	3.87	0.931	2	Imp
Management dearth in planning/ scheduling	113	1	5	3.75	0.902	3	Imp
Poor contact management by contractor	113	1	5	3.72	0.901	4	Imp
Project complexity	113	1	5	3.68	0.947	5	Imp
Insufficient monitoring and control by project management and contract administration group	113	1	5	3.65	0.874	6	Imp
Non-synchronization of Planning with implementation	113	2	5	3.63	0.758	7	Imp
Contractor inadequate project type experience	113	1	5	3.49	0.917	8	Mod. Imp
Inaccurate assessment of projects time by contractor	113	1	5	3.48	0.907	9	Mod. Imp

In construction projects, the mistakes encountered as a result of poor management and insufficient experience of the project team members will result in grave challenges. To overcome these issues, the client may need to hire a good project management team with sound construction site experience. The management team is required to make proficient project plans, schedules, and contingencies to effectively avoid time and cost overruns. In complex and mega projects, it is necessary to have a management team whose purpose will have to plan the project keeping in view the weather conditions, materials, and labors in mind (Keng et al., 2018). If the management team has planned poorly, it can cause cost overrun in the project and that is the reason this factor is marked as an important factor by the experts.

In Pakistan, the implementation of project management practices is not mature enough, and less experienced people on projects generate inefficient results (Soomro et al., 2019). Skilled labor such as mason, who works under technical staff and practically constructs what the designer made in the design. Mason can make mistakes if he is not properly trained and can cause cost overrun in the project. This phenomenon is very common in Pakistan because masons here are not well trained for complex and mega projects.

Apart from this, several of the lowest bids may lack competence, and the contractor's strategy, budgetary control, overall site supervision, and distribution of resources, such as people, monetary, and material resources, may receive less consideration (Maqsoom et al., 2018). Cost overrun can also be caused by this factor because if the contractor has less experience with the contract and its management, then during the implementation stage of the project, the contractor will experience cost escalation in the project.

The third phase of the investigation is related to the procurement-related factors that result in cost overruns in the construction sector of Pakistan (Table 3). The high cost of purchase of machinery was ranked as highest in the contract management-related factors in Pakistani construction projects with the mean importance rating (MIR) 3.81 and standard deviation (SD) 1.048. Followed by modification in the material specification was ranked as the second-highest and most significant factor with MIR 3.78 and SD 0.908. Subsequently, the remaining factors as the findings of Table 3 include high cost of rent of machinery (MIR= 3.72, SD= 0.949), poor contact management by contractor (MIR= 3.72, SD= 0.901), material cost fluctuation and shortage of materials (MIR= 3.72, SD= 1.039), obsolete or unsuitable construction techniques and old machinery (MIR= 3.68, SD= 0.919), dependency on imported material (MIR=

3.60, SD= 1.138), and misunderstanding about material transportation (MIR= 3.25, SD= 1.014).

Table 3. Procurement factors causing cost overrun

Related Variables	N	Min	Max	MIR	Standard Deviation	Ranking	Remark
High cost of purchase of machinery	113	1	5	3.81	1.048	1	Imp
Modification in material specification	112	1	5	3.78	.908	2	Imp
High cost of rent of machinery	110	1	5	3.72	.949	3	Imp
Material cost fluctuation and shortage of materials	113	1	5	3.72	1.039	4	Imp
Obsolete or unsuitable construction techniques and old machinery	113	1	5	3.68	.919	5	Imp
Dependency on imported material	113	1	5	3.60	1.138	6	Imp
Misunderstanding about material transportation	113	1	5	3.25	1.014	7	Mod. Imp

The construction projects involve diverse stakeholders and a mix of different skilled and unskilled workforce. Their roles and responsibilities within the project vary and depend on their past experiences as well. Highways, railroads, bridges, harbors, dams, and structures are all areas of expertise for civil and structural engineers. Mechanical and electrical engineers work on the design and integration of equipment and electrical components in building projects. If the clients do not engage all types of resources i.e., material, machinery, and manpower, cost overrun is inevitable. If in the contract, the cost is estimated on some type of material, and due to certain uncontrollable situations, the material specifications are changed, it will escalate cost (Irfan et al., 2020). This phenomenon is also very common in Pakistan.

Furthermore, fluctuating raw material costs, uncertain cost of manufactured materials, deceptive practices and mismanagement, mechanism of financing and payment for work done, inappropriate planning, high-interest rates levied by bankers on debts obtained by contractors, variation orders, long time between design and duration of bidding/tendering, poor coordination between designer and building contractor, poor coordination among general contractor and subcontractors can result in cost escalations. Keng et al. (2018) highlighted that fluctuation in prices of raw material is one of the main factors in construction projects that cause cost overrun, therefore fluctuation of material cost should be given importance in construction.

According to researches, the domestic currency's weakness against the dollar has an impact on the pricing of imported materials and overall price ranges (Kim et al., 2018). The cost of raw materials was another closely connected element that was ranked as the third most prominent variable driving cost changes. For construction projects, concrete and steel are key cost elements. These elements are in high demand in a variety of other industries. Because need for these materials significantly outnumbers supply, material suppliers establish an artificial shortage of these materials, resulting in a cost increase. In addition, proper logistics for shipping should be put in place. Mismanagement of material transportation from the contractor side can make the procurement process ambiguous for suppliers and can result in cost overrun in near future due to a shortage of material with reduced quality and productivity.

The final phase of the investigation is related to the financial management related factors that result in cost overruns in the construction industry of Pakistan (Table 4). Inaccurate estimation of time and cost was ranked as highest in the contract management-related factors in Pakistani construction projects with the mean importance rating (MIR) 3.88 and standard deviation (SD) 0.898. Followed by poor site management assistance of site engineers was ranked as the second-highest and most important factor with MIR 3.85 and SD 3.855. Subsequently, the remaining factors as the findings of Table 4 include low skilled financial management group (MIR= 3.82, SD= 0.956), lack of cost planning or monitoring during pre-and post-contract stages (MIR= 3.81, SD= 0.950), cost increases due to environmental restrictions and political issues (MIR= 3.70, SD= 0.934), fluctuation in the cost of building materials (MIR= 3.65, SD= 0.924), high transportation cost and wrong estimation (MIR= 3.63, SD= 1.011), monthly payment difficulties from agencies (MIR= 3.60, SD= 1.031), cost increases due to environmental restrictions (MIR= 3.59, SD= 0.941), financing and payment for completed works on time (MIR= 3.55, SD= 0.945), cash flow during construction (MIR= 3.54, SD= 0.978), financial difficulties to contractor from owner (MIR= 3.53, SD= 0.917), optimistic expectation regarding cost forms the funding agencies, (MIR= 3.53, SD= 0.927), inflation of prices of construction requisites (MIR= 3.52, SD= 0.992),

and fluctuation in money exchange rate (MIR= 3.46, SD= 1.035).

Table 4. Financial management factors causing cost overrun

Related Factors	N	Min	Max	MIR	Standard Deviation	Ranking	Remark
Inaccurate estimation of time and cost	113	1	5	3.88	.898	1	Imp
Poor site management supervision of site engineer	113	1	5	3.85	3.855	2	Imp
The low skilled financial management group	113	2	5	3.82	.956	3	Imp
Inadequate cost planning or monitoring during pre-and post-contract phases	113	2	5	3.81	.950	4	Imp
Cost increases due to environmental and political challenges	113	2	5	3.70	.934	5	Imp
Fluctuation in the cost of building materials	113	1	5	3.65	.924	6	Imp
High transportation cost and wrong estimation	113	1	5	3.63	1.011	7	Imp
Monthly payment difficulties from agencies	113	1	5	3.60	1.031	8	Imp
Cost increases due to environmental restrictions	113	1	5	3.59	.941	9	Imp
Financing and payment for completed works on time	113	1	5	3.55	.945	10	Imp
Cash flow during construction	113	1	5	3.54	.877	11	Imp
Financial difficulties to the contractor from owner	113	2	5	3.53	.917	12	Imp
Optimistic expectation regarding cost forms the funding agencies	113	1	5	3.53	.927	13	Imp
Inflation of prices of construction requisites	113	2	5	3.52	.992	14	Imp
Fluctuation in money exchange rate	113	1	5	3.46	1.035	15	Mod. Imp

Because the estimator must alter the unit costs for quantity of items, personnel, location, and construction contingencies, vast experience and discretion are required to generate a credible cost estimate. Native cost estimation strategies do not include in-depth investigations (Heravi and Mohammadian, 2020). Assumptions and forecasting on cost rates are conducted on experience without including price index. The factor and its occurrence are common in Pakistan.

According to Maqsoom et al. (2018), site management is also a big factor that effect cost escalation in construction projects. To overcome cost overrun, site management should do very carefully. Poor site management can result cost overrun in the projects. Further, financing and payment for completed works on time and cash flow during construction are also highly ranked important factors. Many projects suffer from cost overruns because of the skills of finance management teams. As discussed above, cash flows during construction are a key variable and this must be elaborated while planning for the project and financial spending be administered to avoid cost escalations (Sohu et al., 2018). Shaikh (2020) states and recommends that a thorough financial framework for the project should be established to avoid cost overrun.

The increase in material cost is due to a scarcity of materials and variations in currency exchange rates. The project owners, consultants, and contractors should focus to avoid erroneous cost estimates, haphazard planning, frequent design modifications, or design errors insufficient labor/skill accessibility, rising costs for machinery, labor, raw materials, and logistics (Shaikh, 2020). This factor is common in the Pakistan construction industry because causes of cost overrun and inefficient cash flows affect the progress of the project significantly influencing other concerns include the contractor's inadequate site administration, a labor shortage, and insufficient project scheduling.

5. Conclusion

Based on the results of a current study, it was found that construction companies need to carry out their construction activities in an effective and organized way. Based on the objectives of the study, which aims to identify key factors such as communication and coordination in design, procurement management, contract management, and financial management challenges, it was found that there is a lack of coordination and communication between project team members, weak project management and planning, poor contract management knowledge among majority of local contractors, and inadequate financial management of the projects. Changes during construction and challenges with the paying agencies justify cost escalations for the businesses concerned.

Customers need to ensure proper documentation, project control, project planning execution, and entrepreneurial management, as well as seamless communication between participants both at the beginning of the project and throughout its lifecycle. In the case of public contracts, the government must make payments on time so that companies do not suffer delays due to subsequent payments.

The limitation of the research is that the present research concentrated only on the construction sector in Pakistan and there may be several critical factors of cost overruns in other industries of the country as well as in the construction industry of other countries that affect the implementation of their projects within cost estimates. This study evaluates the ranking and effect of cost overrun factors as per mean importance rating values, thus, the further research might examine severity and frequency marks of these variables relative to implementation of perplex developments. Moreover, it is also recommended to undertake this project with an even larger set of factors for producing similar research models that can be generalized and implemented in more developing countries. Apart from this, a similar study can be conducted in different developing countries and their results can be cross-compared to generate more robust and efficient cost reduction models.

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Biographical Data of Authors

Ahsen Maqsoom received the Ph.D and M.Eng degree from Asian Institute of Technology Bangkok, Thailand. He is currently working as an Associate Professor at COMSATS University Islamabad, Wah Campus, Pakistan. He has published various research articles in the peer-reviewed international journals and conferences and has authored five book chapters. His research areas include project management, international business, remote sensing, machine learning, risk management and civil engineering.

Mr. Usman Ali completed his BS in Information Technology from Allama Iqbal Open University Islamabad Pakistan, and his MS in Project Management from Comsats University Islamabad Wah Campus Pakistan. Moreover, he has the sound banking experience, started his carrier as Operation support staff in one of the leading provincial bank, "The Bank of Punjab"s and then worked as Branch Manager Operations and Branch Manager. Currently he is serving as Branch Manager Operation in Summit Bank Ltd Hassan Abdal Attock Branch, Pakistan. Moreover, he is also actively involved in Internet Banking Research. His key research interests lie in Examining the Impact of Digital Banking Services on Customer loyalty Evidence from Pakistani Banks.

Muhammad Raffique Ahmed completed his BBA (Hons) from University of Wah, Wah Cantt. His specialization is finance. He is currently doing MS Finance from University of Wah under the supervision of Dr. Faiza Saleem, Assistant Professor, University of Wah. Moreover, he has a past experience of General Manager and Finance Officer. Currently, he is working as a PBO in Summit Bank, ltd in Hassanabdal Banch. His key research interest is Green financing, corporate finance, international finance and financial markets.

Engr. Muhammad Irfan completed his BSc in Civil Engineering from UET Taxila, Pakistan, and his MSc in Construction Engineering & Management from NUST Islamabad, Pakistan. He is currently doing his Ph.D. in Construction Engineering & Management from COMSAT University, Wah, Pakistan. Moreover, he has the sound construction industry experience and is Managing Director of Start Sustainable Construction Company, which is striving to incorporate sustainable construction practices in the local construction industry of Pakistan. Apart from that, he is serving as a Lecturer at HITEC University, Taxila, Pakistan. Moreover, he is also actively involved in construction management research. His key research interests lie in organizational culture, sustainable construction, industrial revolution 4.0, industrial revolution 5.0, and stakeholder management.

Hassan Ashraf received the MS degree from Asian Institute of Technology Bangkok, Thailand and Ph.D. degree from University of Hong Kong, Hong Kong. He is currently an Assistant Professor at COMSATS University Islamabad, Wah Cantonment, Pakistan. He is actively involved in the research after completing his PhD.

Maria Ghufran holds a bachelor's degree in Building and Architectural Engineering. She has completed her Master's in Construction Engineering and Management from National University of Sciences and Technology, Islamabad, Pakistan. Currently, she is enrolled in Ph.D. in Construction Engineering and Management at National University of Sciences and Technology, Islamabad, Pakistan. Her research interest lies in subjects including Circular Economy, Complex Systems and Dynamics, Supply Chain Management, and Sustainability.

Paper no. 29

Formulation of a Conceptual Evaluation Model for Digital Twins Application in the Construction Industry

Vasileios Basas[1], Antonios Panas[2] and John-Paris Pantouvakis[3]
[1]Civil Engineer, M.Sc. Hellenic Open University, Bentley Systems Europe BV, Computerlaan 14, 2628 XK Delft, The Netherlands, E-mail: vbasas@gmail.com
[2]Civil Engineer, Ph.D., Centre for Construction Innovation, National Technical University of Athens, Zografou Campus, Iroon Polytechniou 9 str., 15780 Zografou, Athens, Email: antpanas@gmail.com.
[3]Professor, Centre for Construction Innovation, National Technical University of Athens, Zografou Campus, Iroon Polytechniou 9 str., 15780 Zografou, Athens, E-mail: jpp@central.ntua.gr

Abstract: The construction industry requires a continuous flow of information that has to be available, accurate and complete, so as to help construction practitioners in the application of information technology and digitalisation in the construction management process. The digital twins (DT), as a virtual model of a physical entity aid in addressing the digitalisation aspects along the whole life cycle of a construction project. As such, this paper critically evaluates pertinent research on DT for the whole project life cycle with the objective of illuminating research aspects focusing on construction site organisation, smart cities and smart buildings applications. The research methodology adopts the systematic review technique by retrieving scientific data from acknowledged scientific databases. A four-category conceptual evaluation framework is presented that serves as a benchmark against which the DTs' self-reliance, aptitude, learning and conformity capabilities are characterized. Although still in concept, the framework may be directly applied in construction projects in order to rank them in relation to DT technologies. The main conclusion of the conducted research is that each DT is defined and modeled at a specific level of abstraction in relation to its physical entity, the extent of which is adjusted according to project needs and objectives.

Keywords: Digital twins, Digitalization, Information Technology, Modeling.

1. Introduction

The construction industry is a sector with an intense flow of information, where there is a requirement for immediate availability of the required data (Spyropoulou et al., 2021). The transmitted information has to be accurate, complete, timely delivered and in a concrete form so as to be understandable by the recipient (Xu et al., 2014). The whole cycle of a construction project, from its conception to its decommission, produces mass data. Thus, a project's success depends largely on the information flow and the capability for processing the vast amount of data and extracting useful information (Bilal et al., 2016).

The Digital Twin (DT) is a technology, whose application started approximately a decade ago in the airspace industry. At the same time, it has been adopted as an analysis tool for mathematical modeling, simulation and optimisation and is now regarded as an integral part of Industry 4.0 (Liu et al., 2021). In the area of smart manufacturing, the DT technology plays the role of information exchanger between the internal and external stakeholders (Negri et al., 2017), as well as for the connection of parts, machinery and systems within a factory or facility (Tchana et al., 2019) for the achievement of the Industry 4.0 requirements.

This technology can potentially offer additional value to an organisation. The broad application of DT increases the operational efficiency, the resource allocation optimisation, the asset management process, the cost reduction incentives as well as productivity and data safety. The DT, as a virtual model of a physical entity, may help in addressing some of the most complex problems in the Architectural, Engineering, Construction and Management (AECOM) industries. The encryption of physical entities in a digital environment for remote projection, monitoring and control affects all processes of an organisation. As such, the integration of DT and other cognitive technologies may redefine the future vision of the construction industry.

The DT gains increasing popularity in the urban design on a global level. The urban lifestyle, with the aid of DT technology, may become more efficient since data may be analysed in real time and complex systems may be tested before their construction (Ketzler et al., 2020). Therefore,

the digitalisation of the built environment, which is favoured by the increase in computational power and the Internet of Things (IoT) actively contributes to the achievement of the sustainable development objectives as posed -inter alia- by the United Nations. The DT play an important role in that ecosystem and it is characteristic that their market value is anticipated to reach 35 billion dollars up until 2025 (Market Research Future, 2019).

The paper opts to clarify the definition of the Digital Twins technology and align the used terminology within the framework of the construction industry. The main objective is the formulation of a conceptual evaluation model which will associate the DT technology with specific Key Performance Indicators such as self-reliance, aptitude, learning and conformity as will be explained in the following sections. The research rationale is based on a research gap related to a structured association of DT with the construction projects' production process. As such, this paper aims at bridging this gap by investigating the application of DT in construction site operations and logistics, intelligent buildings and smart cities.

The structure of the paper is as follows: initially, several definitions of the DT based on published literature are provided followed by an analysis of their components and a delineation of the DT creation process. Consequently, the research methodology is described, in a step-wise fashion, with a particular focus on the research questions to be answered. Finally, the research concludes with the presentation of the suggested conceptual evaluation and assessment model, which is essential a model for benchmarking DT's maturity in an organisation.

2. Background

2.1. Definitions of Digital Twins

The used definitions of Digital Twins are evolving since the 2000s in combination with the advent of the general applications technologies in DTs (e.g. sensors, modeling, data management and interoperability technology) (Qi et al., 2021). After a decade of development, the pertinent research on DT has been rapidly evolving since 2017. The increase of the research interest lead to an expansion of DT definitions comprising the construction management discipline.

The Digital Twins were defined in 2003 by Michael Grieves as "a virtual digital representation equivalent to natural products" (Grieves, 2014). Their development remained stable up until 2012, when NASA gave another definition as "an integrated multiphysics, multiscale, probabilistic simulation of an as-built vehicle or system that uses the best available physical models, sensor updates, fleet history, etc., to mirror the life of its corresponding flying twin." (Glaessgen & Stargel, 2012). In subsequent research published in the same year other definitions were presented such as the life cycle (E. Tuegel, 2012), the mission requirements control (Gockel et al., 2012; E. Tuegel, 2012) and the use of DT for prediction diagnosis purposes (Reifsnider & Majumdar, 2013), which was established as an inherent characteristic of DT in future research. In general, the aerospace industry contributed significantly in the development of DT technology.

In 2015, Ríos et al. (2015) introduced the concept of using DT to manage a "product", rather than solely a "vehicle", thus giving the opportunity to expand DT applications beyond the scope of aerodynamics and space industry. In that sense, Grieves and Vickers (2016) defined the DT as "a set of virtual information constructs that fully describes a potential or actual physical manufactured product from the micro atomic level to the macro geometrical level". Any information retrieved from a physical object during an inspection can be equally retrieved from the DT copy. Rosen et al. (2015) highlighted that the autonomous systems must have access to realistic information models accurately depicting the interactions of the physical model with its environment, which essentially comprises the DT. Based on the definition of the digital model, Kritzinger et al. (2018) suggested that the information flow between a natural object and a digital object must be fully integrated as a DT. In such a combination, the digital object can serve as a benchmarking standard of the natural object. In other words, a change in the physical object status leads directly to a respective change in the digital object status and vice versa. Furthermore, Tao et al. (2019) consider the DT to be "a real mapping of all components in the product life cycle using physical data, virtual data and interaction data between them" for product design applications. In their opinion a DT is comprised of five parts: physical object, virtual object, connection, data and services. Ultimately, the DT has transformed the product life cycle management tool into a digital platform. This evolutionary process led to two main conceptual characteristics of DT, namely (a) the full integration of the product life cycle and (b) the updated dynamic production and management of data through cognitive technologies (Tao et al., 2018).

In the engineering section, the DT is defined as an evolving digital profile of the historical and current behaviour of a physical object or a process which contributes to the optimisation of the business performance. The DT enable the creation of a virtual copy for a product throughout its life cycle, thus making possible the detection of flaws with greater accuracy (Parrott & Warshaw, 2017).

2.2. Components of Digital Twins

The main concept of the Project Lifecycle Management philosophy is that each DT has two sub-systems: the physical system or the real space that always existed and a virtual system that contains all information associated with the physical system (see Figure 1 below). These two systems are interconnected, thus enabling the information flow between the physical and the virtual system (Grieves & Vickers, 2016).

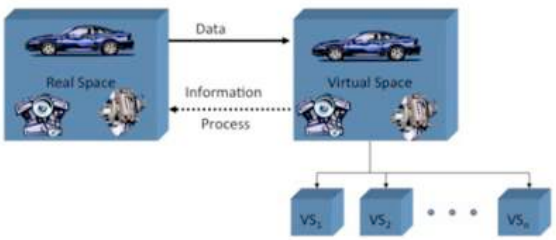

Fig. 1. Conceptual representation of the product life cycle for DT (adapted from (Grieves & Vickers, 2016)

As such, a DT has to use virtual representations in order to express the physical object (Glaessgen & Stargel, 2012; Grieves & Vickers, 2016; Rosen et al., 2015; E. J. Tuegel et al., 2011). In addition, data has to be transferred from the

physical object to the virtual one (Kritzinger et al., 2018) with an option to have also an opposite feedback. Finally, the DT has to offer a special service (Tao et al., 2019), as depicted in Figure 2 below.

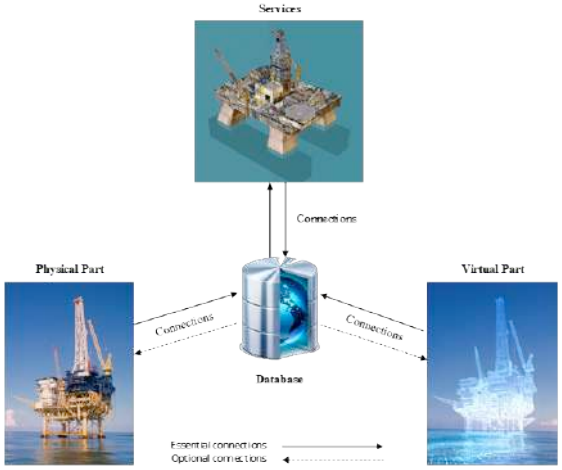

Fig. 2. Five-dimensional structure of the DT (adapted from: Tao et al. (2019))

Taking the aforementioned into account, the architecture of the DT has to be structured as follows (see also Figure 3):

- Physical asset: The physical asset in the physical world.
- Sensors: The sensors are vital for the production process, while the Internet of Things (IoT) is the base on which the smart operations are established (Bi et al., 2014). These sensors provide information in real time for the physical parameters that are linked to the DT.
- Data: The data are received by the sensors and are merged with the information from the operations programming systems.
- Analytics: High-end technologies in Artificial Intelligence are implemented such as patterns recognition, non-structured data analytics etc. in order to gain deeper knowledge with the available information.
- Digital Twin: The digital representation of the physical asset which is shaped via a software as a copy in real time.
- Actuators: the actuators serve as the means with which the DT interacts with the physical asset.

2.3. Digital Twins creation process

The creation of a DT starts with the design of the process. There are typical process design techniques that have to be followed, which essentially depict the flowchart of the input data and their elaboration within the framework of the DT application. There are six main steps that have to be followed in order to establish the DT creation process (Daecher & Schmid, 2016):

1. **Creation:** multiple sensors are used in that phase whose measurements are divided in two subgroups: operational measurements which relate to physical measurements of the scrutinised asset (e.g. tensile strength) and environmental parameters which reflect general conditions (e.g. temperature, pressure, humidity). These measurements are converted to digital signals transmitted to the DT platform. The data are enhanced with ancillary applications (e.g. CAD models, logistics systems) in order to create a holistic model of the DT.
2. **Communication:** this step allows the unhindered, two-way and in real-time integration of the physical process with the digital platform. This step includes meta data processing and poses several data security challenges (e.g. encryption), since the transmission of data must be continuous.
3. **Integration:** this step supports the data entering in a data depository in order for them to be ready to be processed and analysed. The sensors' data are gathered in the cloud and, subsequently, are merged with other operational systems.
4. **Analysis:** this step includes the use of advanced analytics (e.g. Big Data)
5. **Awareness:** all findings and conclusions from the previous steps are presented in this phase through useful visualisation techniques. The purpose is to gain knowledge on the scrutinised object and fine-tune any problematic issues. The essence is to comparatively evaluate the physical asset with its DT along one or more dimensions and locate sectors that may require further investigation of even review.
6. **Action:** this stage includes the utilisation of all usable findings and conclusions from the previous steps. It actually bridges the gap between the digital model and the physical asset by transforming all gathered data into usable information that will improve the DT process.

It is very important to note that the aforementioned architectural structure must be designed with inherent flexibility and scalability in relation to the analysis, processing and number of sensors. The latter is enhanced by the fact that nowadays the increased computational power of contemporary data systems and the possibility of using large data storage depositories may lead to the creation of a DT which is very close to the real, physical asset, hence improving its validity.

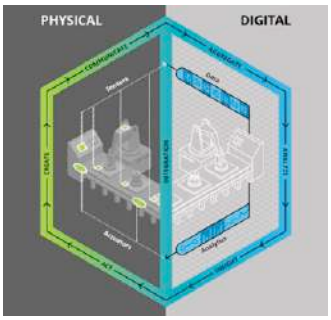

Fig. 3. Digital Twin Architecture (adapted from: (Parrott & Warshaw, 2017))

In view of the presented literature review, the research poses six main research questions that must be investigated. The first three questions relate to the evaluation of the current situation of DT, while the next three questions are associated merely to the investigation of DT capabilities regarding the project management discipline. The research questions (RQs) are formulated as follows:

- RQ1: What is the agreed terminology and definition for a DT?
- RQ2: What is the difference between a DT and the BIM philosophy?
- RQ3: What is the required Information Technology infrastructure that allows the creation of a DT?
- RQ4: What is the proposed definition of a DT in this research and what is the respective evaluation framework for the DT approach?
- RQ5: What are the perspectives, application and possibilities of the DT in the project life cycle (design, construction, operation, management and decommission)?
- RQ6: What are the main challenges and opportunities stemming from the utilisation of DTs?

The exact methodological approach to respond to these questions is presented in the next section.

3. Research methodology

The research objectives are investigated through the systematic review technique, which essentially scrutinises published research in an attempt to locate knowledge gaps in a specific research area (Webster & Watson, 2002). The research contribution to knowledge is closely associated with the fact that particular focus in given on the investigation of DT possibilities for the construction industry. A three-step approach has been implemented: (a) published research in highly esteemed academic journals has been selected, (b) a refinement of the published research was conducted by selecting those that are closely linked with the construction industry and (c) a systematic content analysis has been performed to categorise each published research with a specific DT sector. The following paragraphs provide more details for each step of the aforementioned process.

3.1. Step 1: Investigation of published research

The first step was the collection of respective information through a systematic literature review (Pawson et al., 2005) in order to find and record published research in highly esteemed academic databases. The utilised databases were Google Scholar, Scopus, ScienceDirect and Web of Science, while the investigation time period was set after 2012, which was roughly the period when the adoption of DT was established in the Construction Industry 4.0 (Xu et al., 2021). The utilised keywords were "Digital Twin", "Internet of Things" and "Building Information Modeling" associated with construction projects and building structures. As such, the yielded results included journal articles, conferences proceedings, book and research reports (e.g. PhD thesis). In addition, the document type was set as "article" or "review", since they present the most reliable results (Santos et al., 2017). In total, 170 publications in English were collected which were related to the application of DT in the construction sector.

3.2. Step 2: Selection of research closely associated to DT

In the second phase, a critical and holistic evaluation of the collected literature was conducted. A qualitative refinement of the selected journals for further analysis was performed. More than 80 publications were studied in-depth, in order to ensure that the research pool includes only publications that are related to the implementation of DT in the construction sector.

3.3. Step 3: Content analysis of selected research

In the third phase, a content analysis was conducted to clarify the content and technologies of DT, the state-of-play of their implementation in the construction sector, as well as the practical implementation of DT in the life cycle of construction projects. The main objective of this stage was to establish the theoretical framework for the development of a conceptual evaluation model for digital twins application in the construction industry.

4. Results

4.1. What is a Digital Twin?

Based on the scrutinised research, it became evident that DT have been given different definitions that sometimes even contradict each other. For example, while in some cases it is defined as an accurate copy of a product (as-built), which reflects the mechanical wear during the product life cycle (Hochhalter et al., 2014), in other cases it is regarded as a digital model, based on sensors, which yields real-time simulation results (Grieves, 2014). In addition, another differentiation may be the purpose served through the DT, ranging from the increase of investments yield (e.g. Deloitte) to ensuring mission safety (e.g. NASA).

However, regardless of the used definition, the essence of the DT philosophy evolves around three main pillars: the physical space, the virtual space and the connected data. The published literature is diversified also along the degree of interconnection between the aforementioned pillars. For example, some virtual representations do not allow the automatic bi-directional exchange of information, while the latter is always the case with the fully integrated DT. This research opts to resolve this discrepancy, by prescribing three sub-categories for DT classification (see Figure 4), as suggested by Kritzinger et al. (2018). The first category is called "Digital Model" and presents the lowest degree of integration, since the data flow between the physical asset and the digital object is manual. In this case, the changes in the condition of the digital object do not directly affect the physical asset and vice versa. When the information exchange from the physical to the virtual object is automated, then we must refer to a "Digital Shadow". The complete integration of the bi-directional information flow between the physical and the virtual object reflects the essence of the "Digital Twin".

Figure 5 presents a proposed assessment framework, which cycles through five levels, starting from a simple digital model and moving to higher levels where machine learning and autonomy actively contribute to creating more sophisticated DTs. As the model develops and evolves, feedback and prediction become more relevant.

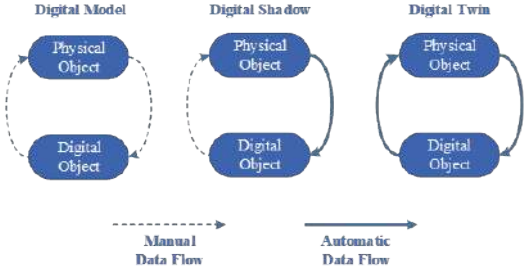

Fig. 4. Digital Model, Shadow and Twin (adapted from: Kritzinger et al. (2018))

The literature review has showed that most DT applications refer to the one-way transfer of data from physical assets to virtual models, thus falling into the category of the "Digital Shadow". It seems that the construction industry is mainly oriented towards the utilisation of the DT for the design and construction of projects. Even when BIM technologies are applied, the "Digital Shadow" is the predominant solution, since all collected data are connected to the BIM model, but the changes imposed on the virtual models do not reflect automated changes in the physical assets. For example, in the case of an electromechanical system that is monitored by the use of a Digital Shadow, then in an unforeseen event the Digital Model will flag the problem, but will not take any action. On the contrary, a fully integrated DT would not only deactivate the respective MEP system, but would also predict a possible emergence before its actual occurrence and suggest respective mitigation measures.

The DT may initially seem as an exact copy, however, they are not necessary realistic representations, but rather abstractions of the physical asset. It is not necessary even for the most advanced smart city to digitally reproduce all building details. The DT and its eco-system may differ in scale and complexity in relation to the size and the field of application. The size refers to the representation detail (how accurate it is, space / time scale etc.), while the field of application is the section of the real world under scrutiny by the model (e.g. a space motor or an entire city). From a technological point of view, DT may use three-dimensional simulations, IoT applications, 4G / 5G networks, block-chain, edge computing, cloud computing and artificial intelligence. Depending on its complexity, every DT may have access to past, present and future operational data as well enhanced prediction capabilities.

In view of the aforementioned facts, the main characteristics of a Digital Twin based on the research investigation are as follows:

1. There is always a physical asset and its virtual or digital copy (the "twin") along with a correlation between them in real time with a specific validation level.
2. The correlation's duration is equal to the life cycle of the associated physical asset.
3. The developed DT must be suitable for the purpose and the validity level, which will vary depending on the intended uses. It is important to note that the DT do not necessarily reflect all details of the initial system.
4. Every DT is modeled at some level of abstraction from its physical counterpart, adopted for its purpose of use. This means that the modeler accepts that some information of the physical asset will not be modeled in order to reflect the actual necessary information.

Within the framework of the present research, the DT is a virtual representation of either a process or a product and, subsequently, the combination of a computational model and a real system, designed for the monitoring, control and optimisation of its operability. The virtual object and the physical asset are connected with a continuous flow of data. The DT conducts analyses based on the collected data. The analysis may be used for ideal prediction of future incidents, the detection of repair needs, the minimisation of downtime and, in total, the increase of productivity. DT allow the testing and simulation of different scenarios for the finding of best practices.

A very important aspect of DT is their ability to understand, learn and create value by using a systematic approach. The DT learn from their environment and develop a certain degree of self-reliance through a continuous feedback of actual and simulated data. It is very important to include the learning factor of DT in the utilised definitions. The DT have the capability to evolve to a level of autonomy that minimises human intervention through design and control procedures via the use of artificial intelligence.

4.2. Conceptual evaluation and assessment framework

The research proposes the use of an assessment framework for Digital Twins, structured in five levels. The goal of the framework is to assess the present state of DTs based on four key metrics: self-reliance, aptitude, learning and conformity. These metrics stem from the comprehensive literature review and reflect the common denominator of the scrutinized research pool. Therefore, this framework promotes a "lingua franca" in describing a DT and its potential, thus enabling stakeholder engagement at all stages of development.

The four metrics of the assessment framework are summarised in Table 4. Although the metrics of self-reliance, aptitude, learning and conformity are associated and interconnected, they should be treated autonomously.

Table 4. Metrics of the assessment framework of a Digital Twin (Source: self study)

Metric	Description
Self-Reliance	The capacity of a DT to act without any human involvement.
Aptitude	The capacity of a DT to reproduce human cognitive functions and execute tasks.
Learning	The capacity of a DT to routinely learn from data to enhance its performance without being deliberately conditioned to do so.
Conformity	The capacity of a DT to approximate reality, based on the degree of accuracy and level of detail of a system. Therefore, it does not constitute an intrinsic property of a DT but depends on the requirements and standards of an asset.

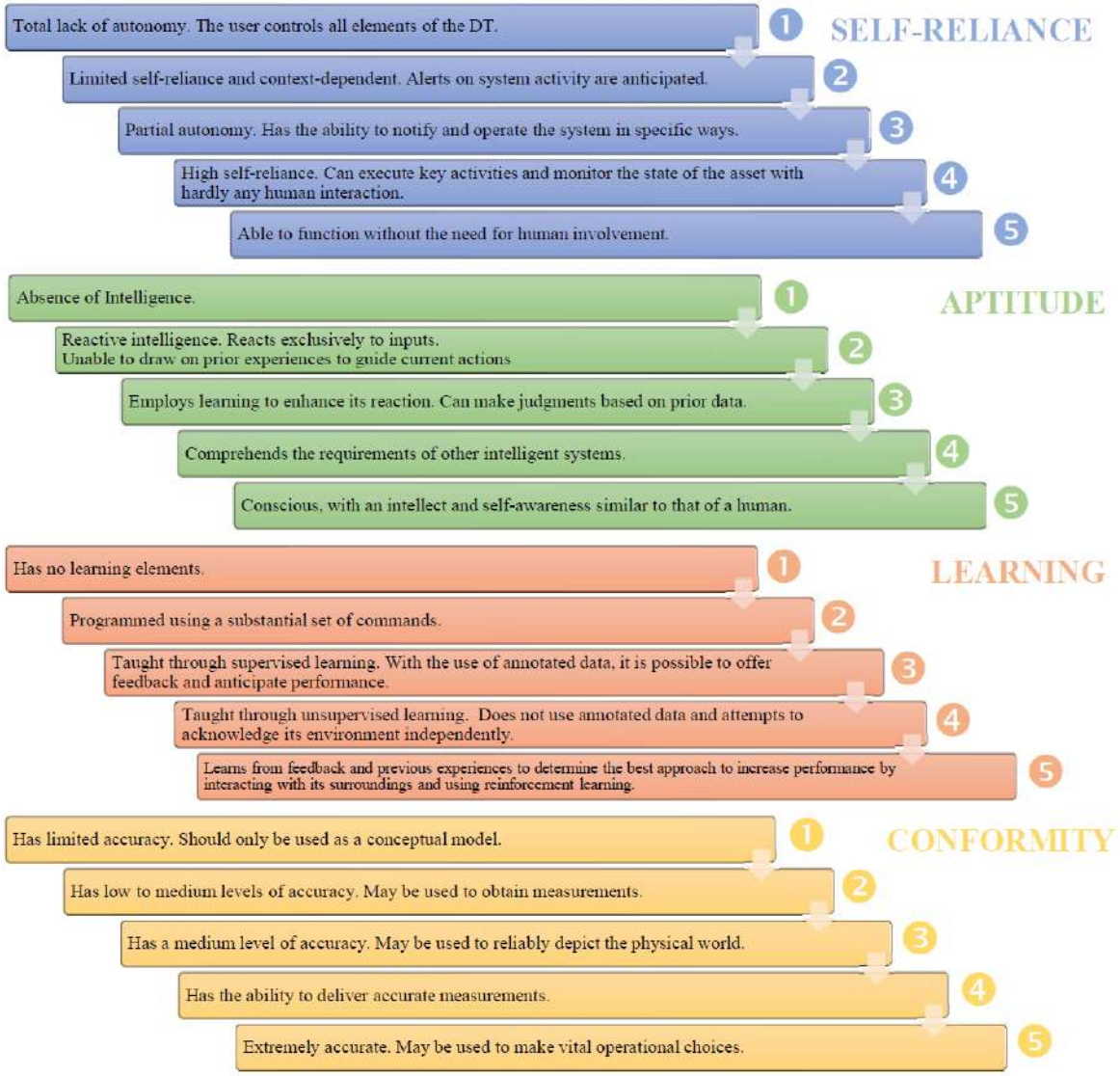

Fig. 4. Digital Model, Shadow and Twin (adapted from: Kritzinger et al. (2018))

Ideally, the construction industry should actively work towards developing and adopting "level 5" DT. However, research shows that the current state of DT development is nowhere near reaching that level and that there is still a long way to go until the prospect of conscient and self-reliant models. Nevertheless, we expect that as DTs evolve, they will grow their traits of self-reliance, aptitude, learning and conformity, thus adding value by managing an increasing number of functions and operations with minimal human intervention.

In its basic form, a DT defines a process, facility, or area model with integrated technical details that allow stakeholders to perform design and planning. However, this form of a DT takes into account only static information and data from a single asset (level 1). At this level, the DT consists of a digital model connected to the real-world system but lacks self-reliance, aptitude, or learning. Thus, its functionality is limited.

Based on this model, a level 2 DT will collect past usage data and generate analytics to consider scenarios that could improve the physical asset or anticipate things that will happen so that issues and risks can be minimised early. The DT consists of a digital model with some feedback and control capabilities at this level. A level 2 model is more proactive than level 1 and can potentially save on maintenance costs by adjusting the design solutions to actual rather than expected needs. However, it is usually bound to modelling systems of a smaller scale, such as sensors that provide feedback information to the operator of the DT.

A level 3 model could include real-time data to evaluate a dynamic scenario planning in real-time. A DT at this level is a digital model capable of delivering predictive maintenance, information, and estimates on the asset's life expectancy. Thus, it has the potential to enhance the asset's use, make the maintenance cost-effective and adjust to the actual needs and use of the asset. Levels 1-3 can serve as the foundation for building a more realistic and complicated model by incorporating associated data sets such as environmental or occupancy data.

A level 4 DT allows the use of operational data to assist decision making and optimise daily activities. At this level, the DT consists of a digital model with the ability to learn from a variety of data sources methodically. The model can apply this learning for self-sufficient decision making in a particular way. For example, the model can convey recommendations in real time on how to improve the user experience or restore a disrupted process to its original state.

Finally, a level 5 DT may draw additional data from various sources (i.e. behavioural, logistical, environmental data, etc.), hence considered a real-time system. At this level, the DT consists of a digital model with a broader variety of capabilities and responsibilities that eventually approaches the capacity to think and act autonomously (artificial intelligence). For example, the model of a neighbourhood in a smart city could constitute a level 5 model that assumes responsibility for activities that a human would typically handle and react to formerly unforeseen events.

Another feature of this level is the integrated inclusion of lower-level DTs. Several separate systems can function in tandem in a smart city to offer input to a central decision-making network. Therefore, a DT at a city scale can enrich the virtual representation of the asset by blending datasets from different areas of application, such as design, construction, planning, operation and maintenance. On this basis, a Digital Twin City could add value in comprehending the subtle connections and interactions between different parts of a city and providing optimal solutions to decision makers.

4. Conclusions

This paper has presented a comprehensive review of the ecosystem around Digital Twins, in an attempt to explore its main characteristics and the way they are associated with contemporary digital transformation schemes. Although DT have been widely implemented in steady-state production systems such as the manufacturing industry, they gain incremental acceptance in the construction industry as well. The main enabler is the Construction 4.0 framework that establishes a digitalisation network around the whole project life cycle. In that respect the main challenge is to create a common denominator amongst the construction stakeholders in respect to the content and structure of DT so as to be able to enhance awareness and facilitate their wide adoption from the early feasibility design stages to the construction projects' decommission. Therefore, a four-category conceptual evaluation framework was presented that serves as a benchmark against which the DTs' self-reliance, aptitude, learning and conformity capabilities are characterised. Although still in concept, the framework may be directly applied in construction projects in order to rank them in relation to DT technologies.

One of the main advantages of the DT is the fact that is advances, inter alia, maturity modeling in a multifaceted manner. First, it aids the development of algorithms and tools digital integration of systems, since the "virtual" aspect is the foundation upon which all DT application are built. In addition, the DT provides digital copies for the existing projects and the landscape which further facilitate the designers. Moreover, the DT may advance the development of smart structures or even aid in faults detection. In essence, the DT may be applied for the in-depth calculation, analysis, optimization and decision making through the use of several technological tools. In that sense, taking also into account the development of Artificial Intelligence, blockchain, 5G networks and IoT applications, is expected that the DT will further elevate the construction industry's skillset in the immediate future.

A further research step would be the experimental implementation of the developed framework in construction projects in Greece, in order to create an empirical database of actual project data that would contribute towards the adaptation of DT to the Greek construction paradigm.

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He is a Civil Engineer, M.Sc., Registered/Chartered Engineer (C.Eng.) and currently employed by Bentley Systems. He holds an MSc in Construction Project Management by the Hellenic Open University. Member of Technical Chamber of Greece (M.TEE-TCG), American Society of Civil Engineers (M.ASCE) and Geo-Institute (G-I). His research interests are related to Digital Twins, Numerical Modelling, Instrumentation and Monitoring, Ground Improvement, Geosynthetics and Data Analytics.

He is a Civil Engineer and holds an MSc in Construction Management from Loughborough University. He completed his PhD at the Centre for Construction Innovation of the National Technical University of Athens. He is an adjunct Lecturer at the Hellenic Open University and has published in highly esteemed academic journals and international conferences. His research interests lie in the area of construction productivity and performance benchmarking. More information is available at www.antpanas.gr.

He is a Civil Engineer and Professor at the National Technical University of Athens. He is a director of the Construction Equipment and Project Management Laboratory and the Centre for Construction Innovation. He has extensive research, professional and teaching experience in related research fields in the National Technical University of Athens, the Hellenic Open University and Nazarbayev University. More information is available at http://paris.pantouvakis.gr.

Paper no. 39

Simulation Modeling and Analysis of a Bottled Water Plant: an Empirical Study on a Medium/Large Manufacturer in Greece

Tsabikos Volas[1], Alexandros Xanthopoulos[2] and Anastasios Kypriotis[3]
[1]Department of Production & Management Engineering, Democritus University of Thrace, V. Sofias 12, 67100, Xanthi, Greece, E-mail: tsabvola@pme.duth.gr
[2]Assistant Professor, Department of Production & Management Engineering, Democritus University of Thrace, V. Sofias 12, 67100, Xanthi, Greece, E-mail: axanthop@pme.duth.gr (corresponding author)
[3]Production Manager Assistant, VAP P. KOUGIOS S.A., Rhodes, Greece, E-mail: tasos_kip@yahoo.gr

Abstract: This application-based paper contributes in bridging the gap between theory and practice of production research enabled by simulation. The case study at hand relates to a bottled water plant that is located in southern Greece. First, we provide an inside view of this real-world manufacturing environment and highlight the complexities of an actual production process in contrast to stylized theoretical models. Then, we showcase the salient features of a detailed, 3D, dynamic simulation model of the plant. The simulation model is a precise digital replica of the actual system and it is a powerful tool for supporting decision making using quantitative data rather than intuition and experience. By utilizing the simulation model, we conduct a series of experiments to facilitate what-if-analysis pertaining to assessment of new investments and risk analysis of inventory management. We evaluate the feasibility of investing on a new monobloc manufacturing station or a combined palletizer/wrapping machine and integrating it in the production line. The experimental results indicate that the increase in system throughput is 13% and 10.5% in the first and second case, respectively. Furthermore, we analyze the effect of stochastic equipment failures on inventory management decisions and customer service levels. The simulation experiments show that, for the current demand pattern, if the seventh and ninth machine operate at a reduced availability level of 40%, this will result in a stockout after 50 and 49 days, respectively.

Keywords: soft drinks industry, bottled water plant, case study, simulation, investment assessment, inventory management.

1. Introduction

Nowadays it is of great importance for dynamic companies to adapt to new technologies and innovations in order to stay ahead of the competition. Along with all the progress being made in the computer science field and the ever increasing computing power, simulation and modeling solutions are getting more frequently adopted by large as well as medium-sized organizations (Amarantou et al. 2021; Amaran et al. 2014; Chronis et al. 2021). Simulation is the replication of a real system and its dynamic processes in a computer model. The aim is to study the behavior of the system and gain insights that can be applied to the actual system.

In a wider sense, simulation means preparing, implementing and evaluating specific experiments using a simulation model (Bangsow, 2015). A simulation model is a digital replica of a real – world structure and it's built with the use of software (Gocken et al. 2017). Modeling is the process through which a system and all of its parameters and characteristics are represented by a digital software structure in order to be analysed in a different, safe environment (Bangsow, 2015; Paraschos et al. 2022; Xanthopoulos and Koulouriotis, 2021).

Mahdoubian (2010) highlighted all the educational aspects of business simulation software and their importance for innovative production solutions. Also a review of simulation optimization was given by Xu et al. (2016) analyzing the importance of simulation methods in the era of Industry 4.0 and smart manufacturing.

In this paper we present a simulation case study of the soft drinks manufacturer VAP P. Kougios S.A. which is a company established in 1967 in Rhodes, Greece. It produces soft drinks such as orangeade, lemonade, beer, bottled table and sparkling water. Currently, VAP P.

Kougios S.A. is the sixth larger company in Greece in this field, it employs about 130 persons, and it has a fleet of 33 vehicles. At the moment, its clientele consists of circa 3500 domestic customers and a few customers in EU and US. The authors documented all the production processes and collected the relevant data that were required to build a simulation model of the production line.

In this paper, the software that was used to implement the simulations was Tecnomatix Plant Simulation. Plant Simulation is an object-oriented simulation software that is being used primarily for discrete event simulation in 2D or 3D. This allows the creation of realistic digital systems like a real-world production line and the use of it for experimenting.

1.1. Research Highlights

This paper focuses on showcasing how the methods of simulation can be applied to a real-world production line using specifically the software of Tecnomatix Plant Simulation. We study and analyze the factors that can determine what is the best option for the production line regarding the efficiency and its optimal output through experimenting with different scenarios.

Firstly, its essential to describe how the 3D model of the VAP bottled water production line was built with the use of Plant Simulation. Many different parameters were taken into consideration before creating the 3D model. The steps that were needed to create a visually appealing and exact replica of the production line will be described.

Following the implementation of the 3D model, we examine different cases of what if scenarios about investments for equipment, failures of production processes and the substitution of old machines with new technologically improved solutions with the use of simulation. More specifically, we examine the feasibility and the resulting producton line improvement of integrating a new monoblock subsystem and a combined palletizer/wrapper machine. In addition, the results of the simulations are being analyzed and we draw conclusions regarding the production line of VAP. Finally, there will be suggestions about how this research could be extended.

2. Methods

In order to showcase the full extend of this research, it is essential to present how the VAP production line works and what it consists of. The understanding of the full characteristics of the production line is very important for implementing the simulation correctly and draw useful conclusions.

2.1. Description of Bottled Water Manufacturing Process

The production line of VAP consists of 10 stations, 3 sources and 1 tank. It produces six-packs of 1,5 L bottles and 24-packs of 0,5 L bottles. The following description of the production line refers to the production of 1,5 L six-packs. In 8 hours of working time the VAP production line produces 115 pallets. Each pallet consists of 84 six-packs.

At the beginning of the production line there is a machine that is feeding the line with the most important raw part, the preforms. Preforms are the plastic bottles in their preliminary form. Prefors are forwarded into the monoblock. Monoblock is a big complex of machines consisting of 6 machines. Firstly, the preforms are cleaned with the use of a vacuum machine before they go to the second station where they are heated at a target temperature of 120 °C degrees. The next station is another cleaning machine which ensures that there are no bacteria inside the preforms. After that, preforms continue into the blowing machine where they are given the size of 1,5 L plastic bottles. Station number 5 inside the monoblock is the portioner. At this point, the plastic bottles are filled with water. The water is coming from an internal tank within the monoblock which is linked with the external water tank of the factory. After getting filled with water, the bottles continue to their last station which is the capping machine. There is an external source type machine which is providing the monoblock with the caps.

Exiting the monoblock, the bottles after having been filled with water and sealed, they continue their way to the labelling machine. There the bottles move in a spinning platform where they spin around themselves and automatically get labelled by the machine within seconds. Exactly after exiting the labelling machine there is a sensor which checks the water level. If the water level is not the desired one, the bottle is automatically discarded as non-conforming. Furthermore, in the same spot there is laser machine that prints the expiration date on the bottles. The next step in the production process is the grouping of the bottles. Bottles line up in front of the grouping machine and the are separated in groups of six. After that they move to the next station where they get wrapped with the nylon pack. Finally, bottles are inserted into the wrapping machine where the nylon pack gets tightly sticked on the six-pack by means of high pressure and temperature. The last station before moving to the palletizer is the one where the handles are attached on the six-packs.

Now moving to the last stage of production, the six-packs are forwarded onto the palletizer. They are being grouped to 21 packs a time and getting loaded on a pallet. After 4 floors of 21 six packs each, the pallet moves to the last station of the line. The last stations is where the pallets get wrapped tightly with transparent nylon to get stored in the storage area. There is a forklift truck that moves the pallets to storage.

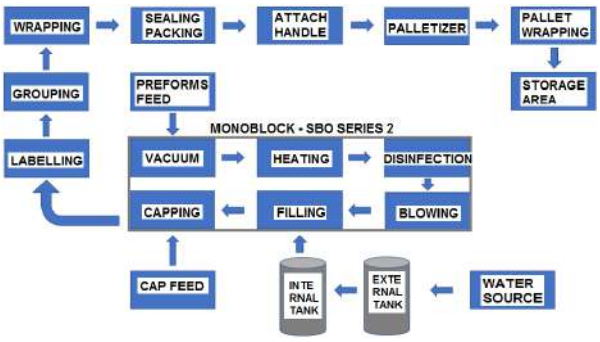

Fig. 1. Flow chart of the VAP production line.

2.2. Implementation of Simulation Model

Tecnomatix Plant Simulation offers various palettes of simulation objects so it can cover the needs of every simulation project. The most basic objects used are the Event Controller through which the user controls the simulation, the Source which provides the raw materials for the production line, the Station, AssemblyStation, DismantleStation, Buffer, Sorter and other objects with

different features and utilities. The parts (in our case the bottles or six-packs) are represented by mobile units (MUs) and the users can create their own MUs and save them in a class library. All the objects can be connected with the object conveyor which represents the conveyor belts of the production line. The software also supports the SimTalk programming language for programming automated applications.

2.2.1. Structure

In order to simplify the simulation we excluded from the model the plant features that do not contribute anything to the simulation logic and to the experimental results. The monoblock is being represented appropriately and the cap feeding component is included in the model primarily for achieving a visualy appealing result. In this way we create a model that is representing an abstraction of the real-world production line but that does not diminish the validity of the model in any way nor its ability to produce verifiable numerical results.

First and foremost, a source is inserted at the beginning of the model that represents the preforms feeding machine and it is being programmed to provide enough preforms for the production of 115 pallets of six-packs (or any required number of pallets). Afterwards, we placed stations representing the heating machine, the blowing machine, the filling machine and the capping machine. Each one of them is characterized by the respective processing time. At this stage we also place the fluid source and the tank that connects with the monoblock to provide the water.

Exiting the monoblock we included additional stations representing the labelling machine, the grouping and wrapping machine, the sealing packing machine and handler placement machine. As soon as the parts move to the next stage, they move to the palletizer. An assembly station was inserted there in order to assemble the pallets with the six-packs that are going to be loaded on the pallet. At the end of the production line there is another station representing the pallet wrapping machine. There is also the object store that is used for storage area within the model.

The object method was inserted in our model to program that at least two bottles per day will be thrown out of the production line because they do not meet the criteria of the desired water level (any other fraction of defects can be programmed similarly). The object chart was also inserted twice for analyzing statistics regarding the occupancy of the conveyors and the percentages of important processing/waiting and blocking times. There were also workers inserted into the model for executing duties within the line such as checking on the control panels of specific stations. Regarding the workers, we also have to insert workplaces and the workerpool object which is essential for the programming of the workers. Factory walls and fences were put into the model to create a sealed space for the monoblock, the palletizer/pallet wrapping stage and the factory in general. Last but not least, there were also some failures programmed to specific stations that facilitate the execution of stochastic experiments. Fig. 2 shows an indicative view of the simulation model at this implementation stage.

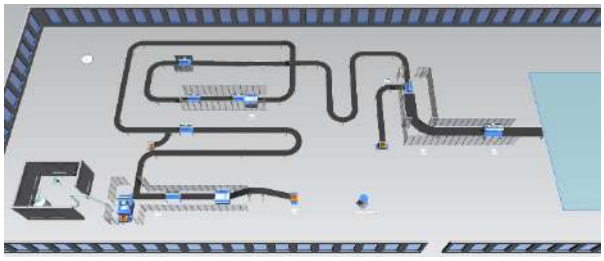

Fig. 2. Simulation model before inserting new 3D graphics.

2.2.2. 3D graphics

The model that was outlined in section 2.2.1 is more than enough to cover the needs of a simulation project. However, in order to make it as identical as possible to the real-world production line we can insert new 3D graphics for all the stations and MUs (moving units).

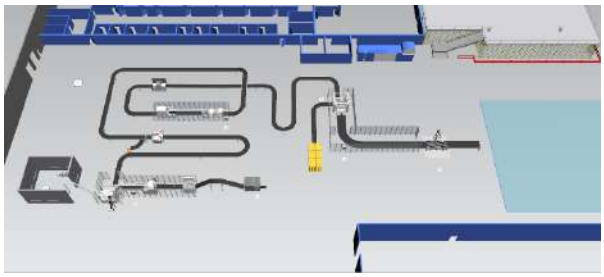

Fig. 3. Simulation model after inserting new 3D graphics.

Fig. 3 shows an indicative view of the simulation model after importing new 3D graphics. Except for just importing selected 3D graphics into the model, the user can also process the existing ones by utilizing the associated features of the graphical user interface of Plant Simulation. Using this function we took the graphic representation of a simple water bottle and created all the graphics for each stage of the production process. For example, in Fig. 4 we see pictures of the graphic that shows the MU exiting the labelling machine and the graphic that was made for the MUs that exit the handle attachment machine (the final product):

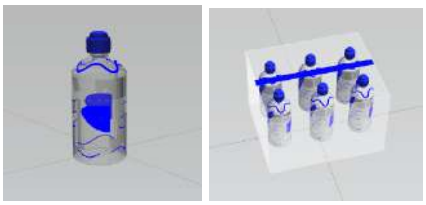

Fig. 4. 3D graphics designed for different stages of the production.

In order to create the second graphic as shown above we combined the 3D models of bottle and box objects and we processed the transparency, colours and size, accordingly. The graphic representation of the loaded pallets was created similarly by combining 3D models of completed six-pack, pallet, box objects and editing them accordingly (Fig. 5).

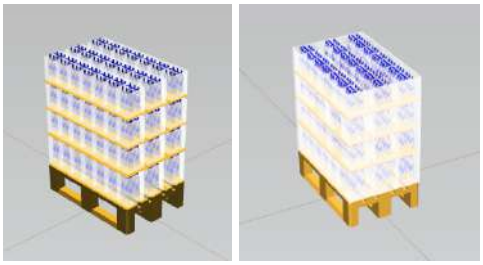

Fig. 5. 3D graphics designed for the final stages of the production.

3. Results

Table 1 summarizes the input and output data of the simulation models. The units of d are number of pallets/day and d is the forecasted average demand. The plant operates for 26 days per month and each working day has an eight-hour shift. Each pallet consists of 84 six-packs; it follows that a pallet contains 504 bottles in total.

Table 1. Nomenclature.

Parameter	symbol
demand per day	d
working hours per day	s_d
working days per month	s_m
number of six-packs per pallet	n_s
number of bottles per pallet	n_b
number of workstations	m
processing time of workstation i	p_i
availability of workstation i	a_i
throughput per day	T_d
throughput per month	T_m
working hours per day for workstation i	W_i
idling hours per day for workstation i	I_i
blocked hours per day for workstation i	B_i
repairing hours per day for workstation i	R_i
number of days to stockout	K_s

The processing time of workstation i refers to its standard processing time, i.e. the time needed to process parts considering that no failures or other unforeseen events take place. Nonetheless, machine failures occur frequently at random time intervals. The availability of workstation i is the fraction of time that we expect it to be operational, that is capable of producing. E.g. if the availability of some workstation is 70% then in 3 out of 10 ten hours (on average) we expect it to be down and under repair.

The daily and monthly throughput is the primary output data of the simulation; its units of measurement are pallets/day and pallets/month, respectively. W_i is the total number of hours that machine i is producing per day. A workstation is idling if it is operational but starving, i.e. there are no parts available from the upstream workstation to work on.

Workstation i is blocked if it cannot forward the parts that it completed processing because the downstream machine is unavailable. R_i is the total number of hours per day that machine i is under repair. Finally, K_s is the number of days until the stock of finished goods is depleted given the current demand and throughput of the plant.

For the purposes of this research we examined five simulation cases. Case 1 is the base case, i.e. the current state of the plant and it is described by the parameter set d = 115 pallets/day, s_d = 8 working hours/day, s_m = 26 working days per month, n_s = 84 sixpacks/pallet, n_b = 504 bottles/pallet, m = 10 machines, p_i = 210 sec for all i, and a_i = 100% for all i (refer to Table 1 for an explanation of the symbols).

Table 2. Parameters of simulation cases 2, 3, 4, 5.

parameters	case 2	case 3	case 4	case 5
d (pallets/day)	131	115	115	127
s_d (hours/day)	8	8	8	8
s_m (days/month)	26	26	26	26
n_s (sixpacks/pallet)	84	84	84	84
n_b (bottles/pallet)	504	504	504	504
m (machines)	10	10	10	9
p_i (sec/pallet)	147 for i = 1,…,6 and 189 for i = 7,…,10	210 for all i	210 for all i	210 for all i
a_i (%)	100% for all i	40% for i = 9 and 100% for $i \neq 9$	40% for i = 7 and 100% for $i \neq 9$	100% for all i

It is noted that the monoblock subsystem is comprised of the first 6 workstations of the production line. The parameters for the additional four simulation cases (2 to 5) are given in Table 2.

Table 3. Key findings of simulation cases 2, 3, 4, 5.

simulation case	major findings
2	installing a new monoblock subsystem increases system throughput by 13%. The utilization of the new monoblock is approximately 72%
3	decreased availability (40%) of the ninth workstation due to degradation cuts throughput to 47 pallets/day. Given the current demand pattern, this will result in a stockout after 49 days
4	decreased availability (40%) of the seventh workstation due to degradation reduces throughput to 49 pallets/day. Given the current demand pattern, this will bring about a stockout after 50 days
5	substituting the two last workstations with a new combined palletizer/wrapping machine increases system throughput by 10.5%. The upstream stages in the production line are not affected

Table 3 summarizes the key findings of simulation cases 2 to 5. Each simulation case is analyzed further in the following sections 3.1-3.4.

3.1. Analysis of Simulation Case 2

The current state of the plant is a balanced production line, i.e. all production stages operate at the same speeds. Simulation case 2 pertains to investing on a new monoblock subsystem with 30% lower processing time than that of the existing one. The remaining machines can be tuned and their processing times can be decreased up to 10% percent but still they cannot keep up with the new monoblock.

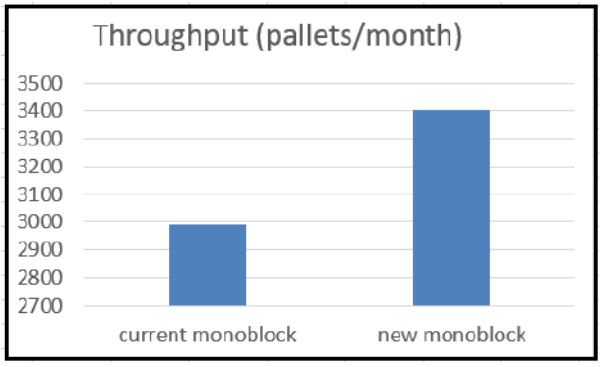

Fig. 6. Throughput per month for the current and the new monoblock subsystem.

This will result in an unbalance production line and it raises the question whether the integration of the new monoblock is worthwhile or not. Using factory simulation the decision maker can obtain numerical results that quantify the impact if this investment on the production process as a whole.

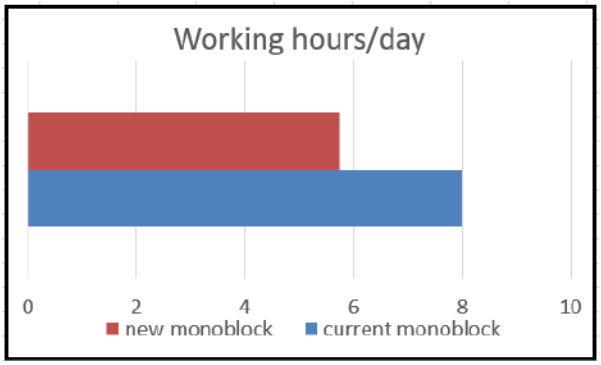

Fig. 7. Working hours per day for the current and the new monoblock subsystem.

The key findings of the simulation experimens are summarized in Fig. 6 and 7. It is observed that the installation of the new monoblock subsystem will increase the system throughput by 13%, that is from 2990 pallets/month to 3406 pallets/month. Due to the fact that the new monoblock subsystem is faster than the remaining machines of the line its daily utilization is circa 72% (see Fig. 7) whereas the utilization of the other machines is 100%. Reducing the working hours ped day of the monoblock could lead to reduced energy costs.

3.2. Analysis of Simulation Case 3

In mass production environments like the one examined in this paper, machines are pushed to their limits and equipment failures are frequent. In case 3 we examine a scenario where the palletizer machine (workstation 9) has degraded and this causes unexpected malfunctions that cut its availability to 40% (see Table 2). We perfrom a what-if analysis to see how this impacts the system as a whole.

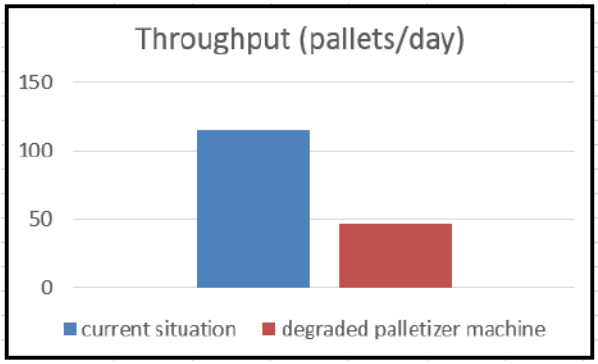

Fig. 8. Throughput per day for the current situation and the case of a degraded palletizer machine.

We observe (Fig. 8) that the degradation of the palletizer reduces the daily throughput from 115 to 47 pallets/day. Due to the fact that the adjacent workstations are synchronized, the reduced availability of the palletizer machine causes all other workstations to work only for approximately 35% of the shift duration. Given a daily demand of 115 pallets per day the finished goods stock reduces constantly with K_s = 49 days, i.e. the palletizer needs to be restored before 49 days elapse or else a stockout will occur.

3.3. Analysis of Simulation Case 4

Case 4 is similar with the previous one; here we examine a scenario where workstation 7 has degraded amd its availability has decreased to the level of 40%. Workstation 7 is the one that bonds firmly the sixpacks and the packaging film.

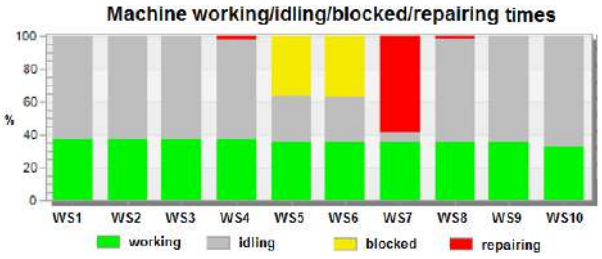

Fig. 9. Working, idling, blocked and repairing times for all workstations (WSi stands for workstation i).

The degradation of the seventh machine causes the daily throughput to drop to 49 pallets per day. Considering a demand of 115 pallets/day, this causes the finished goods stock to reduce steadily K_s = 50 days, i.e. the seventh machine must be restored before 50 days pass to prevent a stockout. In the bottled water industry the summer is the season where peak demand occurs and a stockout during the high season can have significantly adversarial effects to the business.

Fig. 9 shows the utilization of the machines for case 4. The diminished availability of machine 7 cuts the working time of all other machines to approximately 38% of the eight-hour shift. Substantial blocking times are also witnessed in machines 5 and 6 due to the fact that these machines are directly upstream in relation to the bottleneck of the production line.

3.4. Analysis of Simulation Case 5

The current trend in the bottled water industry is to have palletizers that can stack the sixpacks and also wrap the pallet with nylon. In the present situation, the examined plant has two distinct machines for this purpose. Machine 9 is the palletizer and machine 10 does the wrapping of the pallets. We will examine the case where a new, combination machine is procured to replace the existing machines 9 and 10. In that case, the total number of machines in the production line is reduced to nine.

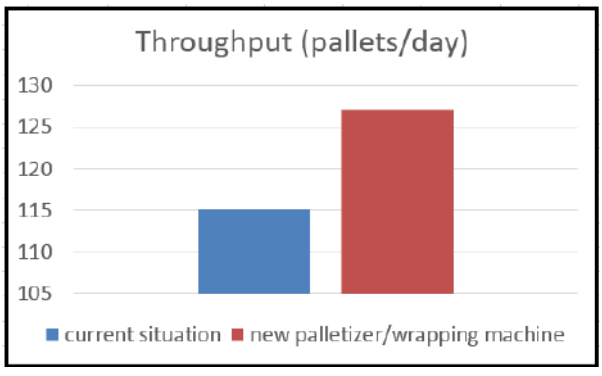

Fig. 10. Throughput per day for the current situation and the case of a new palletizer/wrapping machine.

The introduction of the new palletizer/wrapping machine results in a 10.5% production increase, i.e. the throughput goes from 115 to 127 pallets/day. There is no waiting time or blocking in the new palletizer since its processing time is the same as the previous one so the upstream production stages are not affected.

4. Conclusions and discussion

Factory simulation is a powerful decision support tool as it provides quantitative data that can guide executive decisions. In this paper we presented a real-worl case study of a plant that produces bottled water and we developed the comprehensive 3D model of the production process.

A straightforward way to modernize a factory and increase its capacity is to invest on new equipment. However, industrial machines incur significant costs and the task of integrating them into the existing infracstructure can be cumbersome. It follows that the potential benefits of such long-term investments need to be quantified and based on factual data. In this research we conducted a series of simulation experiments to provide support to the decision making function of the firm regarding the investment on new monoblock and palletizer/wrapping machinery.

Another common issue in high volume manufacturing is machine degradation which causes unexpected failures that disrupt the normal flow of operations. Stochastic simulation is a useful tool for predicting the performance of the system under uncertainty. We carried out a series of experiments where we analyze the system output in the presence of machine failures.

More specifically, we examined five simulation cases where case number one refers to the current situation in the plant. In the second simulation case we examine what will happen if the a new monoblock subsystem is incorporated in the production line. The key finding here is that there will be a 13% increase in system throughput. In the last simulation case we study the effect of substituting the last two machines of the production line with a new combined palletizer/wrapper machine. The prominent result of this investment is a 10.5% increase in system throughput, as indicated by the simulation experiments. Finally, in scenarios three and four we examine the effects of reduced availability for the ninth and seventh workstation that is brought about by degradation. More specifically, if the availability of these two machines is reduced to 40% then then the simulation experiments indicate a reduced throughput equal to 47 and 49 pallets per day. Given the current demand pattern for finished goods this results in a stockout after 49 and 50 days, respectively.

An obvious limitation of this research is that, since it pertains to a real-world case, the experimenta results and the relevant conclusions apply only to the manufacturing system in question. Nonetheless, the adopted methodology itself, i.e. simulation modeling, is by no means restricted to the study of manufacturers similar to the one studied in the context of this research. On the contrary, practically any industry can benefit from application of simulation and this research can provide motivation and examples of questions that that can be answered using experimentation with digital technologies.

This research can be extended in various ways. An obvious extension is to examine additional simulation cases and to incorporate the financial dimension in the analysis. The decisions of the management can be further supported by expressing the outcomes of possible

investments, that have been assessed via simulation, in economic terms.

An even more interesting line of research would be to extent the simulation model beyond the factory walls in order to incorporate the supply chain netweork in its entirety. Finally, it would be of great interest to interface the simulation model of the plant with a MES and/or SCADA system to update its parameters in real time using data from the shop floor. In this way we would move one step closer to obtaining an actual digital twin of the factory that could be used for decision-making in the tactical or strategic level.

Author Contributions

Tsabikos Volas contributes to conceptualization, methodology, software, validation, analysis, investigation, data collection, draft preparation, manuscript editing, visualization. Alexandros Xanthopoulos contributes to conceptualization, methodology, analysis, investigation, draft preparation, manuscript editing, visualization, supervision. Anastasios Kypriotis contributes to conceptualization, methodology, validation, analysis, investigation, data collection. All authors have read and agreed with the manuscript before its submission and publication.

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Tsabikos Volas is Production & Management Engineer from the Democritus University of Thrace. His is an enthusiast of innovative technologies and he pursues to work on pioneering projects that bring change for the better. His interests are mainly focused on warehouse management, logistics, production planning and modelling and simulation research.

Alexandros Xanthopoulos is Assistant Professor at the Democritus University of Thrace, Greece. He is with the Laboratory of Logistics, Department of Production & Management Engineering. His interests include Industrial Engineering and Supply Chain Management as well as relevant applications of Analytics and Machine Learning.

Anastasios Kypriotis, graduated from the Aristotle University of Thessaloniki, Department of Chemical Engineering. He continued his postgraduate studies at the University of the Aegean, Department of Environmental Education. Currently, he is working as a Production Manager Assistant in VAP S.A. company.

Paper no. 45

Integrating Wearable Sensing Device Applications To Improve Construction Workers' Health

Lesiba George Mollo[1]
[1]Senior Lecturer, Department of Built Environment, Central University of Technology, Free State, 20 President Brand Street, Bloemfontein, South Africa, E-mail: lmollo@cut.ac.za

Abstract: Wearable sensing devices (WSDs) are emerging technology that has the potential to monitor construction workers' health. Thus, the purpose of this study is to review the use of WSD in improving construction workers' health. This goal is achieved through the adoption of a systematic review of the literature. The results indicate that WSD health monitoring is necessary for improving the physiological conditions of construction workers. It is also discovered that physiological responses such as electrodermal activity (EDA) and photoplethysmograph (PPG) signals could be used to monitor the health of construction workers. If appropriate guidelines are followed, WSDs hold a lot of promise for real-time health monitoring, which would allow for the early detection of illnesses, potentially improving construction workers' health. Future research should concentrate on integrating WSD to monitor the physiological conditions of construction workers using practical case studies.

Keywords: Construction Industry, Occupational Health, Physiological Conditions, Wearable Sensing Devices.

1. Introduction

Construction workers are exposed to a significant amount of risk due to the inherent nature of the activities performed in the industry (Nnaji & Awolusi, 2021). As a result, construction workers often become ill due to their activities, and occupational illness is estimated to cause more harm than workplace accidents (Turner & Lingard, 2020). According to a Safe Work Australia (2015) report, 250 workers die each year in Australia as a result of workplace injuries, with over 2000 workers dying as a result of occupational illnesses. In the United Kingdom (UK), approximately 81000 construction workers suffered from poor occupational health in 2020, with 46170 workers suffering from musculoskeletal disorders (MSDs) (Health and Safety Executive (HSE), 2020). Therefore, it can be concluded that poor occupational health in construction has never been completely solved; rather, it has always been associated with the anticipation, recognition, evaluation, and control of occupational health hazards known to affect workers.

Langdon & Sawang (2018) observed that construction workers face psychosocial risks to their mental health, which can lead to stress, depression, and even suicide. Physical exhaustion and the resulting mental stress on construction sites can hurt the motivation, job satisfaction, productivity, quality, time, and safety of workers. Therefore, it is critical to monitor workers' physical and mental health on construction sites (Jebelli et al., 2018). This is because the mental health of construction workers poses a significant health and safety risk to the industry. Sun et al., (2022), pointed out that individual studies have found that occupational psychosocial hazards are detrimental to mental health. Mental health issues arise as a result of the high level of physical activity required for construction tasks, and it is the primary source of artefacts and noise in physiological sensor readings (Ahn et al., 2019).

As a result, to mitigate the negative impact of poor occupational health in the construction industry, which contributes to a stressful work environment. The use of wearable sensing devices (WSDs) would assist in the monitoring of construction workers' health. WSD has the unique ability to record and transform user data in real-time (Beh et al., 2021). They can be used to continuously monitor a wide range of important factors, providing workers with high-risk health concerns with early warning signals (Awolusi et al., 2020). WSD has the distinct advantage of tracking and transforming information from users in real time, and they can be used for continuous monitoring of a wide range of construction hazards and vital signs, providing early warning signals to workers with high-risk health issues (Nnaji & Awolusi, 2021). WSD can improve workers' health by collecting and analyzing data more efficiently and by providing real-time information about potential health hazards (Nnaji, et al., 2021).

The use of WSD in physically demanding and hazardous environments has the potential to usher in new

approaches to managing health and safety on construction sites (Choi et al., 2019). However, Awolusi et al., (2020) reported that due to a lack of critical information required for the integration of WSDs into work processes, few construction companies have adopted and implemented WSDs on their projects. It is unclear whether the lack of WSD integration in the construction industry stems from workers' fear of using devices that could share their location or physiological data with others (Awolusi et al., 2020). Therefore, the dissemination of information on factors influencing the implementation of new technology is critical in predicting its success (Awolusi & Nnaji, 2021). As a result, the purpose of this study is to review the use of WSDs in improving construction workers' health. This is because WSDs contain embedded biosensors, which have the potential to provide sufficient opportunities for monitoring workers' physical and mental health (Led et al., 2015). Wider adoption of such technologies could result in a significant reduction in occupational illness among construction workers.

2. Research Methodology

To collect data and achieve the previously stated objective of reviewing the use of WSDs in improving construction workers' health. As recommended by Siddaway et al., (2019) the author performed a systematic review of the literature. Accordingly, a systematic review is defined as a study that investigates a specified issue and makes use of systematic and explicit approaches to locate, pick, and evaluate pertinent research as well as gather and analyze data from the studies that are included in the review (Siddaway et al., 2019). For instance, the author of this study investigated how the use of WSDs could improve construction workers' health. The information in the previous section indicates that construction workers' poor health leads to occupational illnesses.

The author conducted a systematic review of relevant studies on construction health and safety that had been published in several publications to achieve this goal. Table 1 provides a summary of the publications cited in this study.

Table 1. Publications that are included

Publications	Number of papers
Automation in Construction	8
Journal of Construction Engineering and Management	3
Construction Research Congress	3
Biomedical Signal Processing and Control	3
Annual ARCOM Conference	2
Safety Science	2
Construction Management and Economics	2
Journal of Building Engineering	1
Behaviour & Information Technology	1
International Journal Biosens Bioelectron	1
Building and Environment	1
IEEE Transactions on Biomedical Engineering	1
Health and Safety Executive	1
Telematics and Informatics	1
Mobile Health	1
Sensors	1
Technology in Society	1
Safe Work Australia	1
Behavioural Brain Research	1
Annual Review of Psychology	1

A systematic review is used to pinpoint the issue of occupational illnesses among construction workers that were discussed in the previous section. The review procedure was subsequently established and validated by the author, who focused on the study on construction health and safety. Using keywords associated with the construction industry, health monitoring, physiological conditions, occupational health, and wearable sensing devices, the author conducted searches across several databases. The selected literature search is completed by reviewing the titles and abstracts of publications published between 2012 and 2022.

As a result, the author searched for publications published within the last ten years because the scope of this study is limited to the use of WSD, which is an emerging technology currently adopted in the construction industry. The data flow diagram for this systematic literature review study is shown in Figure 1. This approach is comparable to that of Okpala et al., (2020). In conducting this study, the author's first step was to identify the study problems highlighted in the previous section. The second step was to develop and validate the review process for studies on construction health and safety topics. The author searched for related publications in the third phase using databases including Scopus, Google Scholar, and Web of Science. Step four involved the author selecting which publications to accept after reviewing the titles and abstracts of each manuscript. By studying whether the publication adhered to the study objectives in the fifth step, the author evaluated the quality of the publications by screening the full manuscript. The author analysed the data collected from the selected manuscripts in the sixth step to respond to the research questions. The summary of the results obtained from the selected publications is presented in step 7.

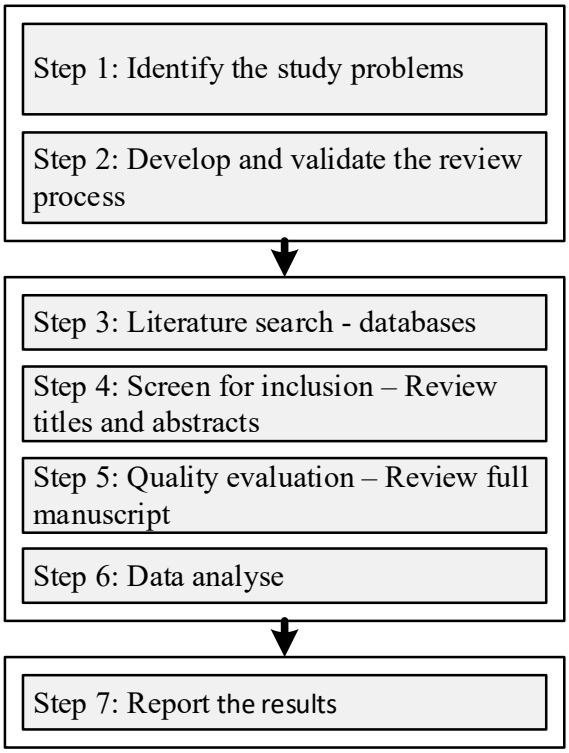

Fig 1: The data flow diagram of the study

3. Results

3.1. Wearable sensing devices in the construction industry

WSDs are described as wearable device that collects data and incorporates electronics and computer technology (Led et al., 2015). Additionally, WSDs refer to electronic devices or computers incorporated into comfortable apparel and accessories (Jebelli et al .2019). According to Choi et al. (2017), wearable technology has been used most frequently in the healthcare industry because it allows for continuous monitoring of a user's physiological status (such as heart rate, blood pressure, and skin temperature) and real-time feedback. The authors further observed that the area of wearable technology applications has been expanded by modern wearable devices that can track a user's location and show their motions by integrating a Global Positioning System (GPS), an accelerometer, or an Inertial Measurement Unit (IMU) into sensor systems.

There are various types of WSDs available today, and they include smartwatches, fitness trackers, smart clothing, body sensors, and other wearable devices for healthcare, public safety, and other industrial purposes (Jeong et al., 2017). Some of these WSDs can be found in the construction industry such as smartwatches, wristbands, smart hard hats, safety vests, smart boots, clips, tags, and so on (Nnaji et al., 2021). In construction, wearable sensors and systems can be used for physiological monitoring, environmental sensing, proximity detection, and location tracking of a wide range of hazards and vital signals providing workers with early warning signs of safety issues (Awolusi et al., 2018).

Several researchers have thoroughly reviewed and investigated the applications of WSDs and their effects in the construction industry. For example, the study by Lee et al., (2017) investigated wearable sensors for monitoring on-duty and off-duty workers' physiological status and activities in construction. The authors discovered that using wearable sensors and collecting data at the individual level will eventually explain how effectively and positively a worker's physiological reactions can change job demands as well as safety and productivity performance. In addition, Nnaji & Awolusi (2021) investigated the critical success factors influencing the implementation of wearable sensing devices in the AEC industry. The results show that critical success factors on construction sites vary depending on the scenario under investigation. Also, workers' education and training, personalized WSDs, and detailed and continuous WSD assessments were identified as key strategies to improve WSD implementation on construction sites.

Jebelli et al., (2019) further investigated the application of wearable biosensors to construction sites by assessing workers' physical demand. The results show that the proposed physiological signal–based physical-demand recognition framework makes two significant contributions, which include considering workers' characteristics to identify their physical demands and providing a method for continuous and non-invasive measurement of workers' physical demands that can be used in the field. In addition, Ahn et al. (2019) reviewed the applications of wearable sensing technology in construction safety and health. In this study, the authors identified the barriers to further development and deployment of wearable applications, specifically signal artefacts and noise in wearable-sensor field measurements, variable standards for personal safety and health risks in construction, user resistance to technology adoption, and uncertainty about the return on investment.

A developing and essential application of WSDs in the construction industry is the treatment of mental health diseases such as depression, anxiety disorders like panic disorder, and post-trauma mental health and wellness. Jebelli et al. (2018) propose that new research opportunities for the objective and continual field assessment of workers' physical and mental health have been established as a result of recent breakthroughs in wearable technology and physiology. For instance, when our bodies are put under intense physical strain or are exposed to stressful situations, the sympathetic system of the autonomic nervous system is activated, which causes an imbalance between the sympathetic and parasympathetic systems. The application of WSDs on the other hand can monitor such physiological signals in a less intrusive way while people go about their daily lives (Lee et al., 2021).

3.2. Integration of WSD for monitoring construction workers' physiological conditions

Construction workers are subjected to a stressful work environment due to poor health conditions (Sherratt, 2018), and excessive stress causes psychological, physiological, and societal pressures (Sunindijo & Kamardeen, 2017). Furthermore, high-stress levels can increase the risk of MSDs and absenteeism in construction workers (Li et al., 2016). According to Antwi-Afari et al., (2018) MSDs are the main reason for non-fatal occupational hazards in the construction industry.

Occupational stress on construction sites affects worker performance and psychological well-being in addition to health and safety procedures (Huang et al., 2018). For instance, high physiological demands at work might lower

employees' well-being, focus, motivation, and capacity for physical tasks, affecting safety and productivity (Gatti et al., 2014). Thus, monitoring workers' physiological status is essential for the early detection and screening of health issues in the construction industry. This type of monitoring would enable the identification of construction workers' excessive physical demands caused by worksite tasks, as well as the timely provision of information for proactive management of high physical workloads (e.g., work duration and intensity) (Hwang et al., 2016).

The selection of physical indicators and the data collecting process is both necessary for the collection of physical data. As an illustration, the used physical indications should be able to convey psychological status and be simple for wearable technology to detect (Guo et al., 2017). The authors also pointed out that although physical indicators have been used to identify emotions in earlier psychology-related studies, most of them require sophisticated equipment, like an electroencephalogram (EEG) machine, to measure things like heart rate, skin temperature, calories burned, and steps walked by users.

In addition, the body's physiological responses can be investigated by looking at changes in the pattern of physiological signals (Jebelli et al., 2018). For example, WSD with embedded biosensors (such as a heart rate sensor and a skin temperature sensor) provides adequate opportunities to monitor workers' physical and mental health (Led et al., 2015). This is because the heart rate (HR) is a low-cost physiological test that determines an employee's physical requirements based on muscle activity. As a result of the use of HR, several wearable health devices now support real-time HR monitoring (Hwang et al., 2016). For example, lightweight and comfortable WSDs health gadgets, such as a smartwatch or wristbands, have a lot of potential for measuring physical demand at work without interfering with workers' daily tasks (Hwang & Lee, 2017). Physiological responses such as electrodermal activity (EDA) and photoplethysmograph (PPG), could be used to monitor workers' health on construction sites (Jebelli et al., 2018).

Table 2 provides a summary of the concepts and variables assessed using WSDs in the construction industry. Some of the established concepts assessed using WSDs include task demands, physical condition, personal well-being, physiological reaction, and individual performance (Lee et al., 2017).

Table 2: Summary of the concepts and variables assessed using WSDs

Concept	Variables
Task demands	Heart rate
	Energy expenditure
	Metabolic equivalents of task
Physical condition	Wet-bulb globe temperature
Personal well-being	Sleep efficiency
	On-duty physical activity levels
	Off-duty physical activity levels
Physiological reaction	Time domain heart rate variability(HRV)
	Frequency domain HRV
Individual performance	Percentage of work time

3.2.1. Electrodermal activity (EDA)

Electrodermal activity (EDA) refers to a change in skin conductivity caused by sympathetic nervous system activity that is commonly used to predict psychological processes such as emotional arousal, stress, or cognitive effort (Shukla et al., 2018). A higher EDA could reflect sympathetic arousal induced by external stressors. In a variety of situations, such as occupational settings, human-computer interaction, traffic and automation, and marketing and product evaluation, EDA has been used to understand an individual's mental status related to sympathetic arousal (e.g., stress, attention, risk perception, etc). (Choi et al., 2019). The measured EDA signals are obtained primarily through the use of two measuring sensor components: electrodermal level (EDL) and electrodermal response (EDR) (Liu & Du, 2018). EDL refers to slow signal changes and aphasic components, whereas EDR refers to a faster-changing signal element (Ahn, et al., 2019). A low, constant voltage is applied to the skin through two measuring sensor components to continuously measure skin conductance or skin potential to measure EDA non-invasively (Lee et al., 2020). The electrodermal signals are the result of activity in the eccrine sweat glands, which are primarily innervated by sudomotor neurons in the sympathetic branch of the autonomic nervous system (Greco et al., 2016).

However, a breakthrough has been made in incorporating the use of EDA to improve occupational health in the construction industry. For example, Choi et al. (2019) investigated the feasibility of collecting physiological sensory data (e.g., electrodermal activity (EDA)) from commercially available wristband typed sensors to understand construction workers' perceived risk during ongoing work. The results show that EDR or short-term changes in EDA, differs significantly between low and high-risk activities and that high-risk activities have a significant impact on workers' EDR while they work. In addition, Jebelli et al. (2018) investigated the discriminatory power of EDA in detecting workers' physical and mental states on the job. The authors highlighted that with the EDR and HR results, workers feel the least stressed when they are walking around, talking with friends, and resting during breaks. Furthermore, the results show that EDR has the potential to capture moments when workers are performing stressful tasks such as cutting steel, handling materials, measuring wall dimensions, and searching for materials. As a result, there is evidence that incorporating EDA could help to improve construction workers' health.

3.2.2. Photoplethysmograph (PPG),

Photoplethysmography (PPG) is an electro-optical technique for measuring clinical parameters such as respiration rate and heart rate (Islam et al., 2017). A PPG sensor, which typically consists of a light source and a

photodetector, can detect changes in light intensity caused by tissue reflection or transmission (Wan et al., 2022). It is very convenient because only one photoelectric PPG sensor is required to irradiate the skin during signal acquisition. This method is also widely used for WSD's real-time heart rate monitoring devices that are both reliable and comfortable, such as smartwatches or wristbands (Castaneda et al., 2018). For example, smartwatches include a PPG sensor for HR monitoring based on spectrographic technology using light-emitting diodes (LEDs) and a photodetector for optical detection of blood-flow rate caused by the heart's activity (Hwang & Lee 2017). The PPG sensor is a non-invasive technique for measuring relative blood volume changes in microscale blood arteries through the skin (Moraes et al., 2018).

However, a breakthrough has been made in incorporating the use of PPG signals to improve occupational health in the construction industry. For example, the study by Hwang et al. (2016) investigated the accuracy of a PPG sensor embedded in a wristband-type tracker to see if it could be used in construction. The results show that PPG-based HR monitoring using a wearable activity tracker has the potential to be used on construction sites by demonstrating HR monitoring accuracy with tolerable levels of error (4.79 % of mean average-percentage-error (MAPE) and 0.85 correlation coefficient), even though the accuracy needs to be improved, particularly during heavy work. In addition, Lee et al., (2021) used physiological signals obtained from wearable biosensors to determine the risk levels that construction workers face. The findings imply that physiological signals collected by wearable biosensors could be used to detect construction workers' perceived risk levels while on the job. As a result, there is evidence that incorporating PPG signals could help to improve construction workers' health.

4. Discussions

WSDs were used to monitor the construction workers' health in the systematic review that was carried out in this study. It is emphasized that the adoption of health monitoring technology on construction sites would provide a proactive means of managing high physical workloads (such as work duration and intensity), which would help identify the excessive physical demands placed on construction workers (Hwang et al., 2016). High physical workloads in the construction industry need to be controlled, Turner & Lingard (2020) noted that construction workers frequently suffer occupational illnesses as a result of their workplace activities, which are thought to be more harmful than workplace accidents.

Additionally, Sherratt (2018) found that because of their poor health, construction workers face a demanding work environment, and excessive stress results in psychological, physiological, and societal pressures (Sunindijo & Kamardeen, 2017). Monitoring workers' physiological status is crucial for the construction industry to identify and screen for health issues at an early stage. Led et al. (2015) tested WSDs with embedded biosensors and found that there are sufficient options for monitoring workers' physical and mental well-being (such as a skin temperature sensor and a heart rate sensor). In addition, Awolusi et al. (2018) noted that the integration of WSDs in the construction industry can be utilized to physiologically monitor a variety of hazards and important signals, providing workers with early warning indicators of safety issues.

The possibility of using physiological responses, such as EDA and PPG signals, to monitor the health of construction workers is also addressed. Jebelli et al., (2018), for instance, looked at the discriminatory capabilities of EDA in identifying the physical and mental states of construction workers while they are at work. According to the EDR and HR data, the authors emphasized that when workers are moving around, chatting with friends, and taking breaks, they feel the least stressed. Furthermore, Lee et al., (2021) found that physiological signals captured by wearable biosensors might be utilized to gauge the perceived risk levels of construction workers while they are at work.

Therefore, it is reasonable to assume that monitoring construction workers' physiological conditions with WSDs will allow researchers to discover new factors driving their poor health conditions. This information will enable the development of a new technique that would account for the various physical demands placed on construction workers.

5. Conclusion

Improving construction workers' health is crucial because it has been reported that workers frequently become ill, and occupational illness is estimated to cause more harm than workplace accidents. As a result, the study's goal was to analyse the use of WSD in improving construction workers' health. The results show that WSD health monitoring is necessary for improving workers' physiological conditions in the construction industry. It is also highlighted that physiological responses, such as EDA and PPG signals, could be used to monitor construction workers' health. For example, it has been discovered that EDR, or short-term changes in EDA, differs significantly between low and high-risk activities and that high-risk activities have a significant impact on workers' EDR while working. Furthermore, PPG-based HR monitoring via a wearable activity tracker has been discovered to have the potential to be used on construction sites by demonstrating worker HR monitoring accuracy. As a result, it is possible to conclude that physiological responses such as EDA and PPG signals could be used in the construction industry to improve worker health through the adoption of WSDs. However, because this study is based on a systematic review of the literature, it is suggested that future research should focus on integrating WSD to monitor the physiological conditions of construction workers through practical case studies.

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Dr Lesiba George Mollo, PhD, is a Senior Lecturer in the Department of Built Environment, Faculty of Engineering, Built Environment, and Information Technology at the Central University of Technology, Free State, (CUT), South Africa. His research interests include construction health and safety, wearable technology and building energy management.

Paper no. 47

An Analysis of Factors Influencing Building Energy Consumption: A Case Study

Lesiba George Mollo[1], Thabo Khafiso[2] and Nomathamsanqa Patience Kheswa[3]

[1]Senior Lecturer, Department of Built Environment, Central University of Technology, Free State, 20 President Brand Street, Bloemfontein, South Africa, E-mail: lmollo@cut.ac.za

[2]Student, Department of Built Environment, Central University of Technology, Free State, 20 President Brand Street, Bloemfontein, South Africa

[3]Student, Department of Built Environment, Central University of Technology, Free State, 20 President Brand Street, Bloemfontein, South Africa

Abstract: The purpose of this study was to identify factors that have a significant impact on building energy consumption. This study used a case study research design to address this issue, and a questionnaire survey was used to collect data within the case survey. The quantitative data were analysed using a statistical package for social science (SPSS). The results revealed that the seven discovered building energy consumption factors have an MS greater than 3.00, indicating that they are the key contributors to building energy consumption. Factors that influence building energy consumption include building service systems, building operation and maintenance, building envelope, occupant behaviour, interior environmental conditions, building features, and social challenges. According to data analysis on building energy consumption in South Africa, the Technikon Residence in Bloemfontein used the most energy at the end of the winter season. Therefore, future studies should use an experimental research design to test the factors on the building when conducting comparative analyses to find new building energy consumption factors.

Keywords: Building, Energy Consumption, South Africa.

1. Introduction

According to Guo et al., (2019), buildings account for around 36% of total global energy consumption and 40% of greenhouse gas emissions, both of which are predicted to peak in the next 20 years. In South Africa, buildings contribute 5% of energy-related carbon dioxide emissions, whereas indirect emissions account for 22% (Climate Transparency, 2021). The gap between planned and actual operating energy consumption is growing, posing a severe threat to fulfilling carbon reduction targets (Alam & Devjani, 2021). As a result, the energy crisis and global warming have become major risks to humanity's existence (Li et al., 2021).

Energy consumption is influenced by several complicated systems (Li et al., 2021). For example, energy consumption rises as a result of economic expansion, population growth, and technological advancement (Jelle, 2016). On the other side, building energy consumption is influenced by four major factors, building characteristics, the behaviour of the occupants, the system efficiency and operation, and climatic conditions (Alam & Devjani, 2021). The total energy consumed by the buildings includes all energy required for heating, cooling, lighting, and water heating (Bohlmann & Roula, 2018). The amount of energy used in a building is influenced by several factors, including energy pricing, weather, energy access, energy efficiency, and the availability of energy sources (Bohlmann & Roula, 2018)

Reducing energy consumption is necessary for long-term environmental sustainability. There have been studies into appropriate strategies for dealing with increasing energy consumption in buildings (Li et al., 2021). Although impact studies on building energy consumption have been conducted, they often neglect the reality that it is a complex and dynamic system (Lei et al., 2021). Because of the interaction of multiple contributing factors, even minor adjustments can have a big impact. Researchers have investigated the causes of high energy consumption in buildings by looking into the types of building factors driving energy consumption (Jelle, 2016). As a result, the purpose of this study is to identify factors that have a significant impact on building energy consumption.

This study provides a comprehensive analysis of factors contributing to building energy consumption. The next

section discusses factors contributing to building energy consumption, followed by a summary of the adopted research methods. The study results are then discussed, followed by conclusions and recommendations.

2. Literature Review

2.1. Factors contributing to building energy consumption

Energy consumption is described as the total amount of energy used to complete a task, make something, or inhabit a place (Teba, 2018). The two categories of energy consumption are primary and secondary energy consumption (Glossary of Environment Statistics, 2001) Primary energy consumption includes the country's total energy demand, as well as energy sector usage, losses during energy transformation and allocation, and end-user energy consumption (European Statistics, 2018). While secondary energy consumption refers to the energy produced by converting primary energy and includes items like gasoline and liquid fuels, refined biofuels, electricity, hydrogen, and heat (Teba, 2018).

Energy consumption in buildings is influenced by both technical and non-technical factors (Liu et al., 2022). Technical factors include building envelope, building service systems, and building operation and maintenance; nontechnical factors include building attributes, occupancy behaviours, internal environmental conditions, and social issues (Hsu, 2015). These two criteria may help researchers better understand how people use energy, including why, where, and how much they use it. Table 1 shows the description of the seven (7) technical and non-technical factors that have been found in the literature as contributing to high building energy consumption. It should be noted that to achieve the goal of the study, these factors are examined using questionnaire surveys.

Table 1: Factors contributing to building energy consumption

Factors contributing to building energy consumption		Description	Sources
Technical factors	Building envelope	The building envelope is the physical barrier that separates a structure's outside and internal surroundings.	Hagentoft, (2001)
	Building service systems	Building systems refer to the mechanical (HVAC), electrical, and plumbing systems found in modern buildings.	Abdelhameed & Saputra, (2020)
	Building operation and maintenance	Building operations and maintenance encompasses all of the tasks required to efficiently run, maintain, and manage your buildings Building envelope is the physical barrier that separates a structure's outside and internal surroundings.	Hagentoft, (2001)
Non-technical factors	Building attributes	Building attributes refer to a high-performing building that has a sustainable design with a good combination of aesthetics, accessibility, cost-effectiveness, safety, and security.	Hagentoft, (2001)
	Occupancy behaviour	Occupant behaviour affects building systems through movement and behaviours and dictates the building's internal environment and energy consumption.	Andersen, (2012)
	Internal environmental conditions	Internal environmental conditions refer to the air quality inside and around buildings and structures, particularly as it relates to occupant health and comfort.	Hagentoft, (2001).
	Social issues	A social issue is a societal problem that makes it difficult for individuals to reach their full potential. Social issues include poverty, unemployment, uneven opportunity,	Glicke, (2010)

	racism, and starvation

3. Research Methodology

This study investigated the factors that significantly impact building energy consumption in Bloemfontein, South Africa. Beyond identifying the factors contributing to building energy consumption, this study measured the building energy consumption for the Technikon Residence in Bloemfontein for 2019 and 2020. This study used a case study research approach and a questionnaire survey for data collection (Plano Clark and Ivankova, 2016). For example, a single case study design was adopted in Bloemfontein, South Africa to measure the energy consumption of a student accommodation building for 2019 and 2020. The selected building in Bloemfontein was based on the fact that the data on the building's energy consumption was accessible. As a result, it may be concluded that purposive sampling was applied in the selection of a single case study project in Bloemfontein. Table 2 shows the specifics of a single case study project.

Table 2: Research sample

Single case study	House Capacity	Years	Period
Technikon Residence	147 students	2019	12 Months
		2020	12 Months

QuestionPro Software and an online survey platform were used to generate the survey questionnaire. A questionnaire survey was used to collect data for the study within a case survey. For example, a survey link to the questionnaire was sent to students living in the Technikon residence. It should be noted that the survey questionnaire was designed utilizing the seven energy consumption factors listed in Table 2. A total of 34 responses were submitted to the survey site between August and September of 2021. The survey questionnaire was created using a Likert scale of 0-5, with 0 denoting unsure, 1 denoting minor, 2 denoting above minor, 3 denoting neutral, 4 denoting near major, and 5 denoting major, according to Plano Clark and Ivankova (2016). The Statistical Package for Social Science (SPSS) was used to analyse the quantitative data gathered. Table 3 shows the results of the quantitative data analysis, including Mean Scores (MS) and Standard Deviations (SD). Variables with an MS of 3.0 or more were considered very significant in the tests. The findings of the investigation are given and described in the following sections

4. Research Findings

4.1. Building energy consumption

Table 3 shows the summary of the measured building energy consumption for the Technikon Residence in Bloemfontein for 2019 and 2020. The building can accommodate 147 students, but there were no students in the building between January and February of 2019 due to building repairs (painting works). Table 3 shows that overall building energy consumption in 2019 was 1110477.75 units, whereas it was 855247.12 units in 2020. When compared to 2020, which recorded energy consumption from January to December, the building in 2019 had the highest energy consumption despite not recording energy consumption for January and February. The decrease in building energy consumption in 2020 was caused by an increase in Covid 19 cases in South Africa. As a result, the country was put on lockdown, and the university was forced to close its doors and shift its learning to the online platform. Only students who were unable to return home were permitted to stay in the residence. It is observed that in 2019, September recorded the highest energy consumption of 191374.40 Units (17%) and in 2020, September also recorded the highest energy consumption of 179930,59 (21%). For both years August recorded the second highest units of energy consumption, in 2019 the building recorded 152815.30 units (14%), and in 2020 it recorded 14 834.15 units (17%). In 2019, July recorded the third highest energy consumption of 144474,33 units (13%), and in 2020, November recorded the third highest energy consumption of 76505,78 units (9%). It is observed that for both years the building energy consumption is at its peak in September and August, which is the end of the winter season. Therefore, it can be concluded that during the winter season there is a need to control the energy consumption of the building.

Table 3: Technikon Residence energy consumption

	2019		2020	
Months	Units (U)	Percentage (%)	Units (U)	Percentage (%)
January	0,00	0%	27084,18	3%
February	0,00	0%	50456,28	6%
March	68637,25	6%	73602,37	9%
April	69080,68	6%	68224,28	8%
May	94738,57	9%	32164,49	4%
June	109004,63	10%	34599,53	4%
July	144474,33	13%	34599,53	4%
August	152815,30	14%	148834,15	17%
September	191374,40	17%	179930,59	21%
October	106825,18	10%	69674,07	8%
November	98489,20	9%	76505,78	9%
December	75038,21	7%	59571,85	7%
Total	1110477,75	100%	855247,12	100%

As mentioned in the previous paragraph, Figure 1 shows the graphical data of the measured building energy consumption for the Technikon Residence in Bloemfontein for 2019 and 2020. Between 2019 and 2020, the building consumed the most energy in September and August. This indicates that the building is consuming a lot of energy as winter comes to an end.

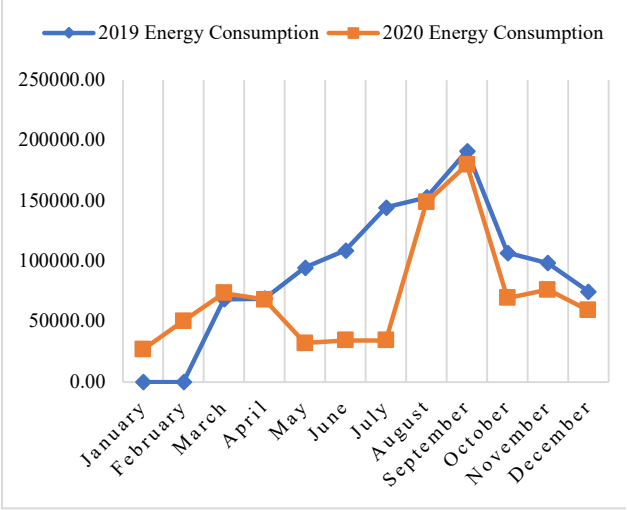

Fig. 1. Technikon residence energy consumption

4.2. Factors contributing to building energy consumption

Table 4 shows the ranking of seven factors contributing to building energy consumption. The ranking of the factors is in terms of percentage responses on a scale of 0 to 5 where 0 = unsure, 1 = minor and 5 = major. The mean score (MS) ranking is between a minimum value of 1.00 and a maximum value of 5. 00. The analysed statistical survey data show that the highest ranked factor is building service systems at MS 4.30, and the lowest ranked factor is social issues at MS 3.25. The 2nd highest ranked factor in building operation and maintenance at MS 4.24, the 3rd ranked factor in building envelope at MS 4.03, the 4th ranked factor is occupancy behaviour at MS 4.03, the 5th ranked factor is internal environmental conditions at MS 3.97, and the 6th ranked factor is building attributes at MS 3.91. According to the statistical data, the seven ranking factors have MS greater than 3.00, indicating that they are the key contributors to building energy consumption. It should also be observed that the data in Table 3 and Table 4 are identical. It's no wonder, then, that the building service system came in first at MS 4.24 and occupancy behaviour came in fourth at MS 4.03. This is because building energy consumption was higher during the winter season in 2019 and 2020, which could be linked to the identified building energy consumption highlighted in Table 4.

Table 4: Factors contributing to building energy consumption

Factors contributing to building energy consumption	Response (%)						MS	SD	Rank
	Unsure	Minor				Major			
	0	1	2	3	4	5			
Building service systems	6.06	3.03	18.18	27.27	18.18	27.27	4.30	1.45	1
Building operation and maintenance	12.12	6.06	18.18	21.21	15.15	27.27	4.24	1.32	2
Building envelope	6.06	6.06	21.21	30.3	15.15	21.21	4.06	1.44	3
Occupancy behaviour	12.12	6.06	18.18	21.21	15.15	27.27	4.03	1.69	4
Internal environmental conditions	6.06	9.09	18.18	33.33	15.15	18.18	3.97	1.43	5
Building attributes	6.06	12.12	24.24	21.21	15.15	21.21	3.91	1.53	6
Social issues	21.88	9.38	28.12	18.75	6.25	15.62	3.25	1.69	7

5. Conclusion

The purpose of this study was to identify factors that have a significant impact on building energy consumption. Building energy consumption is influenced by both technical and non-technical factors as illustrated in Table 4. Technical and non-technical building energy consumption factors include building service systems, building operation and maintenance, building envelope, occupant behaviour, interior environmental conditions, building attributes, and societal issues. The MS of the seven identified building energy consumption factors was found to be greater than 3.00, indicating that they are the major contributors to building energy consumption. It was also observed that the Technikon Residence in Bloemfontein consumed the most energy during the end of the winter season for 2019 and 2020.

For example, as shown in Figure 1, the Technikon Residence building used the most energy in August 2019 and 2020. As a result, it's critical to control the building energy service system, which is ranked the highest in Table 4. This is because the mechanical (HVAC), electrical, and plumbing systems are all part of the building's energy service systems. Managing this aspect will assist in lowering the building's energy consumption because the building systems are frequently used by the students that reside there. Building operations and maintenance, the second-highest ranking factor in Table 4, should also be maintained and evaluated. This is because buildings require a lot of energy, especially during the winter, as seen in Figure 1, so keeping them maintained and functional will assist to lower their energy use. When describing how much energy is used by a building, it is essential to consider occupant behaviour. The movement and activity of students affect building systems, regulate the inside environment, and affect how much energy is used.

Apart from the study's significance, it serves as a starting point for future research. The study has several limitations because it was carried out using a questionnaire survey research design. For example, the list of building energy consumption factors was compiled using previously published data. As a result, the respondents were unable to provide new information which would have identified new factors. Therefore, future research will very certainly utilize an experimental research design to solve this problem when doing similar assessments.

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Dr Lesiba George Mollo, PhD, is a Senior Lecturer in the Department of Built Environment, Faculty of Engineering, Built Environment, and Information Technology at the Central University of Technology, Free State, (CUT), South Africa. His research interests include construction health and safety, wearable technology and building energy management.

Mr Thabo Khafiso, is a post-graduate student in the Department of Built Environment, Faculty of Engineering, Built Environment, and Information Technology at the Central University of Technology, Free State, (CUT), South Africa. His research area focused on building energy management.

Ms Nomathamsanqa Patience Kheswa, is a post-graduate student in the Department of Built Environment, Faculty of Engineering, Built Environment, and Information Technology at the Central University of Technology, Free State, (CUT), South Africa. Her research area focused on building energy management.

Paper no. 53

A Systems Dynamics Approach for Reduction of Container Terminal Congestions Through Application of Lean Six Sigma: A Case Study for Port of Durban

Reggy Seshoene[1], Andre Vermeulen[1] and Jan-Harm C. Pretorius[1]
[1]Postgraduate School of Engineering Management, University of Johannesburg, South Africa, E-mail: jhcpretorius@uj.ac.za

Abstract: The purpose of the study was to investigate the optimal ways of reducing container terminal congestion at the Port of Durban using simulation modelling and the application of Lean Six Sigma (LSS) principles. A simulation model was used to test the "what-if" scenarios under different circumstances with the specific focus on vessel turnaround time.

This research explored the opportunities to prioritise the vessel turnaround time as the main determinant of a port terminal's effectiveness in reducing container terminal congestions. The main objective was to explore ways in which a simulation modelling and LSS can complement each other to reduce the total vessels turnaround times thus resulting in a significant reduction in container terminal congestion. A simulation of vessels calling into a port was built with the aim of creating different scenarios which served as the basis for the application of LSS principles to develop the optimal model. The simulation model was based on the total vessel turnaround time and limited to marine and, to a certain extent, terminal operations.

This study further assessed the causes of longer vessel turnaround time in the Durban container terminal. It was found that there was a positive correlation between the vessel time at berth (berth occupancy) and vessel waiting time at anchorage. The other relationship assessed was between vessel time at berth and cargo dwell time. This study found that the relationship between vessel waiting time at anchorage and cargo dwell time is statistically insignificant. This implied that the longer turnaround time in the container terminal was mainly caused by longer berth occupancy. The simulated optimal vessel turnaround time of 1.68 days was found to be sufficient to avoid container terminal congestion.

Simulation of vessel turnaround time and application of Lean Six Sigma principles were found to be effective when complementing each other to optimise container terminal efficiencies. Simulation modelling helped to understand the scale of inefficiencies prior to the selection of applicable LSS tools.

Keywords: Lean Six Sigma, port efficiency, port capacity utilisation, port congestion, berth occupancy

1. Introduction

South African ports have embarked on a large-scale investment of capacity creation initiatives that aim at handling the larger cargo vessels with quicker turnaround times. Although this is the route taken by various ports across the globe, the initiatives are based on assumptions that there will be a need for more capacity to accommodate more vessels in the ever-changing logistic industry. The ports in South Africa play a vital role of handling huge amounts of cargo on a daily basis. The South African ports are managed by the Transnet National Ports Authority State-Owned Company (SOC) in the landlord capacity and are regulated through the National Ports Act of 2005. This means the company ensures that there is enough capacity, where necessary, to handle various vessels and different commodities. This has been a trend since the establishment of the ports and is continuously being executed to ensure the ports in the country are able to cope with an increased demand of bigger vessels and the rate of expansion of modernised fleets.

The initiatives of capacity creation undertaken in South African ports vary from port berth deepening and widening, to port dig-out and the lengthening of quay walls. This is to cater in future for the larger vessels that use alternative ports

in other countries. Without doing this, the country loses economically as more vessels are redirected to other ports in the African region.

According to Visser et al. (2007), container ports and their terminals face huge challenges of increasing productivity to reduce the congestion in anticipation of growth and to remain competitive. It becomes important to prioritise vessel turnaround time as a factor for improving the efficiency of ports. An adequate port capacity may not necessarily imply optimal utilisation or efficiency. The optimal efficiency of a port is dependent on a number of factors, viz. vessel turnaround time, berth size, availability of resources, crane capacity and utilisation rate. The vessel turnaround time in the container terminal is determined by the efficiency and effectiveness of resources.In reality the ports are in competition with each other. The competitiveness of the port is determined by how customers are satisfied through cost efficiency. Yim et al. (2009) noted that there are several factors that influence the competitiveness of the port. These factors include port tradition and organisation, accessibility, productivity, port selection preferences of carriers and shippers, comparative location advantage and state aid and its impact on port costs.

The ports in South Africa are well-positioned to be considered for use by the shipping liners via the Cape route. Notteboom (2011) noted that by 2020, interlining through the Cape route is expected to outperform the Suez Canal route due to its expected improved cost efficiency. To determine if the Cape route could be preferred as an alternative to the Suez Canal route, factors such as availability of marine services, the availability of cargo, market structure, cost efficiency, high reliability, the draft conditions and vessel size, and logistics factors are important to consider. Should these factors be fulfilled, it would mean that the Cape route can be considered to be the alternative to the Suez Canal. This also implies that the ports along the Cape route need to have a competitive pricing strategy and ensure that there are better vessel economics and reduced transit fees.

To assist with the understanding of the complexity of inefficiency in the container terminals, research questions were formulated. The research questions were biased towards the improvement of turnaround time as a key measure of operational efficiencies in the container terminal. The literature and case study provided support to investigate various factors, which underpinned these questions. The final analysis of container vessel turnaround time would provide accurate answers. The main questions for this research study were:

- What are the causes of congestion which result in sub-optimal container terminal efficiency?
- Is the vessel turnaround time a main cause of vessel congestion at the container terminals?
- What is the impact of longer vessel time at berth (berth occupancy) to the total vessel turnaround time?
- Is there a relationship between berth occupancy and cargo dwell time?

2. Literature Review

2.1. Vessel turnaround time as a measure of terminal efficiency

In this section, vessel turnaround time is studied in detail to identify the key areas to improve the processes. These areas are transferred to a value stream map and broken up into various elements for ease of measurement. The outcome of this study will therefore be based on optimising these key areas.

Many studies have been conducted over the years on port efficiency but few of these focused on vessel turnaround times in ports. The vessel turnaround time is considered a key indicator of efficiency: from the moment the vessel breaks water into the port to when it breaks water out. The calculation of vessel turnaround time entails the average difference between the container vessel calling into the port and leaving the same port in a specific period of time. In most cases the unit of measurement is hours of number of days due to the complexity of operations when the vessels call into the port. For this study, the simulation run focused on a replication length of at least one to three months to get closer to the reality of the number of vessels calling at DCT.

Ports in Africa generally have longer vessel turnaround times. The average turnaround time is more than three days (Ports Regulator SA, 2016). Vessel turnaround time is determined by, amongst other variables, the effectiveness of resources in the terminal. According to Raballand *et al.* (2012), the longer the time that cargo spends within the port adversely affects the efficiency of port operations and increases congestion in container terminals to the detriment of the economy.

2.2. Vessel turnaround time at the container terminal

To understand the complexity of vessel traffic in the port it is important to consider capacity utilisation and the average vessel turnaround time. There are several factors that affect the longer turnaround time resulting in congestion in the port. One of the key factors is the anchorage waiting time, which suggests that the container vessels are waiting for a call before they can proceed to the entrance channel. To improve the vessel turnaround time and reduce waiting time at anchorage some of the approaches that can be used are as follows, (PwC and Panteia, 2013):

- Improving ship-to-shore operations;
- Other terminal operations, for example, improving the infrastructure for loading and unloading operations; and
- Port functions as a whole including marine services such as vessel traffic control function, towage operations and pilotage services.

These approaches are not the only areas of focus as there are many factors which contribute to optimisation of the time efficiency at the ports.

2.3 Container handling and congestion in ports

According to Nyema (2014) the quay crane operation is one of the most important factors in container terminals as it carries out the loading of containers from a truck to a vessel or unloading a container from a vessel to a truck. The efficiency of container terminal operations is determined by, among other aspects, its crane efficiency (crane unloading/loading operation). Crane efficiency is

determined by its availability, i.e. if the number of crane breakdowns are not minimised to acceptable levels, downtimes would be inevitable and result in the vessel occupying the berth for a longer period than planned.

As depicted in Figure 1, vessels arrive at a terminal and dock at a berth for a number of hours for the cargo loading/unloading process using terminal cranes. After this operation, the vessel then leaves the port. This is the total turnaround time of the container vessel.

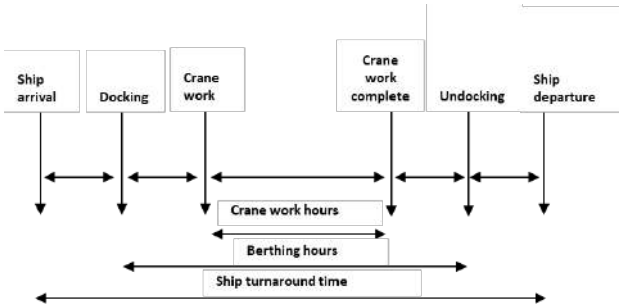

Fig. 1. Container terminal handling process. Source:

Chang et al. (2012)

When the container handling capacity is constrained it can result in vessels staying at ports for longer period. This can cause the congestions, resulting in more costs incurred by shipping liners. Port congestion could be due to massive uncleared cargo in the port, resulting in the delay of ships in the seaport (Oyatoye *et al.* 2011). This implies that vessels remain longer at berth before being attended to. A growing port capacity problem leads to congestion that is detrimental to global supply chain efficiency (Guan, 2009). Congestion at the ports happens when there is a demand for imports and exports through the ports with limited capacity. As a result, the port authorities work hard to reduce or prevent any congestion pressures. The importers and exporters incur additional costs when there is inefficiency with the handling of equipment and cargo through the terminals.

In recent years the container trade has increased globally at a rate higher than international trade (Vacca *et al.*, 2010). This resulted in the inevitable congestion issues in container terminals, especially due to the increase in the volume of container traffic in most developing countries. Congestion, especially at anchorage, results in traffic reduction and this reduces the performance of quay cranes resulting in the passive use of the container terminal capacity.

According to the World Shipping Council (2015), port congestion can arise from multiple causes, and those causes may vary by port or by marine terminal. Frequent disruptions and to a certain extent, infrequent disruptions can cause disturbances that result in longer backlogs of vessels and a higher degree of port congestion. This congestion may include but is not limited to overall terminal efficiency.

2.4 Lean Six Sigma principles for value chain optimisation

This section introduces the theory of Lean Six Sigma (LSS), which was the preferred methodology for the purpose of this research. Laureani (2012) describes LSS as a business improvement methodology that aims to maximize shareholders' value by improving quality, speed, customer satisfaction, and costs. For container terminals and the port industry in general, improving operational efficiencies is key to driving the cost efficiency and sustaining the competitiveness. Improving the efficiency of the core operational processes should result in greater customer satisfaction due to the improvement of vessel turnaround time. This will reduce port congestion resulting in cost savings and the generation of additional revenue for the port authorities. However, using LSS could be a difficult exercise if employees have not been trained on its application and how to implement it in the ports. The key to successful implementation of LSS is to use the right tools and pursue the right type of problems. In order for Lean Six Sigma implementation to be a success, the following principles should apply (Toksoy, 2014):

- **People Involvement**: When people are involved in a lean culture, an atmosphere that fosters mutual trust and respect is created.
- **Built-in Quality**: Getting a job done correctly the first time sounds obvious and simple but this element is often overlooked.
- **Standardisation**: In a lean facility, everyone is trained and expected to follow the documented best practice, using exactly the same steps.
- **Short Lead Time**: Lead time is the period that elapses from the moment a customer places an order until the customer receives the goods.
- **Continuous Improvement**: Continuous Improvement is based on the idea that it is more effective to make many small gains over time than to try to accomplish massive gains all at once.

LSS uses the DMAIC (Define-Measure-Analyse-Improve-Control) approach to solve problems in the value chain. DMAIC was used to define and uncover the root cause of the identified problems, and provide a feasible solution to the satisfaction of the customer. It can be explained in detail as follows:

- **Define Phase**

This is a phase where the problem is identified and defined to validate the business opportunity. According to Dumitrescu and Dumitrache (2011) this phase defined the goals, the deliverables for the customer and also described and quantified the defects and the expected improvement.

- **Measure Phase**

This is the phase for identifying the baselines of the current process performance by using methods such as process mapping, descriptive statistics and matrices, capability studies and measurement systems. The purpose of this phase was to establish a full understanding of the current process performance measures to identify the baselines and measure the deviations (Jafari, 2013).

- **Analyse Phase**

This phase determines the source(s) of defects using specific tools by narrowing the causal factors to the vital few. It identifies a potential solution having used methods such as distribution analysis, graphics, multivariate analysis, hypothesis testing, and plan project applications,

(Dumitrescu & Dumitrache, 2011; Jafari, 2013). In this phase, the causes of deviations are identified to confirm the root causes of the problem. The objective is to provide the correct analysis of the causes of process performance or nonperformance.

- **Improve Phase**

This is where the defects are eliminated by optimising the vital few. Their interrelationships are based on the analysis of the previous step. This phase uses methods such as design of experiments, complete factorial experiments and continued executing and improving on the project plan. It is a stage where potential solutions are generated and their failure mode assessed.

- **Control Phase**

In this phase the performance of the process is controlled and sustained by locking down the gains. The business results are communicated and signed off to close the hand-over and continuous monitoring of the project to ensure the benefits are realised and sustained. To achieve this, the processes performance monitoring system should be implemented.

LSS was applied in the end-to-end value chain of the container terminal to solve inefficiency challenges. The vessel turnaround time is considered a key indicator of efficiency: from the moment the ship breaks water into the port to when it breaks water out. The calculation of ship turnaround time entails the average difference between the container vessel calling into the port and leaving the same port in a specific period of time. In most cases the unit of measurement is hours of number of days due to the complexity of operations when the vessels call into the port. For this study, the simulation run was focused on a replication length of at least one to three months to get closer to the reality of the number of vessels calling into the port.

Ports in Africa generally have longer vessel turnaround times, where an average turnaround time of more than three days is no exception (Ports Regulator SA, 2016). Vessel turnaround time is determined by, amongst other variables, the effectiveness of resources in the terminal. According to Raballand et al. (2012), the longer period of time that cargo spends within the port adversely affects the efficiency of port operations and increases congestion in container terminals to the detriment of the economy.

One of the key factors in the total vessel turnaround time is berth occupancy. Berth occupancy refers to the time during which the vessel occupies the berth. According to Zamanirad et al. (2017) the optimum berth occupancy depends on throughput requirements and site constraints. The assessment of berth occupancy is based on the consideration of vessel arrival and departure times, time at berth or vessel turnaround time, downtime caused by maintenance, severe environmental conditions and other factors such as stopping of loading and vessel leaving the berth.

In Figure 2 is a summary of the steps and key points in the handling of a vessel including key performance indicators and measures of port performance. When the vessel is occupying a berth, it is important to ensure that the occupancy ratio is monitored carefully to avoid longer occupancy times.

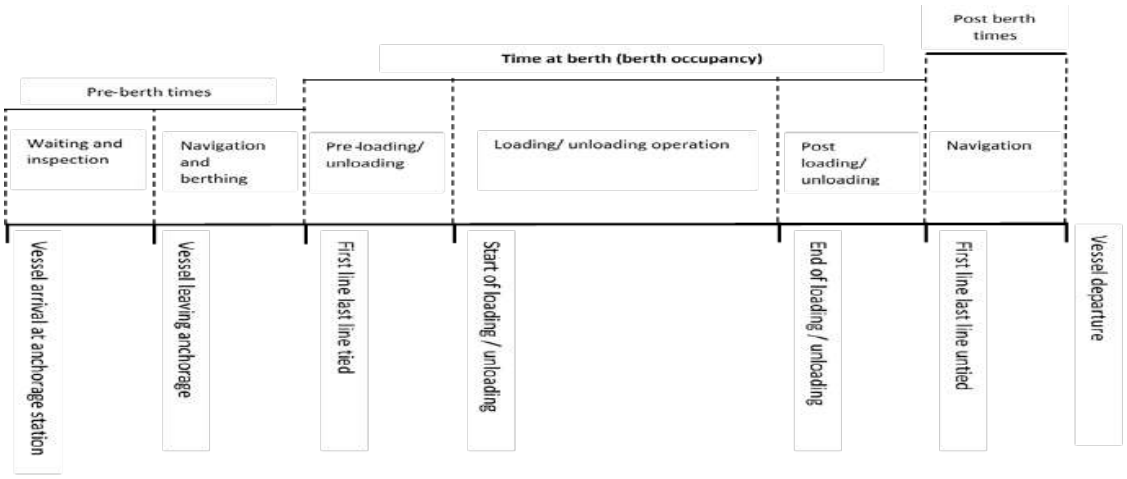

Fig. 2. Breakdown of vessel's times in port. Source: Zamanirad et al. (2017)

3. Methodology

Prior to application of LSS, an Arena based simulation modelling was used in end-to-end value chain of the container terminal to identify inefficiencies in the process. LSS was used as a methodology for identifying the variations and non-value adding activities in the processes. Furthermore, the elements that influenced the capacity utilisation were studied to identify the inefficiencies. The identified ineffiencies were then factored in the second and third phases of the simulation model to mimic the behavior of vessels calling at the port to further examine and eliminate the causes that influence longer vessel turnaround times. This included the total turnaround time of container vessels calling into the ports by the evaluation of vessels entering through the entrance channel (breakwater-in), sailing into the port, cargo-handling efficiency at berth until the vessel leaves.

The Arena based simulation model was used to test the 'what-if' scenarios of the vessel turnaround time to identify opportunities for decongestion. The simulation used a sample from a probability distribution for each variable. This was to produce numerous possible outcomes so that the results could be analysed to obtain probabilities of different outcomes. A few scenarios were assessed:

- Scenario A: The current state of vessel turnaround time in the container terminal to understand the scale of inefficiencies.
- Scenario B: The vessel turnaround time with specific focus on vital few causes with medium impact in the value chain.
- Scenario C: The ideal situation when there are few disruptions or allowable causes of longer turnaround time.

The driving parameter for the simulation model was the number of vessels calling at the port. A number of container vessels call into the port one or more times during the period of simulation. Each vessel call takes place at a particular date and time, and gets docked at a specific berth with container transfers. This container transfer was an import or export of a known quantity of containers. Vessel calls were either obtained from historical data available at the port terminal or gathered during the direct observation of vessels calling into the container terminal. The improvement in total vessel turnaround time remains the key factor to reduce congestion of vessels.

The operational indicators served as input for building a simulation model to mimic the vessel turnaround time in the container terminal. The input is based on the average times (minutes, hours or days), number of resources, service intervals and other relevant variables. After the first phase of simulation modeling, the process inefficiencies and the medium impact root causes were then identified through the application of LSS principles. This was an iterative process which ensured there was continuous improvement in the processes. The process was repeated with the high impact of the root causes which were identified through LSS. The methodology can be explained as follows:

1 – Operational KPIs

Primary input in the form of actual time taken for each operational element including the utilsation of resources. These variables are then analysed to emulate the real-world situation in order to minimise errors of judgement when building the simulation model.

2 – Vessel Turnaround Time simulation modeling

The simulation model focused on the end-to-end vessel turnaround time to mimic the behaviour of such vessels in the container terminals to understand the scale of inefficiencies in the process. The approach considers the arrival of vessels in the container terminal as a discrete event system and the modelling of its function is through a simulation tool, i.e. Arena.

For this study to mimic the behaviour of real vessel calls, the vessels calling to the port take place at a known date and time and were identified with a specific real vessel. This included one or more dock visits and each dock visit consists of one commodity (containers) transfers. A commodity transfer is an import or export of a known quantity of containers. Vessel calls are obtained either from historical data available at the port, stored in the database, or are generated synthetically. In this case, the historical vessel call information can be stored in a manner suitable for use in the simulation, as well as for detailed statistical analysis of port traffic / congestion.

3 – Scale of inefficiency

This was the result of a simulation model based on the container vessels value stream to identify waste or inefficiencies to reduce congestion in the terminals. This inefficiency could be underutilisation or lack of resources, too much idle time, or unnecessary process steps.

4 – Application of Lean Six Sigma

At this stage the Lean Six Sigma principles and tools are applied to identify, and reduce waste and process variations in order to achieve the optimal model. The DMAIC phases on Lean Six Sigma are applied in the value chain with specific focus on identification of root causes to optimise vessel turnaround time.

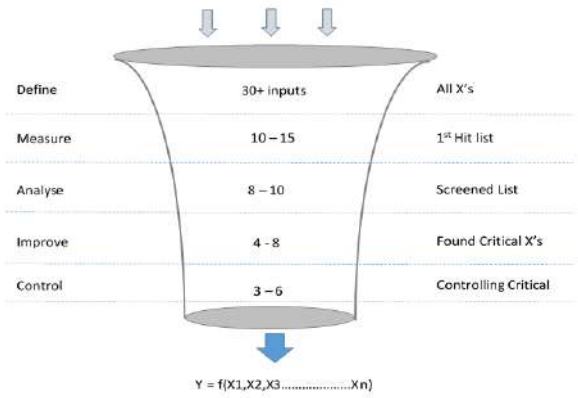

Fig. 3. Depiction of the Lean Six Sigma DMAIC process

From the literature, it can be concluded that the causes of the problem in any process were critical areas of focus to achieve a specific outcome. After the problem areas were identified through a simulation model, lean six sigma was deployed to identify critical causes. From Figure 3, if the causes were dealt with correctly, the result would automatically be improved. The formula (equation 1) for this was as follows:

$$Y = f(X) + \varepsilon \quad (1)$$

Y is the outcome or result desired and a need from a process. This is a dependent factor and it depends on the X's.

X represents the input factors that could result in Y. There could be multiple X's and these are independent factors.

ε represents the presence of error, or uncertainty surrounding how accurately the X's are transformed to create the outcome.

In other words, the input variable(s) were transformed by a function (or process) and combined with error to form the

output. Therefore, the Y is a result of or is a function of the input variables (X's). To determine a desired outcome, a transformation process or function, f, on the inputs was applied.

5 – Optimal approach for reduction of container vessels congestion

The optimal approach was based on the simulated results and application of LSS principles to optimise the processes for reduction of container terminal vessel congestion. The process was repeated until the optimal turnaround time was achieved.

4. Discussion

The vessel turnaround time in the container terminal of the Port of Durban is measured from the point where the vessel enters through the entrance channel (breakwater in) and leaves the same point.

Vessel Turnaround Time (VTAT) = BWO – BWI

- Breakwater In (BWI) is the entrance channel where the vessel passes enroute to the container terminal.
- Breakwater Out (BWO) is the exit point for a vessel after discharging the containers. This is the same point where the vessel entered the port.

The simulation model of the total turnaround time only considered vessels passing through entrance channel and exiting the same as a true measure of container terminal traffic and efficiency in DCT. However, this value chain is underpinned by various other measures once the vessel enters the port; i.e. vessel working hour, vessel productivity rate, berth productivity rate, vessel working hour rate. The simulation model was run in different phases factoring in various causes of delays. The simulation model is as follows (Figure 4):

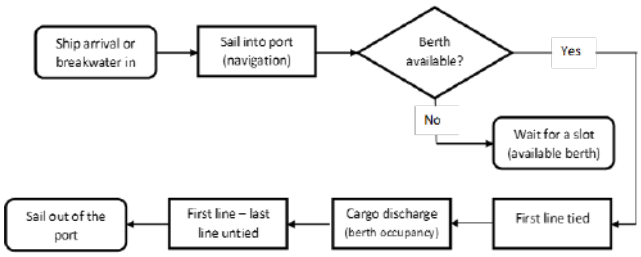

Fig. 4. Simulation model

In the first scenario, the simulation model was built based on the current state of the vessel turnaround time in DCT which experienced more delays due to several causes. The simulation was run with a replication length of 30 days to get an accurate view of the number of vessels serviced in one month per berth. As in Table 1, with the average turnaround time of 3.71 days, the maximum number of vessels that can be served in a typical berth is 8 vessels per month. DCT has eight operational berths and if the assumption is that all the berths are functional in a month, the maximum output will be 64 vessels for the terminal. This implies that there was possible congestion in the container terminal. Due to the strategic location of the port, and vessels traffic at DCT, it implies that there are potential inefficiencies resulting in congestion.

Table 1. Simulation of vessel turnaround time – Port of Durban

	Time in days		
VA Time	**Average**	**Minimum Value**	**Maximum Value**
Container Vessels	0.0579	0.0556	0.0625
NVA Time			
Container Vessels	0.0000	0.0000	0.0000
Wait Time			
Container Vessels	3.6391	3.5282	3.7961
Transfer Time			
Container Vessels	0.0159	0.0145	0.0168
Other Time			
Container Vessels	0.0000	0.0000	0.0000
Total Time (days)			
Container Vessel	3.7128	3.6025	3.8684

The average turnaround time of 3.71 days warrants the application of LSS to identify the root causes. The purpose of this simulation modelling was to establish the scale of inefficiencies in the container terminal value chain. From the simulation results it appears that the area of concern is the terminal operation or vessels at berth due to higher berth occupancy. It is therefore, important to understand to what extent this has on the total vessel turnaround time.

4.1 Relationship between waiting time at anchorage and vessel time at berth

The initial approach was to determine the correlation between the vessel time at berth and waiting time at anchorage to assess if there is any relationship between these as they are two continuous variables (Shown in Figure 5). However, this correlation simply quantifies the degree of linear association or no association between these two

variables. Because there is doubt as to which variable is the causal one, it would be sensible to use a correlation to describe the relationship.

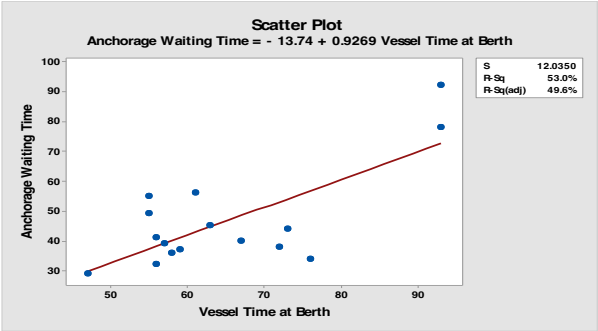

Fig. 5. Scatter plot of vessel waiting time at anchorage versus vessel time at berth

With a p-value of 0.001, it can be concluded that the relationship between waiting time at anchorage and vessel time at berth is statistically significant, i.e. $p < 0.05$ and this means the hypothesis is accepted. Therefore, it becomes imperative that the causes of longer turnaround time of vessels at berth be investigated. It can therefore be concluded that the resulting relationship between vessel time at berth and time at anchorage is linear.

4.2 Relationship between waiting time at anchorage and cargo dwell time

The next regression analysis is between the waiting time at anchorage and cargo dwell time as shown in Figure 6. Kgare et al. (2011) noted that the normal cargo dwell time differs from port to port and also among port users and stakeholders. In the container terminal of the Port of Durban, 28 days is the time limit for customs to classify the cargo as abandoned. This then implies the end of normal cargo dwell time.

If cargo spends more time at the temporary storage area than planned, it can result in congestion, implying that the vessel turnaround time can subsequently increase. Therefore, it becomes necessary to test the relationship between anchorage waiting time and cargo dwell time.

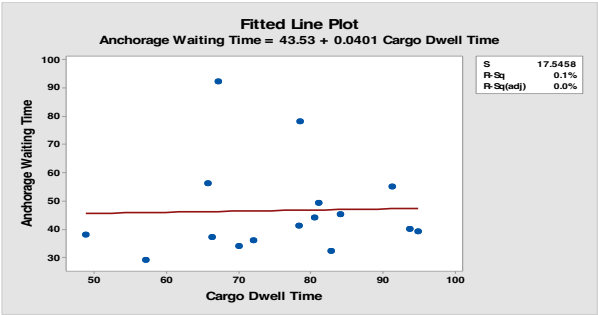

Fig. 6. Scatter plot of vessel waiting time at anchorage versus cargo dwell time

It is evident that there is no relationship between waiting time at anchorage and the cargo dwell time. With the r-squared value at 0.1% and p-value at 0.911, the null hypothesis is rejected, i.e. p-value > 0.05. This means that it cannot be concluded that the anchorage waiting time is directly linked to cargo dwell time. This finding suggests that cargo dwell time at DCT is of relatively lower importance when attempting to reduce congestion in the container terminal. However, this does not imply that cargo dwell time will not result in an increase in waiting time at anchorage. The relationship between the two variables can increase if there is congestion in the storage area.

The results above imply that more focus should be directed at the relationship between vessel waiting time at anchorage and vessel time at berth (berth occupancy) due to positive correlation.

4.3 High berth occupancy root cause analysis

The next step is to plot the fishbone diagram with the causes as per the observations in the case study. Figure 7 shows that the identified causes result in the longer vessel turnaround time; i.e. once the vessel enters the port through the entrance channel (breakwater-in), and until it leaves through the channel after cargo discharge. The critical input variables can be summarised in the following fishbone diagram.

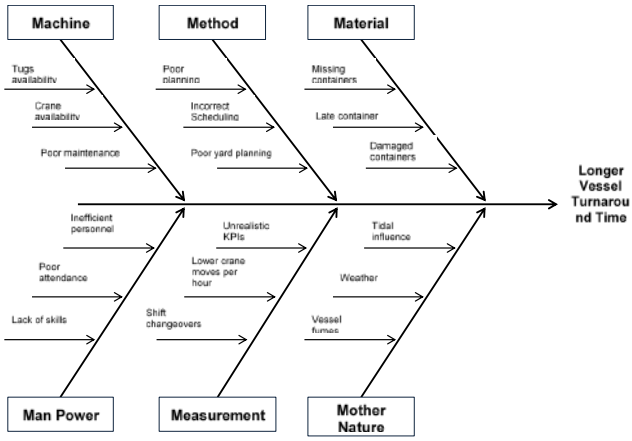

Fig. 7. Fishbone diagram

The next step was to develop a prioritisation tool after the causes had been captured using the "cause and effect" analysis. This prioritisation is done based on factors that are within control and the impact of the factor on the problem or the effect. This was performed with the help of marine operations personnel to identify the causes with 'high impact' and 'out of control'. This would prioritise optimising the container terminal efficiency.

Table 2 shows simulation results with the 'Medium Impact' causes, i.e. cargo dwell time, tidal influence, poor yard planning, incorrect scheduling, missing containers which reduce the initial average turnaround time of 3.71 by 58%. The delay caused by these aspects is already factored into various elements that make up the total turnaround time. The results of the simulation show that with only the medium impact causes, about 14 vessels can be handled at every berth with an assumption that there will be resources at the terminal. Although an average turnaround time of 2.15 days seems better than the current average efficiency levels, it is still higher as compared to international standards.

An optimal situation is when there is sufficient port capacity to overcome the traffic at the port. This means that berth occupancy should be not more than 70% for all the berths as this suggests there is congestion; i.e. vessels waiting at anchorage for longer than required.

Table 2. Simulation results for DCT with less congestion

Value Added Time	Time in days		
	Average	**Minimum Value**	**Maximum Value**
Container Vessels	1.4477	1.3226	1.5936
Non Value Added Time			
Container Vessels	0.0000	0.0000	0.0000
Wait Time			
Container Vessels	0.6938	0.0000	1.9475
Transfer Time			
Container Vessels	0.0277	0.0246	0.0308
Other Time			
Container Vessels	0.0000	0.0000	0.0000
Total Time (days)			
Container Vessel	2.1591	1.4013	3.5304

Table 3 shows the simulated results of the ideal container terminal with delays; i.e. delays are within the allowable tolerance resulting in higher utilisation rate and optimal berth occupancy – an improvement of 77% from 2.16 days. All the other causes of delays resulting in longer turnaround time have been eliminated from this simulation run to assess the ideal optimal situation to avoid congestion or elimination of vessel waiting time at anchorage.

The simulation was run for a replication length of 30 days to get accurate results of the ideal berth efficiency. From the results in Table 3, a typical berth optimal efficiency at DCT will be achieved with an average vessel turnaround time of 1.68 days (40.4 hours) with the average berth output of 18 vessels per month to eliminate congestion at anchorage.

Table 3. Simulation results of DCT berth with ideal optimal efficiency

Value Added Time	Time in days		
	Average	**Minimum Value**	**Maximum Value**
Container Vessels	0.0456	0.0413	0.0493
Non Value Added Time			
Container Vessels	0.0000	0.0000	0.0000
Wait Time			
Container Vessels	1.6246	1.5164	1.7485
Transfer Time			
Container Vessels	0.0132	0.0111	0.0150
Other Time			
Container Vessels	0.0000	0.0000	0.0000
Total Time (days)			
Container Vessel	1.6835	1.5742	1.8042

For comparison purpose, Figure 8 shows the turnaround time for different global regions for comparison purpose. The simulation exercise for the ideal vessel turnaround time of the Port of Durban shows that it has to be 1.68 days to avoid congestion and to be on par with other international ports. In comparison with other regions, the average container vessel turnaround time in Africa is lagging behind at 2.54 days. This is attributable to longer berth occupancy ratios and other factors such as inefficiency of terminal operations. The average global turnaround time for the container ports across the world (as per Figure 8) is 1.4 days.

The average vessel turnaround time of 1.68 days in DCT will be above the average of 2.54 days in Africa. As already indicated in the literature study, the Port of Durban's container terminal is one of the busiest in the southern hemisphere. The turnaround time of 1.68 will be sufficient to minimise the waiting time at anchorage, thus

eliminating congestion. This means this turnaround time can be sufficient to achieve an optimised cost efficiency.

Berth occupancy (also referred to as vessel time at berth) is the ratio of time the berth is occupied by a vessel to the total time available in that period (Mwasenga, 2012). According to the study by Thoresen (2014), berth occupancy of more than 70% implies that there is congestion, i.e. one or more vessels occupy a berth for a longer period than planned resulting in more vessels waiting at anchorage. This means that the berth occupancy should be less than 70% to achieve a high berth utilisation rate and avoid the congestion which increases the vessel waiting time at anchorage.

The number of berths influences the berth occupancy value (Thoresen, 2014). Table 4 shows that when there are 6 berths or more, the maximum berth occupancy is 70% on average. Therefore, any improvement should be focussed on berth occupancy which will result in improvement of the total vessel turnaround time.

Table 4. Berth occupancy ratios (Source: Thoresen (2014)

Number of berths	Control of arrival vessel to berths		
	None	Average	High
1	25%	35%	45%
2	40%	45%	50%
3	45%	50%	55%
4	55%	60%	65%
5	60%	65%	70%
6 or more	65%	70%	75%

According to the root cause analysis that was conducted, there should be a considerable reduction in vessel time at berth to minimise the total vessel turnaround time. The causes of longer berth time can be summarised as crane efficiency, labour productivity, and shift changes resulting in increased vessel waiting time. Higher berth occupancy should be avoided as much as possible if the objective is to improve the vessel turnaround time. The causes mentioned above should be reduced in order to achieve the berth occupancy that is within the tolerance levels.

5. Conclusion

This study focused on the literature of LSS, which is the preferred best practice methodology for improving the process efficiency in the vessel turnaround time value chain. However, the application of LSS principles is preceded by systems dynamics to understand the scale of the problems existing in the container terminal. The first step was to identify the problem by developing a simulation model to understand the scale of inefficiencies in the container terminal. LSS was then applied to optimise the vessel turnaround time in the container terminal of the Port of Durban.

This helped in identifying areas for improvement and were further validated by the interviews and observation in the container terminal. To answer the research questions, this study assessed the relationship between various variables, i.e. vessel time at berth versus waiting time at anchorage and cargo dwell time respectively. It was found that the only positive correlation is between the vessels waiting time at anchorage and vessel time at berth. The relationship between anchorage waiting time and cargo dwell time was found to be statistically insignificant.

Establishing the relationship between these various variables helped in narrowing down the areas of focus to identify the causes of variations. Finally, the ideal turnaround time of 1.68 days for DCT was determined taking existing factors in the port and other improvement aspects such as equipment efficiency and other high impact causes which are out of control. The model was validated through a comparison of the simulation results with port operations performance reports and the interviews with the marine personnel.

It can also be concluded that the berth occupancy in the container terminal should be managed at a range of 35% to 70% if a port's objective is to eliminate vessel congestion. From this study, it is evident that a simulation modelling of vessel turnaround time helped in identifying areas of inefficiencies. This was followed by the application of LSS as the best practice methodology for reduction of variations and elimination of waste. The rationale is that the areas of improvement cannot be pre-empted without understanding the scale of inefficiencies in the container terminal. There are several best practice methodologies but in order to select the appropriate one, factors such as scale of inefficiency and the setup of the environment should dictate.

The limitation of this study related to other variables which could impact on vessel turnaround time but were not necessarily considered to be statistically significant. These were:

- Quayside storage; and
- Information on the efficiency of the rail operations.

These variables could provide fundamental and necessary information of how cargo dwell time can be optimised. In this study, it was found to be statistically insignificant among the causes of longer turnaround time. It was difficult to conduct further analysis based on the limited amount of this data. The other important piece of information that was difficult to obtain was concerning labour, i.e. shift patterns and the number of employees per shift. Such information would have contributed to understanding the extent of how efficient labour assisted to turn the vessels quicker.

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Reggy Seshoene obtained a PhD in Engineering Management at the University of Johannesburg and currently involved in Industrial Engineering education through research supervision and reviews on research output for journals. He is certified in Six Sigma (Black Belt) and project management and his doctoral thesis focused on systems dynamics approach and Lean Six Sigma to optimise container terminal capacity utilisation in maritime ports. He is currently employed at the state-owned forestry company where he is leading Business Development (including Business Optimisation and Innovation) and Project Management Office, and also serves on the board of a timber processing company as independent non-executive director. His 15 years of work experience was gained from various industries including banking, petroleum, maritime and manufacturing where his main responsibilities involved application of Industrial Engineering best practice methodologies and techniques to optimise efficiencies.

Andre Vermeulen is a Senior Research Associate at the Post-Graduate School of Engineering Management in the Faculty Built and Engineering Management at the University Johannesburg, South Africa. He obtained a DPhil Engineering Management from University Johannesburg and presently supervise numerous doctoral and master's students. Dr. Vermeulen completed research project in An Analytical Instrument to Measure the Status of An Organisation Business Process Capability. His research interests include manufacturing, simulation, optimization, reliability, scheduling, manufacturing, lean, Lean-Six Sigma, and Business Process Capability

Jan Harm Christiaan Pretorius obtained his BSc Hons (Electrotechnics) (1980), MIng (1982) and DIng (1997) degrees in Electrical and Electronic Engineering at the Rand Afrikaans University and an MSc (Laser Engineering and Pulse Power) at the University of St Andrews in Scotland (1989). He worked at the South African Atomic Energy Corporation as a Senior Consulting Engineer for 15 years. He also worked as the Technology Manager at the Satellite Applications Centre He is currently a professor: Postgraduate School of Engineering Management in the Faculty of Engineering and the Built Environment where he worked since 1998. He has co-authored over 240 research papers and supervised 61 PhD and over 270 Master's students. He is a registered professional engineer, professional Measurement and Verification (M&V) practitioner, senior member of the Institute of the IEEE, fellow of the SAIEE and a fellow of the South African Academy of Engineering.

Paper no. 57

Harnessing the Multiple Benefits of Fragmentation of Capital Infrastructure Projects

Edoghogho Ogbeifun[1] and Jan-Harm C. Pretorius[2]

[1]Postgraduate School of Engineering Management, Faculty of Engineering and the Built Environment, University of Johannesburg, Email: edobunmi@gmail.com

[2]Postgraduate School of Engineering Management, Faculty of Engineering and the Built Environment, University of Johannesburg, Email: jhcpretorius@uj.ac.za

Abstract: The mode of executing the construction phase of infrastructure development has a significant influence on the success of project delivery. Several project execution models have been adopted with significant success, such as the use of a single contractor, a single contractor with multiple sub- and specialist contractors, as well as fragmentation of capital projects and using multiple contractors. Adopting the concept of fragmentation and use of multiple contractors holds the potential of timely project delivery, creating multiple employment opportunities, facilitating skills development and enhancing the prospect of achieving value for money. Furthermore, the phase or the whole project completed, on time, reduces the negative effects of inflation and infrastructure deficit, increases end-users' satisfaction and positively impacts on the economy. The multiple sites case study strategy of qualitative research was adopted, using the principles of comparative analysis to examine some of the benefits of adopting the practice of fragmentation in the execution of a building and a road rehabilitation projects. The findings revealed that through fragmentation, the projects were delivered on schedule, created multiple direct employment opportunities, achieved client and end-users' satisfaction, as well as value for money. Therefore, this research recommends the 'contextual' adoption of the practice of fragmentation for the execution of all capital infrastructure type projects.

Keywords: employment, fragmentation of capital projects, infrastructure deficit, timely project delivery, value for money.

1. Introduction

Infrastructure projects conceived, executed and put to functional use have ripple effects on the economy of a nation (Muller et al., 2015; Kara et al., 2016; Roberta et al., 2017). The effectiveness of infrastructure delivery is influenced by many factors, which include, but is not limited to the procurement method, the mode of execution, competency in planning and management of the execution process and availability of adequate resources. However, focusing on mode of execution, the practice of using a single contractor, or main versus subcontractors and fragmentation (using multiple contractors) has been used to achieve different degrees of success. If the concept of fragmentation is appropriately crafted into the execution of the proposed capital project, the approach holds the potential of the timely execution of the projects, reducing the incidence of abandoned projects and infrastructure deficit, as well as the provision of multiple employment opportunities. This approach also enhances end-user satisfaction, the effective use of resources, ameliorating the negative effects of inflation and ensuring that the client receives value for money (VFM) invested in the project (Watermayer, 2013; Watermayer, 2014). The need to ameliorate the negative effects of time overrun in capital development projects has been a major concern to infrastructure project stakeholders. Therefore, it is helpful to consider adopting the concept of fragmentation (among other prospective solutions), to ameliorate the negative effects of time overrun during the execution of capital infrastructure projects. Adopting this concept allows for the effective use of available project funds, reduces the negative effects of inflation and enhances the prospect of receiving VFM.

Similarly, when a capital project is executed through a single contractor, the single contractor works at his own pace and provides reasons to justify his delay in meeting the scheduled timeline (Ogbeifun et al., 2018a). Whereas, when as one among many contractors, each contractor is compelled to work at a steady pace commensurate with other contractors, by adopting the principles of self-regulation (Bogsnes, 2014). This allows the simultaneous execution of the different portions of the whole project, through knowledge sharing, healthy competition and indirect benchmarking. This option holds the potential that

the different components of the whole project will fit into each other seamlessly and will be completed within the time schedule proposed for the whole project (Ogbeifun et al., 2018a; Fagbenle et al., 2018).

This paper presents a comparative study of two capital projects, a building project in Nigeria and a highway infrastructure project, in South Africa, where the principle of fragmentation was adopted. Therefore, the question this research hopes to answer is, "What are the tangible benefits of adopting the concept of fragmentation of capital infrastructure projects, as a mode of execution?" To find answers to this question, the central objective is to evaluate the influence of adopting the concept of fragmentation on:

a. the project completion time,
b. possible employment opportunities and
c. the effective use of resources to achieve VFM.

2. Method

2.1 Procurement Method

The level of success achieved during the execution of any capital construction project is significantly influenced by the project procurement method (Pourrashidi et al., 2017). Some common project procurement methods used for the execution of capital projects in the public and private sector in many developing economies are the traditional design/bid/build (DBB) system and design/build (DB) system (Babatunde et al., 2010; Idoro, 2012). Each of these procurement methods has different variants, enabling the client to select the one most suitable for the execution of its project.

The traditional method of contract procurement can be described as the process where the three phases of DBB are treated as three separate tasks (Babatunde et al., 2010). Adopting the DBB system requires an adequate number and quality of human capacity in every phase of the project, by both the client and the project execution team (PET) members (Escamilla and Ostadalimakhmalbaf, 2016). The client may decide to use a single contractor to execute his capital project, or the variant of fragmenting the capital project into smaller lots, requiring multiple contractors. However, by adopting either mode of execution (single or multiple contractors), each contractor has a direct contractual relationship with the client, allowing the client to measure the performance of each organisation.

The DB procurement system integrates the fragments of design, bid and build into one contract which allows the contractor to be involved in the project from inception to completion (Idoro, 2012). There are different variants of the DB system, like concession, turnkey, build operate and transfer. Some of the common modes of operating the DB system include:

i. Pure DB: both the design and construction teams are in the same organisation, commonly referred to as a 'consortium'.

ii. Partially integrated DB: here, the consortium invites other consultants or contractor(s) to execute specific or specialised functions within the project.

iii. A third variant is where different organisations (consultants and contractors) converge to form a consortium or joint venture, using the instrument of a 'memorandum of understanding' (MOU), like the one used in alliance contracting. In this regard, the collaborating consultants and contractors' function in their areas of expertise (Idoro, 2012; Jefferies et al., 2014).

Irrespective of the project procurement method and the variant adopted, the mode of execution of the construction project, has overarching effects on the success of infrastructure delivery.

2.2 Project Execution Models

Generally, construction projects may be executed using a single contractor, main versus subcontractors or through a fragmentation system. The concept of the single contractor system, as well as the variant of main and subcontractor system, suggests that the whole work package to be executed is bundled together and awarded to a single contractor. The practice of fragmentation occurs where the project is divided into smaller lots or work packages and awarded to multiple contractors. When single contractors are used for the execution of infrastructure projects, they may execute the project through their in-house project personnel or rely on subcontractors for the actual execution. The ability and capability of main contractors to effectively deliver capital infrastructure projects is significantly influenced by the quality of their subcontractors and the harmonious relationships that exist between them (Akintan and Morledge, 2013; Fagbenle et al., 2018). The main contractors adopt the practice of using subcontractors or specialist contractors to reduce their overheads, operating cost, maximise profit and still aim to achieve the efficient delivery of the project (Akintan and Morledge, 2013). In many instances, this approach has positively impacted on project delivery. Unfortunately, many of the main contractors focus more on maximising profit rather than building long-term relationships with subcontractors. Other negative attitudes of main contractors that impair cordial relationships with subcontractors, observed by the authors (Akintan and Morledge, 2013) include:

- The main contractors' authoritative attitudes.
- The use of stringent contract agreements and conditions that erode the rights of the subcontractors.
- The subtle transfer of the project risks to the subcontractor.
- The main contractor views the suggestions from the subcontractor more from the point of cost rather than added value.

Expanding further on the sour relationship between the main and subcontractors, especially around payment for services rendered, Akintan and Morledge (2013, p. 6) observed the following:

> Unfortunately, efforts at getting main contractors to deal fairly with their chain of subcontractors have mainly been unsuccessful. Irrespective of the fact that standard contracts stipulate periods within which subcontractors should get paid, such specified periods are repeatedly ignored, with subcontractors often stretched to the limits before getting paid. These negative attitudes demoralise the subcontractors, stifle innovation, reduce productivity, causing delays and inhibiting improvements in the efficacy of the project delivery process (Dainty et al., 2001; Akintan and Morledge, 2013).

The practice of fragmentation involves that each lot or work package of the whole project is awarded to a different contractor. Each contractor has a direct contractual relationship with the client, engages adequately resourced project personnel for the execution of their lot and work within the specific and general project schedule. Work in each lot or work package is executed simultaneously, each contractor making steady progress commensurate with other contractors by adopting the principle of self-regulation (Bogsness, 2014). The principle of self-regulation is like the concept of a roundabout, considered to be the most 'cost-effective' method of traffic control in urban cities where motorists circulate through the roundabout seamlessly, with minimum external control. In this regard, contractors in the fragmented project, through knowledge sharing, healthy competition and indirect benchmarking, execute the different portions; the different parts of the whole project fit into each other seamlessly and is completed within the time schedule proposed for the whole project (Ogbeifun et al., 2018a; Fagbenle et al., 2018).

Whatever the procurement system and mode of execution adopted, the quality of contractor has a significant influence on effective infrastructure delivery. Therefore, the process of selecting the contractors should be given critical consideration.

2.3 Contractor Selection Process

The contractor is the most visible active force among the PET members, whose action or otherwise significantly influences the effective delivery of the construction project (Ogbeifun et al., 2018c). Therefore, this group of actors should be carefully selected. Contractor selection involves a multi-faceted decision-making process with multiple selection criteria. The selection of quality contractors holds the potential of engaging adequately resourced contractors, knowledgeable in the project at hand, reducing the incidence of rework, capable of producing an overall quality project, which is delivered within schedule, at reasonable cost and enabling the client to achieve VFM (Jafari, 2013; Ruparathna and Hewage, 2015; Mkazi et al., 2021). In practice, the contractor selection process follows a two-stage process, known as pre-qualification and post-qualification stages (Jafari, 2013). The pre-qualification process involves inviting several contractors to submit the information required by the procuring client to identify an array of eligible contractors, which is required for the post-qualification phase (Jafari, 2013). The information in the pre-qualification document should be as comprehensive as possible. The examination of the documents submitted by each contractor should be complemented with physical verifications. The category or categories of contractors to be invited for pre-qualification should be specified, so that the shortlisted contractors will be approximately of equal capacity and capability. Some of the information required should include essential attributes and key factors (Doloi, 2009; Alzahrani and Emsley, 2013), as summarised in Table 1.

The result of the pre-qualification stage is the shortlist of suitable contractors. In the second stage – the post-qualification stage – the shortlisted contractors are invited to tender for the construction project. The submission of each contractor is examined to establish their technical competency, balanced pricing and workable schedule or project timeline; these form the basis for selecting the most suitable contractor(s), and not necessarily adopting the practice of 'lowest bidder' (Jafari, 2013; Deep, et al., 2017).

Table 1. Essential attributes and key factors

S/No	Attributes & key factors
1	Attribute: Financial attributes
	Key factors: Up to date audited account for not less than three years, showing history of cash turnover, credit history and cash flow.
2	Management and technical attributes
	Staff qualification, quality, quantity, and experience of technical personnel; knowledge of suitable construction method(s) for the project under consideration; suitable work programme or project timeline.
3	Experience and performance attributes
	List and size of completed projects in the last five years, with certificates of practical completion; project time and cost overrun, if any, with reasons; evidence of uncompleted projects with reasons; evidence of conflict, disputes, or litigation with reasons; experience of construction activities in the region of the proposed project.

Literature has adequately identified the influence of the project procurement system and mode of project execution on successful infrastructure delivery. Therefore, this paper hopes to explore the benefits of adopting the concept of fragmentation in the execution of infrastructure projects.

3. Research Method

The multiple sites case study method of qualitative research was adopted (Yin, 2014). The strength of the case study method of research is that it allows the researcher to observe and study the different aspects of the same subject, putting each part in relation to the whole in the environment where it operates. This method is useful when holistic, in-depth investigation is needed (Njie and Asimiran, 2014; Gammelgaard, 2017). The focus of this research was to explore the multiple benefits of adopting the concept of fragmentation for the execution of capital projects. Since the projects used for this research have been completed, the data were obtained through contextual analysis and the evaluation of minutes of site meetings, documents from the website of organisations, published articles and the comparative analysis of the organisational structures (Vaismoradi et al., 2013; Maguire and Delahunt, 2017). The analyses of the qualitative data followed the principle of content analysis (Hsieh and Shannon, 2005). To ensure reliability and validity of data, the information on the same subject was cross-checked with multiple sources by adopting the principle of triangulation (Turner et al., 2015). The analysis of the research findings revealed that the two projects were executed, first by selecting a phase of the larger project and fragmentation of the chosen phase into smaller lots or work packages. The respective lots or work packages were executed by different contractors within the time schedule; thus, completing the chosen phase on schedule. The details of the research findings are discussed in the findings and discussion section.

4. Findings and Discussion

4.1 Background of the Projects

The two projects used for this research are a build project situated in a higher education (HE) institution in Nigeria and the rehabilitation of a network of roads in South Africa. The building project is the construction of a phase in the development of the infrastructure for the use of the faculty of Environmental Sciences, tagged as Project 1. This project is a two-storey building, fragmented into seven lots and awarded to seven different contractors. One of the conditions set by the funding agency is that any approved project must be completed within twelve calendar months to reduce the negative effect of inflation and attendant variations. During the tender stage, the project execution timeline was set at ten months, allowing a two-month float. Each contractor developed his timeline for the ten months. Work in the seven lots started simultaneously in February 2013 (Ogbeifun et al., 2018a). Each contractor worked steadily and achieved the milestones. The individual lots and the whole project were delivered earlier than the scheduled ten months, with cost savings and no compromise on quality (Ogbeifun et al., 2018a).

Similarly, Project 2, is a portion of the Gauteng freeway improvement project (GFIP), South Africa. This is a long-term freeway upgrade and expansion project, which entails the eventual upgrade and construction of about 561 km of freeways (Weidemann, 2010). The project was divided into four phases and a timeline, for execution. The phases were phase A1, A2, Phase B, and Phase C. Phase A1 involved the substantial upgrading of about 185 km of freeway, including pavement rehabilitation, interchange (I/C) upgrades and land additions on the N1 and N3, sections of the N12 and the R21 road network. The projects for phase A1 were scheduled for completion in 2010 but were adjusted to 2011 (Weidemann, 2010). Furthermore, some of the work package connected to the successful hosting of the 2010 Soccer World cup were isolated for speedy execution. This paper will focus on work packages C and F, commonly called “the Ben Schoeman Freeway”. The two work packages were awarded to a joint venture corporation with five collaborating contractors. These work packages were executed successfully and ready for use for the 2010 Soccer World cup. Similarly, all the projects in Phase A1, were successfully completed by the 2011 scheduled date.

4.2 Achieving Project Timelines Through Fragmentation

Project schedules or timelines are a critical tool for effective construction project management. It is a tool developed at the beginning of the project and used progressively to evaluate the progress during the life of the project, providing information for effective communication or critique of the construction project (Mukula et al., 2015; Subramani et al., 2016). At the inception of Project 1, the minutes of the site meetings and interviews with some of the PET members revealed that general site meetings were held every two weeks for the first two months; thereafter, the site meetings were held monthly and occasionally as the need arose **(**Ogbeifun et al., 2018a**)**. The contractors demonstrated their commitment to the project and achieved practical completion within the project timeline, as shown in Figure 1 **(**Ogbeifun et al., 2018a).

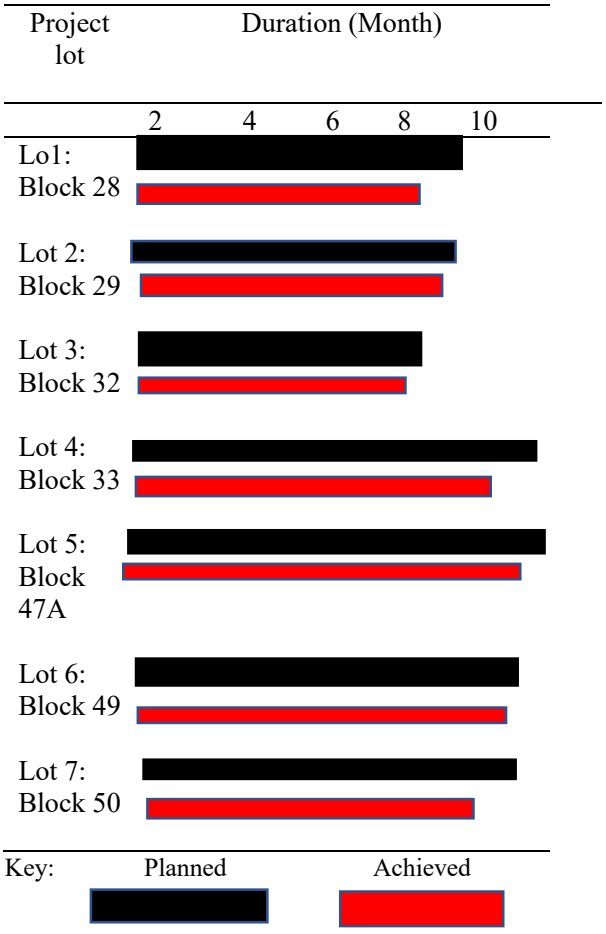

Fig. 1. Project timeline

Similarly, in Project 2, the portions of the project that were considered critical to the hosting of the 2010 Soccer World Cup and all the projects earmarked for Phase A1, the upgrade of 185 km of freeway, were completed according to the schedules of 2010 and 2011 respectively. This feat was achieved because the entire phase A1 of the GFIP project was divided into different work packages, each team executing the content of their work package simultaneously, which enabled the whole projects to be achieved on schedule (Graumann, 2010; Weidemann, 2010; Ogbeifun and Pretorius, 2022).

The success recorded in Projects 1 & 2 would have been difficult if the projects were bundled into one work package and awarded to a single contractor, no matter how well resourced the contracting organisation might be. If the two projects were awarded to main contractors, who would in turn have engaged other subcontractors, the prospects of achieving these projects on schedule would have been difficult. This is because the relationships between main and subcontractors are not usually the best and have been identified as having contributed significantly to delays in the execution of construction projects (Akintan and Morledge, 2013; Fagbenle et al., 2018). Conversely, the multiple contractors engaged in Projects 1 & 2, were independent, yet inter-dependent. They had a healthy competitive relationship with each other and had direct relationships with the client, a scenario not practicable in the practice of main contractor vs. subcontractor procurement system (Akintan and Morledge,

2013). The intrinsic factor underpinning the success in the management of fragmented projects, is the adoption of the 'self-regulation' principle, which allows each contractor or PET members in the project to execute their portion of the project diligently and in collaboration with other contractors. Thus, delivering their portions of the project and ultimately the whole project, on schedule (Hong and Chan, 2014; Mba and Agumba, 2018).

4.3 Employment Opportunities

The human capacity (technical) at the tactical level of leadership (both in quantity and quality) is critical to the successful execution of capital development projects (Ogbeifun et al., 2018b). Table 2 provides a comparison of the quantity of the technical personnel for two identical building projects executed through single and multiple contractor systems, executed in the same HE institution, Project 1. As shown in Table 2, the single contractor did not have the full complement of the engineering and the built environment professionals. The comparison of technical personnel, the ones available in the PET team of the single contractor, is to the ratio of between 1:4 and 1:7 (Ogbeifun et al., 2018b).

Table 2. Quantity of technical personnel

S/No	Project	Technical personnel at tactical level						
		Civil Eng.	Mech Eng.	Elect Eng.	Project manger	Builder	Architect	Q/Surveyor
	Single contractor							
1		1	-	1	1	-	1	1
2	Multiple contractors (Project 1)							
	Lot 1	-	-	-	1	1	1	1
	Lot 2	1	-	-	1	-	1	1
	Lot 3	1	1	1	1	-	1	1
	Lot 4	1	1	1	1	-	1	1
	Lot 5	-	1	1	1	1	1	1
	Lot 6	-	1	1	1	1	1	1
	Lot 7	1	1	1	1	-	1	1
Compare		1(4)	0(5)	1(5)	1(7)	0(3)	1(7)	1(7)

The two work packages in Project 2 were awarded to five independent, yet interdependent contractors - members of the same joint venture, including the technical personnel (professionally qualified and experienced specialists and mid-management) engaged at the tactical levels represented in Table 3. Cumulatively, they engaged 45 technical personnel at the tactical level of leadership (Ogbeifun et al., 2022).

Table 3. List of contractors in work package C & F

S/No	Tactical leaders (Professionally qualified and experienced specialists and mid-management)	Qty
1	Grinaker-LTA Construction & Development (Work package C)	12
2	Aveng Africa (Pty) (Bridges, off and on-ramps and interchange constructions)	20
3	Moseme Road Construction (Pty) Ltd (Work package F)	12
4	Boitshoko Road Surfacing	8
5	JET Demolition (Pty) Ltd	5
	Total	45

Extrapolating the information in Tables 2 &3 projects possible employment opportunities in the lower categories of construction workers (operational leaders – trade/artisan's leaders and artisans & unskilled labour hands). This indicates a ratio of 1:4:20, (tactical leader: operational leaders: artisans & unskilled labour) for building construction projects and 1:6:30, for road construction projects. Table 4 presents the summary of possible employment opportunities in the three levels of construction work force. Furthermore, the employment opportunities in the fragmented projects with multiple contractors are higher than the available opportunities when using a single contractor system. In the same vein, it is in practice difficult for any single contractor (on any infrastructure project) to engage the number of personnel engaged in a fragmented project with multiple contractors, without the negative effects of duplication and redundancy of personnel.

Table 4. Summary of personnel at the tactical and operational levels

S/No	Project	Tactical leaders	Operational leaders	Artisans & Unskilled labour
1	Single contractor	5	20	100
	Multiple contractors			
2	Project 1	28	112	560
3	Project 2	45	270	1350

4.4 Achieving Value for Money

Many of the capital projects being executed in developing countries are funded through loans. The rate at which the whole project or part(s) of it is completed will determine the effects of inflation and exchange rate on the local currency and on the total cost of the project. It suggests, therefore, that the earlier the project or part(s) thereof is completed, the better the chance of reducing the negative

effects of inflation, the associated cost variations, the ability to achieve VFM as well as customers' satisfaction (Watermayer, 2013; Ruparathna and Hewage, 2015).

For example, in Nigeria, the Mambilla hydroelectric power (MHEP) project was conceived in 1982, initially to produce 2,600MW, but was reviewed upward in 2012 to produce 3,050MW of electricity for the national grid. Unfortunately, the project was still at the preliminary stages of execution in December 2021. The component parts of the MHEP project include the connection of three dams across the brownish River Donga (Terkula, 2014), to produce four dams; (i) Main dam (ii) Regulatory dam (iii) Operational dam (iv) another regulatory dam, part of which will be situated underground (Oruonye, 2015). Further details about the project are the following.

> The MHEP dam will involve a main, large rolled compact concrete (RCC) dam and reservoir (storing water and thus regulating river flow) at 1300 meter above sea level (Gembu Dam). The water will be diverted off the reservoir towards the western side of the plateau through 3 hydraulic tunnels totalling 33 km and intercepted by 2 smaller RCC dams, both at an elevation of 1250 m (Sum Dam and Nghu Dam). Beyond these dams, the tunnels lead into a 1000 m drop shaft tunnelled down through the rock to a massive underground powerhouse. Through a short tunnel, the water will then exit the base of the plateau and flow into a tributary river that re-joins the Donga River downstream of the plateau (Oruonye, 2015, p. 21).

Initially, this project was estimated to cost US$1.46 billion in 1982, but reviewed to US$3.2 billion in 2011. In 2017, the project was further reviewed, and a contract awarded for the sum of US$5.79 billion (Aborisade, 2021). Technically, in 1982, 1000MW would have been executed at an approximate sum of US$562m, in 2017, the estimate, for 1000MW, has gone up to about US$1.9 billion (Aborisade, 2021). From inception to date, over US$2 billion has been spent, with little result. Sadly, these funds are borrowed.

Retrospectively, if the concept of phased development and fragmentation was adopted, each of the three primary dams on River Donga could have been developed into functional hydroelectricity power stations, connected into the national grid, as each station is completed. The burden of executing each phase would have been lighter to bear and each completed functional phase would have contributed significantly to the power demands in the country. In a nutshell, adopting the principles of phased development and fragmentation of capital development, could ameliorate time and cost overrun, provide more employment opportunities as well as enhance the effective use of available resources, mitigate the menace of inflation and exchange rates, thus, ensuring VFM being received.

4.5 Limitations

The two projects used as case study for this research may not have provided sufficient information to effectively explore the benefits of adopting the concept of fragmentation for the execution of capital infrastructure projects. Besides project completion time, employment opportunities and achieving value for money, there are other areas of project success factors that should be explored. However, these limitations notwithstanding, the information provided from this exercise should encourage further studies on this subject and provide solutions on how to improve on effective delivery of capital infrastructure projects.

5. Conclusion

The focus of this research was to explore the benefits of adopting the practice of fragmentation as a mode of executing capital infrastructure projects. Two projects, Project 1, a building development project and Project 2, a highway improvement project, were used for the research. The concept of phased development and fragmentation of capital infrastructure development was used in the execution of the two projects. Achieving the project timeline, schedule or milestone is very important in any construction project. Although contractors provide timelines during tender, many of them, especially the single contractors, do not follow through during construction. Depending on the procurement system adopted, the relationship between the PET members and the project sponsors or client, may influence the capability of the project manager to enforce compliance. The prospects of achieving completion of a typical construction project better in a multi-contractor setting than in the single contractor scenario. The single contractors work at their own pace but any contractor working as one among many, indirectly practices internal benchmarking and faces healthy competition with other contractors by adopting the principles of 'self-regulation'. This 'self-regulation' principle inherent in the multi-contractor approach assists the contractors to keep to their timeline. In addition, the steady progress achieved by the contractors allows them to draw proportionately from the project fund, reduce the negative effects of inflation and exchange rates on local currency, thus, enhancing the prospect of achieving VFM.

As shown in the two projects used for this research, the phases identified for execution were completed within the time schedule, through fragmentation of the phases chosen for execution, into smaller lots. The contractors worked simultaneously, achieved their individual timelines and ultimately the whole project on schedule. Thus, the application of this concept holds the potential of reducing the incidence of delays in the execution of construction projects; achieving the completion of projects on schedule; providing numerous employment opportunities; reducing the incidence of time and cost overruns; allowing clients to make judicious use of project funds and achieving VFM. Therefore, this research recommends that the concept of phased development and fragmentation should be crafted contextually into the project execution mode for all infrastructure projects in engineering and the built environment industry.

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Biographies

Edoghogho Ogbeifun holds a doctorate (2016) in Engineering Management from the University of Johannesburg and MSc (2011) in Project and Construction Management from the University of the Witwatersrand, South Africa. He had his earlier education in Nigeria, obtaining the Higher National Diploma (Structural Engineering) in 1982, postgraduate diploma in Civil Engineering in 1990. He is a registered civil engineer with the Council for the Regulation of Engineering in Nigeria (COREN) and an accredited Facilities Professional (AFP) of the South African Facilities Management Association (SAFMA). Currently, a senior lecturer in the department of Civil Engineering, University of Jos and Research Fellow in the Postgraduate School of Engineering Management, University of Johannesburg. His work experience spans across teaching and research, civil engineering design, project management, construction supervision and maintenance of infrastructure. His research interest includes facilities management, structural stability and building pathology, safety within built facilities and project governance.

Jan Harm Christiaan Pretorius obtained his BSc Hons (Electrotechnics) (1980), MIng (1982) and DIng (1997) degrees in Electrical and Electronic Engineering at the Rand Afrikaans University and an MSc (Laser Engineering and Pulse Power) at the University of St Andrews in Scotland (1989). He worked at the South African Atomic Energy Corporation as a Senior Consulting Engineer for 15 years. He also worked as the Technology Manager at the Satellite Applications Centre He is currently a professor: Postgraduate School of Engineering Management in the Faculty of Engineering and the Built Environment where he worked since 1998. He has co-authored over 240 research papers and supervised 61 PhD and over 270 Master's students. He is a registered professional engineer, professional Measurement and Verification (M&V) practitioner, senior member of the Institute of the IEEE, fellow of the SAIEE and a fellow of the South African Academy of Engineering.

Paper no. 73

The Assessment of General Conditions of Contract for Addressing Rework Issues in New Zealand Construction Projects, Case Study of NZS3910

Ramin Asadi[1], James Olabode Bamidele Rotimi[2] and Suzanne Wilkinson[3]
[1]PhD student, School of Built Environment, Massey University, SH17, Albany, Auckland 0632, E-mail: R.asadi@massey.ac.nz, (Corresponding author)
[2]Asociate Professor, School of Built Environment, Massey University, SH17, Albany, Auckland 0632, E-mail: J.rotimi@massey.ac.nz
[3]Professor, School of Built Environment, Massey University, SH17, Albany, Auckland 0632, E-mail: S.wilkinson@massey.ac.nz

Abstract: Contracts in the construction industry are an essential part of the process that connects pre and post stages of the projects. Evidence shows that the contract documents' terms and conditions do not adequately address part of the critical issues in construction projects. Thus, various aspects of contracts have been studied over the years to address change orders, risks, payments, claims, and safety. This study assessed the conditions of the construction contracts under rework events. The mixed-method utilized in this paper follows various steps to identify and classify rework causes from the literature, establish the relationship between rework and contracts using questionnaire survey, investigate rework provisions in contract clauses through document review and propose a framework that addresses rework by conducting professional interviews. The initial result revealed the common causes of rework in construction projects, and findings from the survey and interview showed relevant clauses of the contract under rework circumstances. The most commonly used standard form of contract in New Zealand has been reviewed as the case study, and findings showed that the general conditions do not adequately address rework issues. Overall, the study identified five rework provisions in clauses of General obligations, Engineer power, Variations, Time for completion, and Defect liabilities. Further discussion with industry professionals through 12 interview sessions resulted in a set of recommendations that provided the basis for contract improvement. Professionals were selected through stratified sampling method based on their experience in construction contracts. A flowchart was developed to cover identified provisions in the contract clauses to address rework that effectively reduces contractual claims and disputes. This paper contributes to the body of knowledge by assessing contract conditions under rework situations. It helps construction practitioners to revise contract clauses during the contract negotiation. The method used in this paper can also be extended to the other standard forms of contract in future studies.

Keywords: construction, contracts, rework, conditions, provisions, clauses.

1. Instruction

Rework is an issue for the construction industry as it happens in all stages of a project and affects the project performance. The more understanding of construction contracts under rework events may prevent cost overruns and delay in projects, resulting in lower contractual claims and disputes. Contracts play a significant role in achieving project goals in the construction industry. How relevant issues in construction projects are addressed in contract conditions is an important part of a professional contract that enhances the project's performance. Previous research show that numbers of factors that affect construction contracts have been studied and various methodologies have been suggested (El-adaway et al., 2016; El-adaway et al., 2017; Assaad et al., 2020; Saseendran et al., 2020; Abdul Nabi et al., 2020). However, rework provisions in the contract have not been evaluated adequately (Mendis et al., 2015). When ambiguity is minimized in the contract conditions, the relationship between the contract parties will be improved (Construction Industry Review Committee, 2001). This improvement leads to higher achievements in terms of project performance. Therefore, in several studies the necessity of changing the conditions

of contract have been advised to improve legal contract frameworks (Chan and Chan, 2017).

Many construction projects are experiencing time and cost overruns in which rework is the main root of these issues (Forcada et al., 2017). Institute of Construction Industry reports shows the average rework cost equal to five percent of total construction cost. Previous studies also have reported the correlation between rework, time and cost overruns (Eze and Idiake, 2018). These evidence results in this statement that, rework issue influences the performance of construction projects. Literature review of rework issues in construction project revealed the main study areas for rework management generally including factors affecting rework, rework causes, the impacts of rework, mitigation models, and reduction or prevention strategies to manage rework issues (Asadi et al., 2021b).

If the causes of rework are identified at early stages, the rework impacts are managed properly. The identification of rework causes requires contract parties to be familiar with the process of rework management. Rework can remain a fundamental problem when there is not enough knowledge about the causes of rework (Ahmed and Naik, 2016). Having enough knowledge about the root causes of rework is the key concept of rework management and it is required for proposing an effective rework reduction strategy (Ye et al., 2015). Few evidences are available within the life cycle of a project to incorporate rework in construction contracts (Asadi et al., 2021a). In other word, not enough is known about relationship between rework and contractual terms for construction projects and that is considered as research knowledge gap. Hence, this paper identifies rework root causes at early stages and then classifies them for further investigation to improve the conditions of contracts by addressing rework issues.

However, rework issues have been studied with different perspectives, the evaluation of contract conditions under rework events has not been explored yet. The contract is a critical step in construction projects to control and manage interactions between parties under various circumstances. The clauses of contracts to address contractual issues and reduce conflicts between contract parties has been studied effectively over the years. Therefore, the contract conditions have been improved under different situations (Seo and Kang, 2020; Assaad et al., 2020). Hence, this research follows the same pattern to address rework related issues in construction contracts, which consequently improves the contract conditions. This study will open this new angle to providing the initial basis for future studies. The relationship between rework and contract can be investigated through the assessment of rework root causes in the clauses of the contracts. The novelty of this research is to provide basis for rework management in the contract documents by searching for these broad questions:

1- Is there any relationship between rework and contract conditions?

2- What are the causes of rework in New Zealand construction contracts, and how could contract conditions be improved in addressing rework to avoid conflicts and disputes.

In this study, the most commonly used contract in New Zealand, known as NZS3910, is assessed as the case study. The result provides frequent recommendations to change the contract conditions for addressing rework issues. The list of recommendations will be used for proposing guidelines to address rework provisions in standard form of contract in New Zealand. The result of this research will contribute to the body of knowledge by practical suggestions for rework management in contracts to achieve higher performance and lower contractual claims and disputes. The study also proposes a framework that shows relevant clauses of the contract which need to be amended under rework events.

2. Research Methodology

The selection of an appropriate research method influences the study's success (Yeung et al., 2007). Research studies generally follow one or a combination of four methodologies: qualitative, quantitative, mixed-method, and review. This study will focus on the causes of rework in construction contracts, to find relationship between rework issues and contractual claims. The aim of study is to assess the construction contract under rework events to address issues that generate contractual claims. By conducting a comprehensive literature review, rework root causes are identified and then through utilizing a systematic literature review, all identified causes are classified liable to both sides of the contract. The common causes of rework in construction contracts then are investigated to find the relationship between rework and contract by conducting a questionnaire survey. The established relationship reveals the relevant clauses of the contract under rework circumstances. The standard form of contract in New Zealand is used in this study to assess the contract provisions that address rework issues. When the relational aspect of rework is identified in the contract conditions, a series of professional interviews are then scheduled to search for solutions and the best practice to address rework. The adopted method for this study is outlined as follows.

Overall, the method used in this study will consist of four steps of (1) literature review, (2) questionnaire design, pilot study and conducting surveys, with (3) the contract document review to find the answers to the research objectives and validate the results of research (4) semi-structured interviews with professionals in the construction contract field in conjunction align with documentary review. Accordingly, the techniques used for data collection and analysis are based on the triangulate system (Johannesson

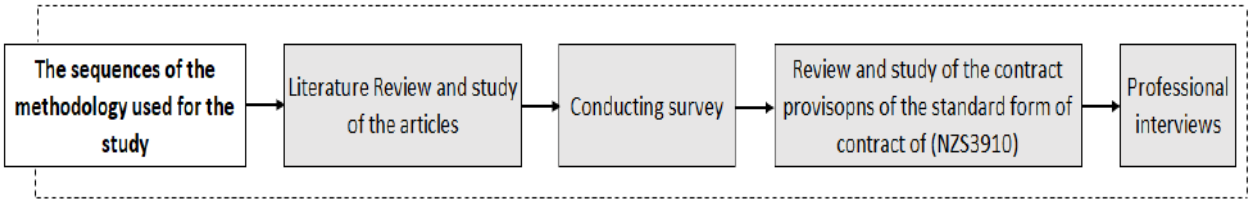

Fig. 1. The adopted methodology used in this study

and Perjons, 2014). The commonly used contract "NZS3910" are assessed to find out which contract provisions can be used as reference for addressing rework. Thus, the study is customized based on the investigated relational aspects of rework in the contract conditions of NZS3910. The initial findings revealed that the contract conditions do not address rework issues adequately. The result suggests some amendments to the contract documents to manage rework better and to promote the performance of projects. The following sections briefly discuss the methodology used in this research study.

2.1. Step1- Literature Review

In the first step of the study, the causes of rework in various project stages were reviewed to provide a comprehensive list of rework root causes. This was started by a comprehensive literature review that revealed the research gaps surrounding rework with potential impacts on construction contracts (Asadi et al., 2021b). The comprehensive list of identified rework root causes can be achieved by searching the published papers. The knowledge gaps for further research are generally attained through literature review (Bao et al., 2018). The literature review also will provide the theoretical framework for conducting research. The process then was completed by a systematic literature review to prepare a comprehensive list of rework causes. The systematic literature review also was used for classifying the identified rework causes. The designed classification model has been adjusted by combining the concepts of previously used classification methods in the literature review and adopted based on current research needs in three levels including liable contract parties, project stages and root cause categories (Robinson et al., 2004; Zhang et al., 2012; Hwang et al., 2019). Literature review identified 37 causes of rework as shown in the classified list in Table 1.

2.2. Step 2- Questionnaire Survey and Pilot Study

In this step, a survey questionnaire is prepared to identify the most significant causes of rework in New Zealand construction contracts. Questionnaire is a technique to collect data which then will be analyzed and interpreted (Johannesson and Perjons, 2014). The questionnaire examined the effect of rework on contractual claims and also measured the conditions of a contract in addressing rework issues. The results of this step validate the identified causes in step one. The most common rework causes in construction contracts were identified by ranking of the survey result. Based on the initial results of the survey a pilot study was performed with a smaller sample of participants. The survey divided into two series of questions. The developed questionnaire was distributed to get the industry's opinion through conducting a pilot study. The pilot study helps quicker step-in to the stage for performing professional interviews. The first series of questions assessed the effects of rework causes in the contract conditions, and the second series asked if rework is addressed adequately in the contract. The pilot study identified the most significant rework causes that generate contractual claims. The second series of questions revealed the relationship between rework and contractual claims. The result of pilot study validated the existence of relationship between the selected contract conditions and the comprehensive list of rework root cause (Asadi et al., 2022). This relationship was further assessed to extract the underlying factors of contractual claims originating from rework as shown in Figure 2. More details about respondents, and method of data analysis is discussed under analysis and results section.

2.3. Step 3- Documentary Review

Due to a large number of the identified rework root causes from the literature review, this study uses exploratory approach through conducting interviews and document analysis with New Zealand construction sector. The contract conditions of NZS3910 were evaluated as part of the document analysis in this study, which provided valid evidence to support survey and then interview results. The documentary analysis completed the questionnaire, and the findings of the literature review were then validated (Gibson and Brown, 2009). The document review on the conditions of NZS3910 was also aligned to the analysis of the collected data from the interviews conducted in the next step. It proposed a flowchart to address rework causes across various clauses of the contract. Numbers of recommendations also were suggested to better administration of the contract.

2.4. Step 4- Professional Interviews

Professional interview is performed in the last step of the research. The aim of interview was to evaluate rework provisions in the contract to validate the results of the previous steps and providing solutions for addressing rework. The interview can be conducted with structured and semi-structured questions or performed in an unstructured way without the sequence of questions (Fellows and Liu, 2015; Johannesson and Perjons, 2014). This study considered semi-structured interview as an appropriate method to achieve expected results. The interview helps to understand more about the problem through opinion of the purposefully selected participants (Creswell, 2016). The interview questions were designed to establish a method to revise the contract conditions. The questions raised from the results of the previous steps, first investigated rework issues in the construction contract and asked for the best approach to reduce it. Then, rework provisions in the contract were explored to find relevant clauses of the contract and further recommendation to improve the contract conditions. A wide range of descriptive information were collected through an open-ended conversation (Patterson and Spreng, 1997). The interviewees were selected based on their expertise in the construction contracts and they were professionals with over an average of 25 years of experience. The interviewees represent various backgrounds, from the client, contractor, and legal entities, including quantity surveyors, architects, contract engineers, lawyers, consultants, and commercial managers, thus the collected data considered to be accurate. In total 12 interviews were performed, and the collected data were analyzed and compared to clauses of NZS3910 obtained from step three. The result of this comparison showed that the current conditions of the contract does not address rework adequately and it revealed relevant contract provisions that need to be revised. The summary of the adopted methodology in this research is briefly shown in Figure 1.

3. Analysis and Results

For conducting systematic literature review three search engines of Scopus, Web of Science "WoS," and Google Scholar were employed for searching rework (Bao et al., 2018; Habibi and Kermanshachi, 2018; Wang et al., 2020). The process resulted in selection of 329 papers from 128 in Scopus, 92 in Web of Science, and 109 in Goggle Scholar.

The selection of more relevant papers will lead to more accurate results. The title of papers was reviewed based on the research scope. None relevant papers were removed and then the abstract of articles was reviewed to select papers for further investigation (Malek and Desai, 2020). Finally, 157 papers were listed for further analysis. The content analysis of the collected papers identified 48 rework causes in design, 15 in tendering and 47 in construction stage of project which then were combined to present a comprehensive list of 37 rework root in liable to both sides of the contract. This paper also proposes a structured classification model of rework causes that includes five main group factors as shown in Table 1. All identified and classified rework causes in this table extracted from the study done by (Asadi et al., 2021a) are considered for the preparation of the questionnaire survey.

For conducting survey, a list of 173 companies was considered for distributing the questionnaire. This list was extracted from Infrastructure New Zealand and Association of Consulting and Engineering in New Zealand "ACENZ" authorities including 133 architects and consultant firms and 40 civil and construction contractors. The questionnaire was sent by email through a provided link. All invited firms were asked to complete the questionnaire if they have contract management experience and use NZS3910 contract for their projects. After one and half month 46 participants completed the survey, a response rate of about 26.58%. This rate is suitable for starting the initial analysis on ranking the causes of rework which is required to design the interview questions. According to (Yap et al., 2017), the sample size between 30 to 500 is adequate for initial analysis in most of the conducted research. The collected data were transferred to the SPSS for performing the required analysis. A more detailed review of the completed

Table 1. The comprehensive list of rework root causes extracted from literature review

Group factor	Rework root causes
Process	P1- Changes, modification and revisions in design / construction changes
	P2- Error in design, drawings and specifications / construction error
	P3- Incomplete design, any omission in the design or construction process
	P4- Inadequate procurement methods / poor contract execution
	P5- Improper contractor and subcontractor selection
	P6- Lack of document control
Human Resources	H1- Lack of experience and personal expertise in design and construction
	H2- Inadequate supervision staff
	H3- Inadequate manpower to complete the task
	H4- Insufficient skilled level manpower
	H5- Poor knowledge of team member, lack of education and training
	H6- Lack of employee motivation and rewards, Carelessness
	H7- Poor workmanship approach and inappropriate personal attitude
	H8- The absence of job security and other safety rules
	H9- Labor reallocation, alteration and staff turnover
	H10- Conflict of interests
Material / Equipment	M1- Defective materials, Non-adherence to material specifications
	M2- Poor-quality material or substandard products / Prefabrication errors
	M3- Replacement or misplacement of material and equipment
	M4- Inefficient equipment use or altered material
	M5- Untimely deliveries of material and equipment
Technical	T1- Ineffective use of quality management practices / deviation due to poor monitoring
	T2- Poor technology application and lack of information technology use
	T3- Poor communication system for coordinating between members
	T4- Inefficient management process, poor site management practice
	T5- Poor project documents, unclear instructions, poor contract documents
	T6- Conflicting and incomplete information
	T7- Inadequate planning and poor scheduling of workload
General / External	G1- Financial issues such as lack of funding, low contract or payment fee, delay in payment and cost pressure
	G2- Lack of client involvement
	G3- Unclear line of authority
	G4- Time pressure, schedule acceleration to finish the task, insufficient time to prepare contract documentation
	G5- Lack of constructability
	G6- Damage / defects / Deviations in the product due to poor handling and safety considerations
	G7- Governmental regulations / changes and policies
	G8- Environmental conditions, poor site condition
	G9- Unpredictable factors from different sources

survey revealed that only 34 respondents answered all questions. Thus, the participants' cumulative response rate dropped to 20% based on 173 distributed and 34 returned surveys. The Relative Importance Index (RII) of each rework cause has been utilized for ranking of rework causes. The results showed that process related factors, technical related factors and human resources factors are more generating contractual claims than other factors. This initial result also showed that the general conditions of NZS3910 do not address the causes of rework adequately as shown in Table 2. This table only shows top 10 addressed causes and the remaining rework causes had score lower than 3.4 as none-addressed items. The mean scores over 3.4 are considered significant items with a Likert scale of 1 to 5. (Beale and Smallwood, 2019). Surveys with a response scale in construction research generally are analysed through ranking the results using either RII (Zanldin, 2020), or frequency analysis through comparing means (Beale and Smallwood, 2019). The survey results to understand which cause is addressed in the contract conditions were analysed using Mean and Standard deviation. The result of the survey conducted for construction contracts to address rework causes in the contract clauses has been summarized in Table 2. Thus, the exploratory approach used in the pilot study revealed the necessity of further empirical investigations to find solutions for contract process improvement.

The survey process was continued and completed by sending 560 links to invited companies with a reminder follow-up email after one month. Over a period of six months, 162 responses (29%) were collected. The response rate was higher than the required ratio for proposing a reliable solution. Statistical analysis based on the achieved rate is reliable (Yap et al., 2020). The analysis of collected data from the survey then followed up trough factor analysis to identify the underlying factors of rework involved in the contractual claim process. The exploratory factor analysis "EFA" method, clustered the correlated rework causes into fewer underlying factors. The result of EFA is shown in Figure 2. Conducted analysis determined that rework management is an appropriate approach for claim handling, with four predictor dimensions as follows: material and equipment, management and planning, human resources, and process. These factors largely explain both rework and contractual claims in construction contracts. These factors can be considered by project managers during the contract negotiation. Taking such approach at the beginning of projects reduces the probability of rework occurrence and prevents contractual claims.

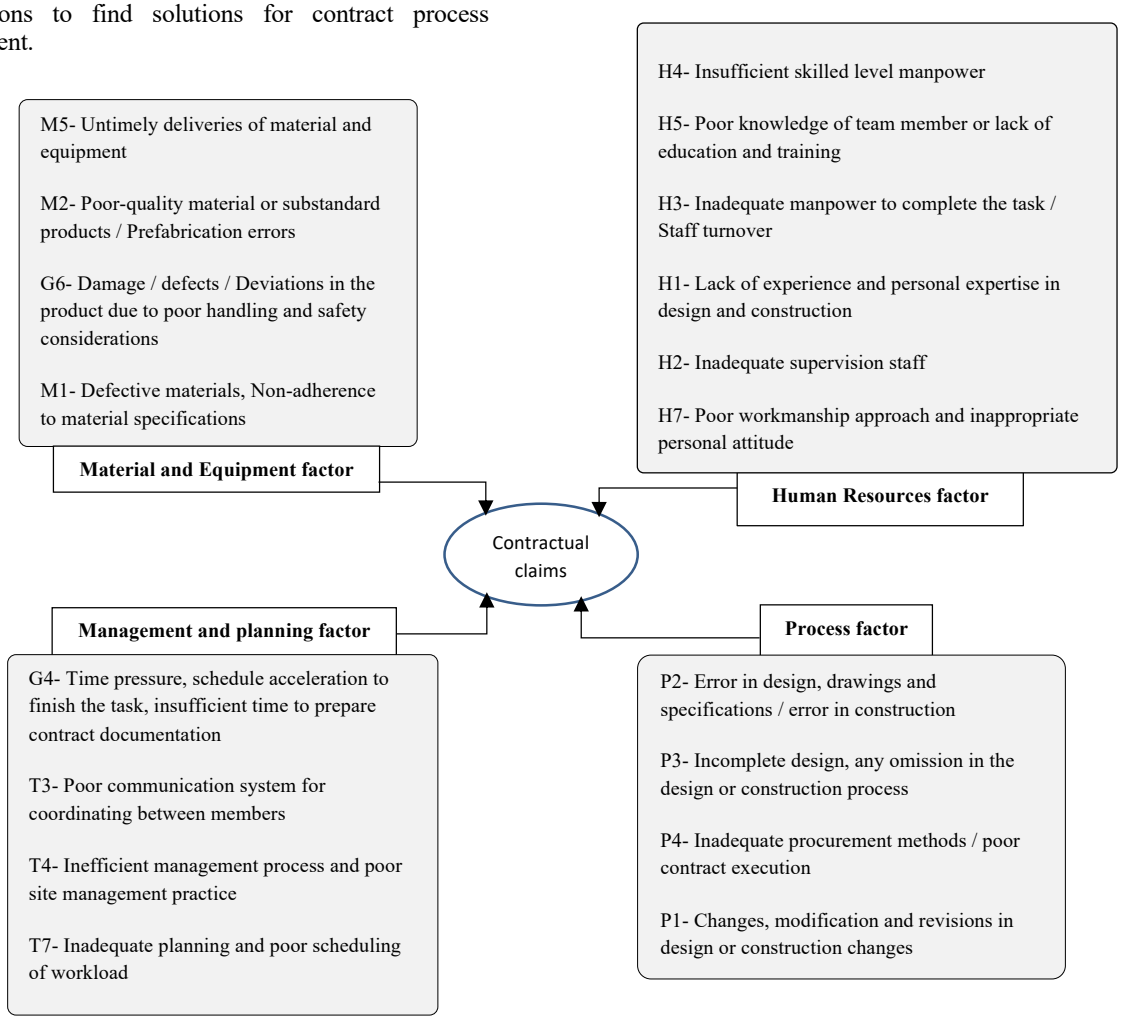

Fig. 2. Identified four underlying factors of rework in generating of contractual claims

Table 2. Addressed causes of rework in NZS3910

Rework cause	Rank	Mean	SD
P1	1	3.83	1.088
P2	3	3.50	1.091
P3	5	3.39	1.085
M1	2	3.55	0.967
M2	4	3.43	1.053
M3	7	3.23	1.125
T6	6	3.23	1.043
G3	8	3.20	0.973
G6	10	3.15	1.032
G8	9	3.20	1.072

For performing interviews, the total of 12 sessions took place and three of the scheduled interviews were canceled. Interviews result with 12 participants reached the theoretical data saturation (Jelodar et al., 2021). Provided answers to the semi-structured questionnaire were recorded and transcribed for further analysis. The first part of interview search answered to the following questions:

Q1- How is rework addressed within clauses of NZS3910?

Q2- Which clauses relate to the causes of rework?

Q3- Do you recommend adding a new clause for covering rework in the contract?

3. This table presents interviewees' opinions on identifying rework provisions in the contract clauses. These provisions are in the following clauses of the contract:

(clause 5) General obligations,

(clause 6) Engineer power,

(clause 9) Variation,

(clause 10) Time for completion, and

(clause 11) Defect liabilities

Solutions for addressing rework issues in the general contract conditions were investigated in the second part of the interviews. The identified rework provisions were explored in more details. The final results of the interview were compared with documentary analysis of NZS3910. After three steps analysis including thematic, conceptual and comparison analysis, the final list of recommendations to improve contract conditions by addressing rework was suggested. This list was then used for providing guidelines to map rework in the contract conditions. The results suggested some amendments to relevant clauses of the contract. This study revealed that NZS3910 does not provide a specific definition for rework in the contract terms, while several clauses of the contract can be referenced to address rework issues. A checklist for addressing rework in NZS3910 was developed as shown in Table 4 and then a framework that shows required amendments to the contract clauses also was provided as shown in Figure 3. More details of recommendations from

Table 3. Identified clauses of NZS3910 in relation to rework provisions

Interviewee	NZS3910 Clause No.	The title of Contract Clause "provisions"
1	6.4 to 6.8 and 11	Engineer Power + DLP
2	6.4 and 9 and 10.3	Test and inspection + EOT + Variation
3	Did not identify	No need
4	6.5	Making Good
5	11.2 and 9 and 10.3	Remedying Defect and its provisions + EOT + Variation
6	5 and 9 and 10.3	Quality of work + EOT + Variation
7	5 and 9 and 11.2	Remedying defects + Variation + General Obligations
8	5 and 6.5 and 11.2	Remedying defects + Making Good + Normal completion
9	6.5 to 6.8 and 9	Making good + Variation
10	6 and 9 and 11	Related to the engineer + Defect Liability + Variation
11	9 and 11 and 13 and 14	Defects liability + Defaults + Variation + Disputes
12	5 and 6 and10 and 11	General Obligations + Engineer Power + EOT + Defects liability

This part of research provided a more practical perspective in respect to the causes of rework. The interview result identified five adequately addressed rework causes in the contract conditions. The results clearly indicated that most of the causes of rework are not addressed adequately in the contract conditions of NZS3910. This means that contract management practice requires improvement under rework events. Responses were based on real cases in practical work. Participants agreed that rework in contract conditions must be referenced. However, most of the participants did not agree to add an extra clause for covering rework issues. The most relevant rework provisions in contract were identified through the performed thematic analysis as shown in Table

the interview stage for addressing rework issues in the contract conditions of NZS3910 have been listed in Table 4. Overall, 16 items are suggested for revising clauses of the contract to address rework, which reduces contractual claims and disputes. Professional interviews showed the current form of contract gaps in addressing rework. This process revealed relevant clauses of the contract. On the other hand, the interviewees' opinion to address rework is used for mapping rework in the contract conditions. Comparing this information resulted in a guideline for improving NZS3910, as shown in Figure 3.

Table 4. List of recommendations to address rework in the clauses of NZS3910

	Suggestions/recommendations to reviewe contract clauses under rework events
1	Check if the contract has an appropriate definition of rework.
2	Does subclauses 5.6.6 deal with the responsibilities regarding loss and damage under rework events? If not, so add appropriate revision to this clause.
3	Check clauses 6 for independently defined obligations of the Engineer. The Engineer must not be employed by either party and it needs to be stated in the contract.
4	Check for the availability of the Engineer's agreement for performing the role.
5	Check clause 6 to see if the method of rework processing is clearly stipulated.
6	Under clause 6.4 add this "The Engineer has to provide evidence for his/her decision regarding determination of rework resulted from inspection".
7	Check how rework is processed under variation clause if it caused by change orders. Clause 9 needs to be reviewed for addressing rework?
8	How unforeseen circumstances is followed up when rework occurs? Check the contract clauses if it places an appropriate procedure for rework processing under such situations.
9	Check if the list of delays under clause 10 cover rework as well. It is important for the cases that the contractor is entitled for an extension of time resulting from rework out of his/her responsibilities.
10	Search conditions for the eligibility of the contractor in time-adjustment when rework occurs.
11	The cost and time effects of rework need to be addressed in the contract.
12	Check if Defect under relevant provisions address rework or not. Look after for processing rework under clause 10.4, specifically for practical completion when there is evidence of rework. If any provision needs changes to address rework, so provide revisions on the contract.
13	Control the alignment of the contract provisions under defect liability period with the time bars in Building Act regulations under clauses 11.
14	Review dispute clause to see how contract parties follow up if conflicts raised from rework. Rework circumstances have to be traced under despite clause.
15	Provide risk register to attach to the contract, so it requires to prepare list of parties obligation during contract negotiation.
16	Provide a guideline to audit the Engineer periodically. When it is required to add such provisions to to the contract, then make revision to the relevant clause.

4. Discussion

Rework causes, and the relationship of rework and contractual claims were used as the main triggers to assess the terms and conditions of the contract. Improving the contract conditions by addressing rework is assumed as an important part of construction management. The contract conditions are improved by answering to this question that how clauses of the contract address contractual issues such as delay, cost overruns, claim and disputes. It is expected that the result of this study bridges the identified knowledge gaps between rework and construction contracts. The initial outcome of the research revealed rework causes which are embedded in contract documents. The systematic literature review results identified rework causes throughout the project's life cycle and proposed a classification model to classify the identified causes in respect to the contract parties. Classification of rework root causes at this level is served as a reliable structure to define a new strategy on rework management in cooperation with the contract.

The outcome of this study is an outline of contracting processes to manage rework by critical analysis of rework causes and relevant contract clauses. The likelihood of rework occurrences can be managed more effectively when project participants are able to check the causes of rework at the time of contracting. Rework management following this mechanism will bring more awareness to the contract parties. The performance of project is also improved when contract parties recognize the benefit of this approach. Evaluation of involved contract clauses in terms of addressing classified rework root causes revealed the relational aspect of rework in the contracts. Amendment to the relational aspects of rework in contract documents improves the construction project outputs such as performance and productivity. Therefore, the study outcomes contribute to the body of knowledge by proposing a framework that suggests revisions to the conditions of New Zealand's standard form of contract. This framework regarding the case study done for NZS3910 is presented in Figure 3. It shows that rework issues are linked to three main categories of Design, Change orders, and Inspections under clauses 5, 6, and 9. Further assessments of clause 9 revealed that rework issues affect the other provisions of the contract. These provisions are under Time for completion "Clause 10", Defect Liability "Clause 11" and Disputes "Clause 13". Addressing rework under these clauses of the contract needs revision, and the list of recommendations in Table 4 helps construction

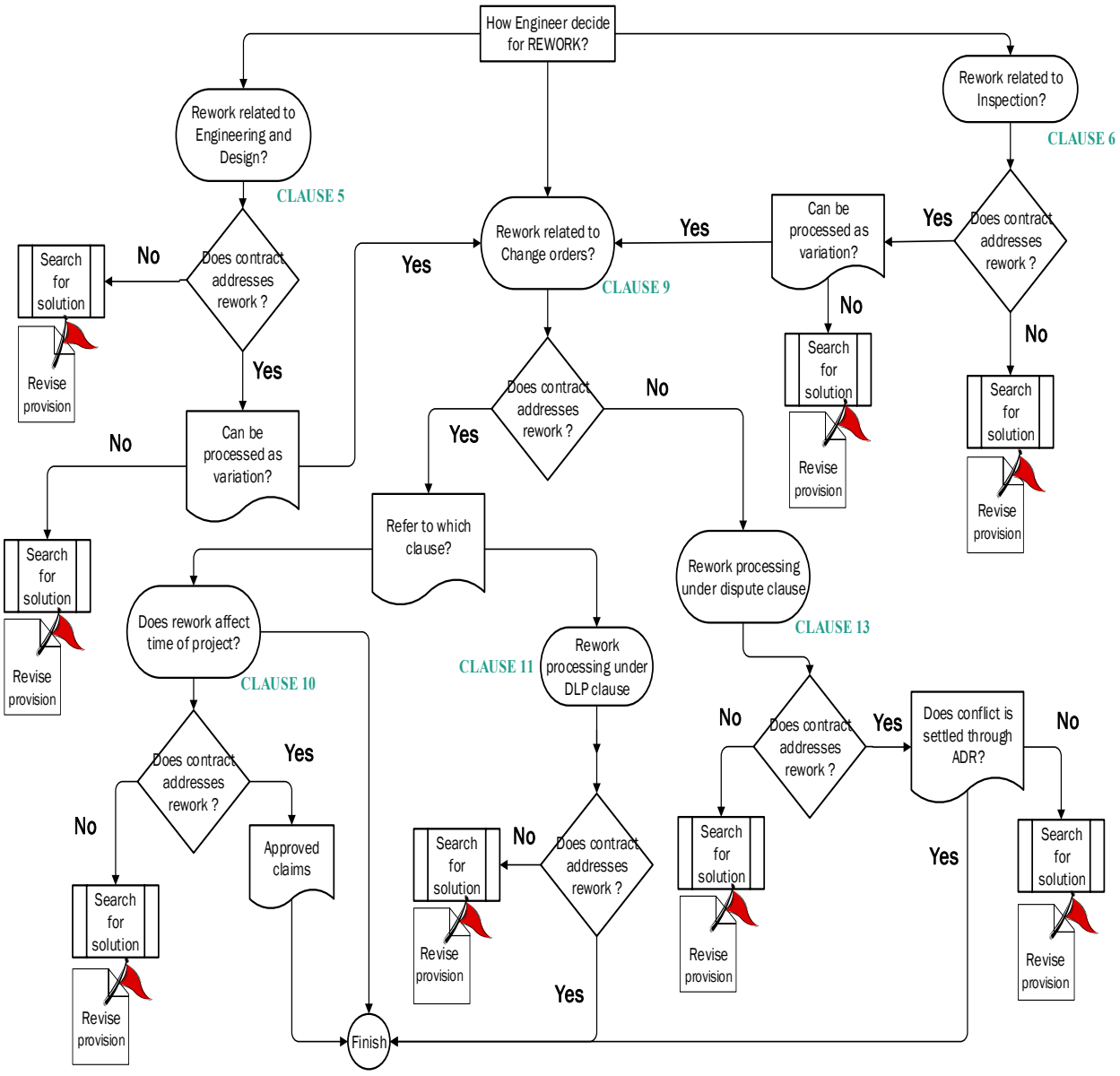

Fig. 3. The flowchart for mapping rework in the contract conditions of NZS3910

practitioners to fill the existing gaps in the contract provisions for covering rework issues.

5. Implications of the study

The theoretical implication of this study are as following:

1- Identified rework causes in NZ contracts
2- Developed concept "rework and contract link"
3- Cover knowledge gap in procurement to address rework

The practical implications can be listed as below:

1- Guidelines to improve contract conditions
2- Checklist during contract preparation
3- Clear responsibility under rework events
4- Reduce contractual claims, conflicts and disputes
5- Make the contract more fit for the purpose

6. Conclusion

Overall, this study provides guidelines for rework management in contract conditions based on the analysis of NZS3910 as the most commonly used contract for construction projects in New Zealand. The research aim was to manage rework through relevant provisions in the conditions of NZS3910 contract, where rework have not been addressed adequately. Addressing rework issues in the contract enhances the overall construction performance by reducing contractual claims and disputes. The result of this study is significant as it influences the success of construction projects. The common causes of rework are linked to contractual claims and on the other side, contractual claims are connected to the contract conditions. This connection has been used to establish the relational aspects of rework into the contract clauses. Thus, rework provisions are identified which then facilitates addressing

rework issues in conditions of the contract. Accordingly, the relevant clauses of the contract can be amended to address rework. Such amendments improve the conditions of the contract by recommendations on the current provisions that refer to rework issues. This study developed a flowchart processing map based on the above-mentioned recommendations. The developed process map also can be used with a checklist to improve the conditions of the contract in terms of rework-related issues. This checklist helps practitioners to fix a clear set of responsibilities during contract preparation. It also removes ambiguity around rework related clauses of the contract. This study is limited to assessing the standard contract form used for construction projects in New Zealand. So the result of the research cannot be generalized to other international contracts. Still, the method used in this study can be duplicated for different types of contracts, such as FIDIC, NES, and standard American forms of contracts.

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Ramin Asadi, Massey University, School of Built Environment, Auckland, New Zealand, Ph.D. in construction management, MBA, membership of NZQS, research interest in contracting management for construction project.

Dr James O. B. Rotimi is an associate professor in the School of Built Environment, Massey University, New Zealand. He is also a visiting associate professor in the School of Construction Economics and Management, University of the Witwatersrand, Johannesburg, South Africa. James has qualifications in Building, Construction Management, Civil Engineering, Commerce and Education. He is a Fellow of the Chartered Institute of Building UK. and holds professional membership of the Royal Institution of Chartered Surveyors, UK, New Zealand Institute of Building, Facilities Management Association of New Zealand and the Nigerian Institute of Building (NIOB). James' research endeavours have focused on improving performance within the construction industry, integrating its supply chain and optimising the achievement of construction and project deliverables. He has over 29 years of tertiary teaching and research experience in academic institutions in Nigeria, UK, South Africa and New Zealand. He also has various building construction industry experiences, including a senior associate role in a quantity surveying consultancy in Nigeria. James publishes extensively within peer-reviewed Journals and conference proceedings and in edited books. He is the Founding Editor of the International Journal of Construction Supply Chain Management IJCSCM (Q3), established in 2011.

Prof. Suzanne Wilkinson, Professor of Construction Management in the New School for Built Environment, Massey University, Auckland. PhD in Construction Management, and a BEng (Hons) in Civil Engineering, both from Oxford Brookes University, UK. Graduate Diploma in Business Studies (Dispute Resolution) from Massey University.

Paper no. 75

Development of a Building Readiness Rating Index for an Outbreak/Pandemic: A Pilot Study

Amna Salman[1], Anoop Sattineni[2], Eric Wetzel[2], Keith Rahn[2] and Jeff Reece[3]
[1]Assistant Professor, McWhorter School of Building Science, Auburn University, USA
[2]Associate Professor, McWhorter School of Building Science, Auburn University, USA
[3]Professor & Department Head, Department of Special Education, Rehabilitation, and Counseling, Auburn University, USA

Abstract: SARS-CoV-2/COVID-19 (Severe Acute Respiratory Syndrome Coronavirus-2/Coronavirus Disease 2019) has impacted the functionality of buildings around the world. Currently, there is no systematic framework or guidelines that can predict a building's level of preparedness against airborne viruses. In this research, through extensive literature review and feedback from medical experts, building performance, and maintenance experts, a list of key indicators to mitigate the spread of airborne viruses in buildings is proposed. However, all key indicators do not hold the same importance and therefore a method is needed to prioritize (weight) them. This study evaluates three different methods to prioritize and weight the indicators i.e. (1) Simo's Procedure, (2) Analytical Hierarchy Process (AHP), and (3) Step-Wise Weight Assessment Ratio Analysis (SWARA). The paper explains each method followed by its pros and cons in relation to the research under consideration. Finally, the paper describes the pilot testing of the selected method. The final weighted indicators from this paper are used to develop a building readiness rating index for the design and construction of future buildings.

Keywords: Outbreaks/Pandemics, Rating system, Multi-criteria decision-making methods

1. Introduction

SARS-CoV-2/COVID-19 (Severe Acute Respiratory Syndrome Coronavirus-2/Coronavirus Disease 2019) has affected all trades in the built environment, but facilities management (FM) divisions were hit the most. Many FM organizations immediately created a "Task Force" to come up with viable solutions (Salman et al., 2022). Many measures were taken, however, most of these measures were reactive measures and their effectiveness is not fully known. We are still not out of the woods as data shows COVID-related deaths, individuals contracting COVID-19 despite the vaccinations, and virus mutation (CDC, 2020). Current research proposes layers of defense in the design and construction of future buildings. Buildings in the post-pandemic era should be designed after close collaboration between the architects, facility managers, mechanical engineers, healthcare professionals, epidemiologists, virologists, and builders (Megahed & Ghoneim, 2020). Currently, there is no systematic framework to guide facility managers for future outbreaks or guidelines for future construction (Salman et al., 2021). Through extensive literature review, feedback from medical experts, and building performance and maintenance experts, a list of key indicators was created to mitigate the spread of an outbreak/airborne virus in future buildings. The comprehensive list of indicators is shown in Table 1.

The indicators do not hold the same importance and a simple checklist does not provide a holistic level of safety of a building. Thus, this paper proposes a multi-criteria-based rating system to assess a building's preparedness against an outbreak/pandemic. There are many kinds of multi-criteria decision-making methods (MCDM) that can quantitatively assess the performance of each stated element and building as a whole (Salman et.al., 2022). The three MCDMs selected were based on their use in the Architecture, Construction, and Engineering (AEC) industry. The three methods are (1) Simo's Procedure, (2) Analytical Hierarchy Process (AHP), and (3) Step-Wise Weight Assessment Ratio Analysis (SWARA). This paper evaluates the pros and cons of each method and selects the SWARA method for this research. Finally, the method is then used in a pilot test of this research.

2. Literature Review

Based on the lessons learned from the COVID-19 pandemic, it is important to understand virus transmission and aerosols behaviors. It is also important to understand the challenges facility managers faced during the pandemic to build safer structures in the future. An extensive literature review,

feedback from medical experts, and building performance and maintenance experts were conducted to identify the indicators that could help in reducing the virus spread in buildings (Table 1). Future design and construction should accommodate all these practices. Due to many indicators not being equally important, it is difficult to determine the level of safety for a building. Therefore, the application of Multi-Criteria Decision Making Models (MCDMs) is proposed in this paper (Chitsaz & Banihabib, 2015) to prioritize the list. Decision-making processes are often complicated due to many conflicting criteria, however, the use of MCDMs can statistically notify the most beneficial criteria (Chitsaz & Banihabib, 2015). Evaluation of different alternatives and making a decision based on their importance depends on the MCDM selected (Yilmaz and Harmancioglu 2010; Yacov and Haimes 2011). This paper lists three MCDMs used in the AEC industry and evaluates the best method to create a readiness index for airborne virus mitigation. The literature review is divided into the following three sections defining the three methods:

- Simos Procedure (also known as the method of cards) (Marzouk et al., 2014).
- AHP Method (tries to identify the relative significance of each element of a decision by comparing each pair of alternatives at every hierarchy level) (Thakkar, 2021).
- SWARA (an algorithm primarily used for determining the relative weights of the criteria to evaluate alternatives) (Akhanova et al., 2020).

In the current research, assigning weights to the indicators is a critical task. The weights of indicators are classified as subjective and objective. For example, indicators H2: Quality of water system provided in the building, may have a subjective weight. Whereas, indicators A6: Pre- or Post-Occupancy Flushing Strategy, will be objective. The subjective weight approach reflects the subjective judgments of an expert, resulting in the ranking of the alternatives to the problem followed by the obtaining of less rigorous values (Yazdani et al., 2016). However, the objective weights are achieved by mathematical methods (Yazdani et al., 2016). The debate in most decision problems is associated with the weight determination of qualitative and quantitative attributes, which sometimes includes errors and mistakes. Only some methods are suitable for criteria evaluation and the listed methods are discussed below.

2.1. Simos Procedure

Simos procedure was proposed by Jean Simos in 1990 to evaluate indicators and is very popular for its convenience and simplicity (Siskos & Tsotsolas, 2015). The main concept of this approach is made up of "play cards'' with each indicator. The decision-maker (DM) has to manage the cards to rank them, inserting the white ones, between equally important indicators. The next step is to ask the user to arrange these cards from the least important to the most important. Therefore, the user arranges it in ascending order according to the importance of the indicator. The first indicator in the ranking is the least important and the last in the ranking is the most important. According to the user's point of view, if indicators have the same importance (the same weight), it must build a subset of cards and introduce white cards between them (Figueira & Roy, 2002). The greater the difference between the weights of the criteria mentioned, greater the number of white cards.

The Simos method consists of the following three steps, concerning the interaction with the DM and the collection of information:

1. The DM is given a set of cards with the name of one indicator on each card. Some white cards are also provided to the DM.
2. The DM is asked to rank the cards/indicators from the least to the most important, by arranging them in ascending order. If multiple indicators have the same importance, she/he should build a subset of cards.
3. The DM is finally asked to introduce white cards between two successive cards if she/he deems that the difference between them is more extensive.

Limitation of Simos Procedure: The literature review has repeatedly criticized the procedure for its lack of robustness related to indicators having the same importance (Figueira & Roy, 2002). In such a situation problems can arise when one or more indicators have identical values among all alternatives. This can lead to no final decision and hence modification of this method is proposed (Agarski et al., 2019).

2.2. Analytical Hierarchy Process (AHP)

AHP tries to identify the relative significance of each element of a decision by comparing each pair of alternatives at every hierarchy level. It is a method for organizing and analyzing complex decisions, using math and psychology (Akhanova et al., 2020). The technique thus examines multiple alternatives and provides the decision-maker with relative priorities of the various considered alternatives (Thakkar, 2021). But since it is based on the participants' preferences, the participant has to input the preference in the calculation. In the last two decades, researchers and practitioners have successfully implemented this technique for a variety of decision making which involves evaluation, benefit-cost analysis, planning and development, priority and ranking, forecasting, and health and related fields (Agarski et al., 2019).

AHP begins with the construction of a decision matrix representing the relative significance of various attributes/indicators relative to each other. For example, in a decision to buy a house A or house B, what is the significance of cost, design of the house, neighborhood culture, schools, etc. for the final decision. The DM is asked to judge the importance of cost in terms of "intensity of importance" like "very important", "more important", etc. This helps a DM to understand the relative priorities of the alternatives and select the one or set of alternatives that rank high in the list (Thakkar, 2021).

Limitation of AHP: AHP is technically not applicable in the current research since it only works in pairs i.e. buying house A versus house B. The current research has several indicators that are assessed simultaneously and thus cannot use the AHP method.

2.3. Stepwise Weight Assessment Ratio Analysis (SWARA)

The SWARA method is the most efficient method for criteria evaluation. It involves recruiting experts followed by the following three steps (Thakkar, 2021):

1. Every expert specifies the priority of each criterion based on his or her implicit knowledge, information, and experience.
2. The decisive factors are ranked from first to last considering the total outcome. The most significant criterion is given rank 1, and the least significant criterion is given rank last.
3. Subsequently, the average value of ranks is considered to determine the overall ranks.

The SWARA method is advantageous because it accommodates the expert's opinion concerning the accuracy of the weighted criteria. Experts can consult and work with each other, which leads to more concrete and accurate results compared to the other MCDM procedures. This method is applicable where priorities are determined based on a set of policies and defined strategies. This method also leads policymakers to make better decisions in wide-ranging situations and prioritize criteria according to the predefined goals and objectives (Thakkar, 2021).

Limitations of SWARA: One of the limitations of SWARA is that although it helps to determine an initial decision matrix, it is sometimes necessary to use other MCDM approaches for evaluating the decision matrix (Zolfani et al., 2018). In such instances, reliability tests are applied to the ranking received from the experts. Kendall's coefficient of concordance test is often used to assess the agreement among the raters.

Table 1. List of indicators

Building systems and strategies to mitigate the spread of an outbreak				
Category	**ID**	**Description**	**Source**	**Reasons**
A. HVAC System				
	A1	MERV 13 or better filters	(Gao et al., 2016; Li et al., 2021; Morawska et al., 2013; Salman et al., 2021; Sodiq et al., 2021; Wang et al., n.d.)	Recommended by ASHRAE.MERV 13 demonstrates at least 50% removal efficiency.
	A2	A system capable of MERV 13		Older equipment does not have the power to use MERV 13.
	A3	Maintain outdoor airflow rates for ventilation		For minimum air recirculation.
	A4	Ultraviolet Germicidal Irradiation (UVGI)		UVGI light can kill or inactivate viral, bacterial, or fungal species.
	A5	Limit re-entry of contaminated air/Damper Position		Open outdoor air dampers beyond minimum settings to reduce or eliminate HVAC air recirculation
	A6	Pre- or Post-Occupancy Flushing Strategy		Flush the space with fresh air before or after occupancy.
	A7	Deposition Method		Deposits that are left behind in a system require removal by the deposition method.
B. Building Design				
	B1	Botanical air filtration systems	(Abdul-Wahab et al., 2015; Afolaranmi et al., 2018; Cui et al., 2014; Gawande et al., 2020; Irga et al., 2017; Kim et al., 2020; Lin et al., 2021; Zhang et al., 2010)	Reduces and removes volatile organic compounds from indoor air
	B2	Indoor Gardens		Improve IAQ-built in design
	B3	Operational Windows		Option of opening them when needed
	B4	Natural ventilation		Through doors, windows, balconies, etc.
	B5	All seating is socially distant		Advised by CDC according to the level of outbreak.
	B6	Signage placement in seating areas, hallways, and elevators		Recommended by CDC
Waste Management	B7	Disconnected drainpipes for waste management		A disconnected drain pipe and exhaust pipe for the toilet should be recommended in the architectural design.
	B8	Efficient exhaust systems for waste management		A disconnected drain pipe and exhaust pipe for the toilet should be recommended in the architectural design.
C. Air Quality and Monitoring				
	C1	Volatile Organic Compounds(VOCs) reduction Methods	(Kannaki et al., 2020; Parkinson et al., 2019; Roskams & Haynes, 2019)	Built-in design strategies or added later on.
	C2	Microbe and mold control		Mold can occur indoor spaces due to many reasons. Mold spores can trigger asthma, headaches, allergies, and other respiratory system disorders.
	C3	Advance/Portable air purifiers		Portable air purifiers can help reduce P.M from the air (as small as P.M 2.5).
	C4	Source Control Strategies		The most effective way of removing pollutants from indoor air is to control the source (Source control tabs).
	C5	IAQ Monitoring		The system will display levels of IAQ

Building systems and strategies to mitigate the spread of an outbreak				
Category	**ID**	**Description**	**Source**	**Reasons**
A. HVAC System				
	C6	Sensors/ IoT system		The sensors will be able to detect threatening levels of IAQ.
	C7	AI/ML/DL system for Building Automation		The system will be able to alert facility managers in case of threatening IAQ levels.
D. Human-Centric Design				
	D1	Touchless Entrances	(Megahed & Ghoneim, 2021;	CDC recommendation to touch minimum surfaces as possible.
	D2	Sound recognition/ face recognition for doors and offices	Salman et al., 2021) & Brainstorming	CDC recommendation to touch minimum surfaces as possible.
	D3	Touchless faucets	sessions with the Research Team	CDC recommendation to touch minimum surfaces as possible.
Mental Health				
	F1	Availability of Greenery and Gardens	(Cui et al., 2014;	Healthy building movement
	F2	Availability of outdoor common spaces	Tokazhanov et al., 2020,	Healthy building movement
	F3	Availability of common indoor spaces maintaining social distancing	Awada et al., 2022)	Healthy building movement
	F4	Availability of port spaces		Healthy building movement
G. Energy Efficiency				
	G1	Building mechanical systems (more than 10 years old)	(Morawska et al., 2020; Salman et al.,	New HVAC units contain technology that allows the system (furnace, air conditioner) to run at optimal energy efficiency
	G2	Regular inspection for leaks in building shells and ducts	2021; Tokazhanov et al., 2020, 2021;	Conduct pressurization tests to locate leaks in buildings and ducts.
	G3	Natural ventilation control system	Department of Energy, 2015)&	The natural ventilation control system can reduce cooling loads by 30%.
	G4	Advanced sensor Promotion of sustainable and alternative energy sources	Brainstorming sessions with the Research Team	Advanced sensor and control systems provide ventilation only where and when it's needed. Use of energy-efficient materials
	G5	Use of energy-efficient appliances		
H. Continuous Building Commissioning				
	H1	Verify HVAC systems are working as designed regularly	(CDC, 2020; Stewart et al., 2020b) & Brainstorming	Regular inspection of the HVAC system by a certified commissioning provider (CxP) or certified testing for serving critical buildings or spaces within buildings
	H2	Quality of water system provided in the building	sessions with the research	Regular inspection by a certified commissioning provider.
	H3	Check for particulate accumulation on filters, replace filter as needed	Team	Regular inspection is needed
	H4	Check ultraviolet lamp, replace bulbs as needed (If applicable)		Regular inspection is needed

3. Research Methodology

The use of the SWARA method is selected for the pilot study which has many advantages in relation to the current research. For example, it has the capability of estimating the experts' opinions in the quantitative form to calculate the final weights. It can gather data from experts, is user-friendly, and is straightforward in its application (Zolfani et al., 2018). This method gives experts a crucial role in evaluating the weights. Furthermore, the SWARA allows policy and DMs to select their priority based on society's current situation, environment, and economy (Akhanova et al., 2020).

Expert Selection: The panel of experts for the SWARA technique included local professionals related to the AEC

industry. The following key factors were used as a guide to select the structure of a panel: expertise in mechanical engineering, experience in preparing buildings during COVID, public health experts, and experience in the AEC industry. The experts are included based on their education, experience, and position. The pilot study presents results from 3 experts.

SWARA Application: This research employed the SWARA technique to establish a weighting system for creating a readiness index for future buildings. The weight given to each category and indicator depends on the expert judgment. In this technique, the criteria are ranked from the first to the last, by assigning the first rank to the most important criterion and the last to the least important. The overall ranks are identified according to the average value of ranks; accordingly, the SWARA technique's main application is defining the criteria weight, as demonstrated in Figure 1.

In Stage One the assessment criteria/indicators are determined. Then, indicators were prioritized by experts based on their importance. Further on, the indicators were sorted in descending order.

In Stage Two the criteria weight is computed and assigned in the following order. The respondent points out the relative importance of indicator j concerning the previous (j-1) indicator, which is done for each indicator, starting from the second indicator. Deduced by the comparative importance of the average value, Sj is determined using the following equation :

$$S_j = \sum_i^n \frac{A_i}{n} \quad (1)$$

Where n expresses the number of experts, Ai means the offered ranks by the experts for each factor, and j stands for the factors.

Then, the coefficient Kj is calculated as follows:

$$k_j = \begin{cases} 1, & j = 1 \\ S_j + 1, & j > 1 \end{cases} \quad (2)$$

The recalculated weight q_j is determined as follows:

$$\boldsymbol{q_j} = \frac{\mathbf{k_j - 1}}{\boldsymbol{k_j}} \quad (3)$$

The relative weights of the evaluation criteria are calculated as:

$$\boldsymbol{W_j} = \frac{\boldsymbol{q_i}}{\sum_{j=1}^{m} \boldsymbol{q_j}} \quad (4)$$

Wj represents the jth indicator's relative weight, and m indicates the total number of the indicators.

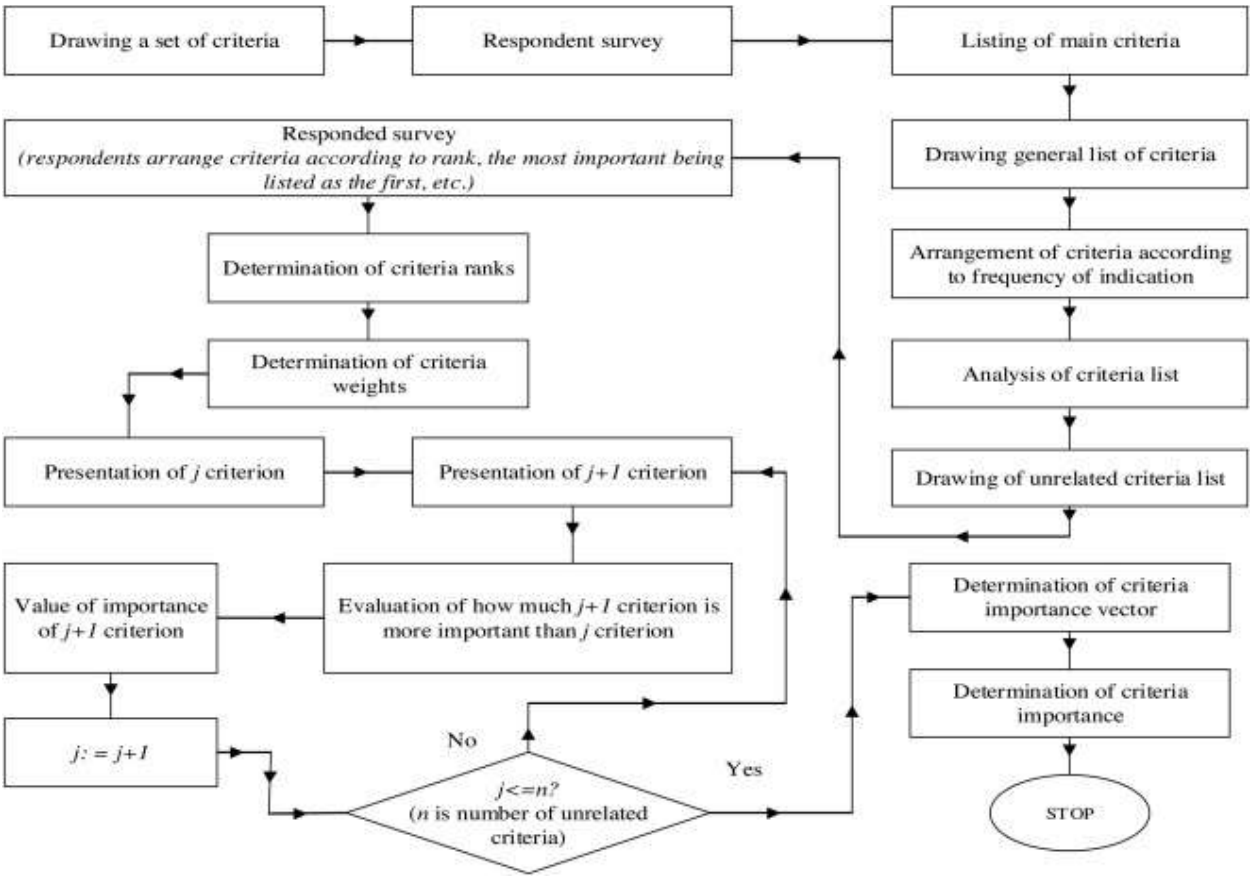

Fig. 2.1. Criteria Identification and Weighting method for SWARA technique (Akhanova et al., 2020)

4. Data Collection

As discussed above, the SWARA method was used to finalize the main indicators. Table 2 shows the main indicators discussed in this study. Table 3 shows the prioritization of criteria by expert knowledge and opinion based on the importance. Table 4 shows the results including the assessment categories and indicators' weights. Only the main indicators were evaluated in the pilot study. Their attributes will be assessed in phase II of the study.

Table 2. Main indicator categories

	Indicators
A	HVAC System
B	Building Design
C	Air Quality and Monitoring
D	Human Centric Design
E	Mental Health
F	Energy Efficiency
G	Continuous Building Commissioning

Table 3. Arranging criteria in descending order

Expert	Criteria ranks values						
n =1…3	*A*	*B*	*C*	*D*	*E*	*F*	*G*
1	1	2	5	3	6	7	4
2	1	3	4	2	5	7	6
3	2	3	4	1	6	7	5
Sum of ranks	4	8	13	6	17	21	15
Average rank value	1.3	2.7	4.3	2.0	5.7	7.0	5.0
Criteria rank	1	3	4	2	6	7	5

Table 4. Final results of SWARA in weighting assessment of indicators

Criterion	Comparative importance of average value s_j	Coefficient $k_j = s_j + 1$	Recalculated weight $w_j = \frac{kj-1}{kj}$	Weight $q_j = \frac{wj}{\Sigma wj}$
A		1	1	0.201
D	1.00	2.0	0.5	0.100
B	1.33	2.3	0.6	0.115
C	2.17	3.2	0.7	0.143
G	2.50	3.5	0.7	0.143
E	2.83	3.8	0.7	0.148
F	3.50	4.5	0.8	0.156
			5.0	1.0

5. Results

The SWARA method is used for weighing each indicator according to expert opinion. The results were acquired using the direct ranking method, the highest is the most important and the lowest is the least important. First, experts identified the most important indicator and then starting from the second indicator gave the relative importance value compared to the previous indicator. This was done for each indicator in the framework. It can be seen in Table 3 that the HVAC system is the most important indicator for mitigating the spread of an outbreak (0.531), followed by Human-Centric Design (0.068). The Building Design category is in third place (0.066) and Air Quality and Monitoring is in 4th place (0.081). The detailed analysis and calculations can be seen in Tables 3 and 4. The study is yet limited to three experts only and results may vary once the detailed study is executed.

5. Conclusion

This paper presents a pilot study of an ongoing research study. The ultimate goal of the study is to create a readiness index that measures the preparedness of a building against an outbreak. A list of indicators was found through literature review and interviews with experts (Salman et al., 2021). This paper aims to evaluate a method to rate the indicators. Three methods were assessed i.e., (1) Simo's Procedure, (2) Analytical Hierarchy Process (AHP), and (3) Step-Wise Weight Assessment Ratio Analysis (SWARA). The SWARA method was selected due to its efficiency in handling uncertainty and simulating human judgment ambiguity. In this pilot study, the main indicators were weighted and their attributes will be evaluated in the next phase of the study. The results show that the HVAC systems are the most important criteria in mitigating the spread of an outbreak in buildings. This is ongoing doctoral research with the ultimate goal of creating a readiness index to measure a building's level of safety against an outbreak. Upon completion, building owners and facility managers will have some guidelines for preparing themselves for future outbreaks/epidemics/pandemics. The list of indicators will continue to expand as technology advances.

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Authors:

Amna Salman is an Assisstant Professor at the McWhorter School of Building Science, Auburn University, USA. She was awarded the prestigious Presidential Scholarship and Associated General Contractors (AGC) Industry Residency Fellowship. Her research interests are improving Indoor Air Quality (IAQ), facilities managemnet, structural analysis, and construction education.

Anoop Satineni is a William A. Hunt Endowed Associate Professor and Executive Programs Chair at the McWhorter School of Building Science, Auburn University, USA. His research interest are information and communication technology, facilities managemnet, and structural analysis.

Eric Wetzel is an Associate Professor at the McWhorter School of Building Science, Auburn University, USA. Dr. Wetzel complete is Doctorate Ddegree in 2016 from Virginia Tech. His reserch inetrest are construction robotics, virtual reality, construction education and project controls.

Keith Rahn is an Associate Professor at the McWhorter School of Building Science, Auburn University, USA. Professor Rahn has a vast expirience in the MEP industry and is a liscensed mechanical contractor. His research interests are building systems and internation construction management.

Jeff Reese is a Professor and the Department Head in the Department of Special Education, Rehabilitation, and Counseling at Auburn University. He is also a licensed psychologist. His research interests are psychotherapy process/outcome, psychotherapy supervision and training, telepsychology, and sport psychology. His current research is focused on investigating the process of client feedback and the use of technology to provide psychological services for underserved populations.

Paper no. 85

A Bibliometric Analysis for Sustainable Development and Digitalization in Construction Industry

Ceren Sahin[1] and Nihan Yildirim[2]
[1]Istanbul Technical University, ITU Ayazağa Campus, Graduate School, Management Division, 34469, Maslak, Istanbul, Turkey, E-mail: sahincere@itu.edu.tr
[2]Istanbul Technical University, ITU Ayazağa Campus, Building of Graduate School, Management Division 34469, Maslak, Istanbul, Turkey, E-mail: yildirimni@itu.edu.tr

Abstract: The construction industry requires effective management among all shareholders and resources because of being a knowledge-based, labour-intensive and virtually organized industry by its planning, design, procurement, post-construction, etc. phases. Sustainability and digitalization are the key strategic orientations of all sectors in our era; hence, these concepts are also on the construction industry's agenda. These two concepts are referred to in many studies which focus on solutions for overcoming the challenge of time, cost, quality, labour and wastage problems. With this intention, this study aims to review the literature on the interfaces of sustainability and digitalization in the construction industry by a bibliometric analysis on 94 papers derived from the Scopus database. In conclusion, initial studies on digitalization and sustainability in construction focus on building information modelling. Since both digitalization and digital transformation and sustainability approaches are relatively new to practice in the industry, they are revealed in limited publications on use cases and applications. However, academic studies accelerated after 2017 in this domain, representing a developing research field.

Keywords: sustainability, digital transformation, construction industry, sustainable development, industry 4.0, bibliometric

1. Introduction

The construction industry is a knowledge based, labor intensive and virtually organized industry (Rezgui et al., 2011). It requires effective communication between all of these, effective and efficient management through the unskilled labor to skilled staff, and productive operation on-site with low waste and high quality and sustainability as the labeled circular economy (Norouzi et al., 2021). This paradigm has its place in today's digitalization and sustainable development world and in the construction industry. The importance of the construction industry is evaluated by being one of the largest sectors of the global economy, so even a small jump may have significant effects (Nikmehr et al., 2021); (Sategna et al., 2019). However, this severity still encounters the high cost, low quality, labour productivity, planning and managerial problems and foremost, poor sustainability, innovation, solution-oriented operations, and lack of successful decision making (David Thelen, 2021). Towards this challenge, many studies reveal that digitalization in the construction industry with a better sustainability perception should be at the strategic direction and vision of the construction companies (Nikmehr et al., 2021). Recently, Chihib et al., (2019) conducted a bibliometric study on building information modelling. Norouzi et al., (2021) also made a scientific evolution analysis of the circular economy in the building and construction sector. Adekunle et al. (2021) also provided a bibliometric review on the construction industry's digital transformation. However, bibliometric studies are relatively rare on the intersections of digitalization and sustainability in literature. De Almeida Barbosa Franco et al., (2022) recently conducted a bibliometric analysis on sustainability in the civil construction sector supported by Industry 4.0 Technologies using VosViewer. Their study is limited with the Industry 4.0 concept, excluding "digitalization" and "digital transformation" keywords. Hence, there is still room for research in the literature review on the interfaces between the sustainability and digitalization in the construction industry, combining digital transformation and Industry 4.0 concepts.

In the light of all, research is designed for contributing the research domain of bibliometric analysis for digitalization and sustainability in construction industry and understanding of digitization, digitalization and digital transformation in construction industry both with sustainability perception. And, this study analyzes and reviews the literature by publication performance, citation analysis, clustering analysis, co-word network and trend topics, co-occurrence networks of the publications covering both sustainability and digitalization concepts in the

construction industry context. We used biblioshiny tool of Bibliometrix package in R (Aria & Cuccurullo, 2017), retrieved on the Scopus database 2013-2022 (February) publications. The first study seen in the literature was in 2013 by Xu et al.. Hence, we used this publication as a milestone providing the start period of the study. Overall study results revealed some dimensions studied in the literature, such as perceptions, applications and imperatives on sustainability and digitalization in construction.

The first section of the study points out the data collection, identification process, and methodology of the review; the following section states the data analysis and descriptives of the bibliometric analysis. The last section remarks on the visualization of the data findings and discussions and conclusions.

2. Data Collection and Methodology of Bibliometric Analysis

For a comprehensive and focused literature analysis, it is assumed that construction industry intensive sustainability and digitalization papers should contain the keywords in their titles, abstracts or keywords. This logic is also tracked in a bibliometric analysis (Zhang et al., 2017). Regarding that, the algorithm in Table 1 was applied when searching the Scopus database. The selection of the boolean (searching sequence/algorithm/wordings) field also analyzed with a literature review background and boolean logic. We used "sustainability" related words as seen in the table for covering sustainability papers in the construction industry as well as capturing the latest and one of the most popular research and institutional topics as sustainable development and sustainable development goals (e.g. Rooshdi et al., (2021)). The main advantage of searching in article title, abstract, and keywords is that this combination gives a focused insight into the research field's main trends. For capturing "construction industry," related words are seen in the table because construction industry, construction project, and construction management terms are the umbrella terms of the industry and captured wider (e.g.Slivkova et al., (2021)). Compassing the subject of "digitalization", we used the terms In table 1. Because the era of digital technologies and digital transformation are used in papers and industry 4.0, and in early studies "digitization", too. (e.g. Vite & Morbiducci, (2021)).

Table 1. Boolean logic selection and justification in the searching of the unit of analysis in Scopus

SEARCH WITHIN (Unit of Analysis)	SEARCH DOCUMENTS (with Boolean Logic)	Document Type
ARTICLE TITLE - ABSTRACT - KEYWORDS	sustainability OR "sustainable development" OR "sustainable construction"	ALL
ARTICLE TITLE - ABSTRACT - KEYWORDS	"construction industry" OR "construction project" OR "construction management"	ALL
ARTICLE TITLE - ABSTRACT - KEYWORDS	digitalization OR "digital transformation" OR digitization OR "industry 4.0"	ALL

After applying the search rationale and retrieving the data from the Scopus database with the logic seen above, overall refinements and creation of eligible data are listed and used in Table 2 as our sample space for the bibliometric analysis. The sustainability and digitalization subject field in the construction industry is relatively niche in the literature as revealed by previous studies. Identifying the literature gap identified, we selected eligible data as it is, to see all the efforts in the literature with 94 papers retrieved.

Table 2. Eligible data creation with justification

Characteristics	Data selection
Year	ALL (2013-upto 2022)
Subject Area	ALL
Publication Stage	ALL (Final or Article in Press)
Search Results	94 papers
Refinement	94 papers
Justification	to capture all recent efforts in the literature and to see the progress no publication type and year refinement applied from 2013 to 2022 first quarter.

As Scopus is one of the most common databases that stores the latest and most influential publications, it provides a user-friendly search environment and the selected analysis tool R, "bibliometrix" package, "biblioshiny" web interface. The retrieved dataset comprises the applicable content for the analysis such as titles, keywords, abstracts, publications, references, etc. This interface is also a pathfinder for analyzing and displaying the emerging research fields regarding to co-occurrence, co-citations, three-fields plot, source impact and dynamics and country dynamics, etc..

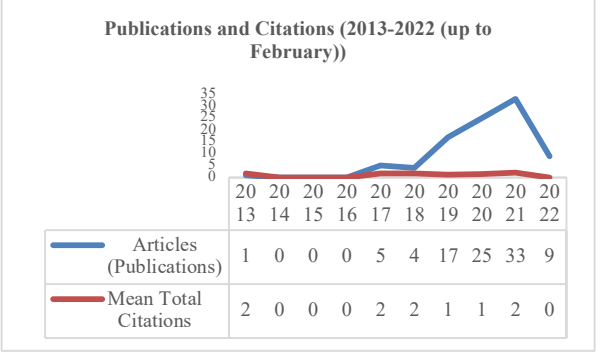

Fig. 1. Publications and Citations in Each Year of 2013-2022

In Fig. ***1*** the overall search results for 94 papers are seen yearly with the total citations per year. According to the graph, 2013 was the first year of sustainability and digitalisation-related terms started to be spoken together in the construction industry. There was 3-year gap from 2014

to 2016 where no publication produced with the subjected terms seen together. After 2019, the publications acclereated, more than doubling (2,35 times) the production volume.

3. Finding and Data Analysis

3.1 Main information of studies and overview of descriptives

Table 3 represents the main description about overall data for 94 documents and 57 different sources retrieved, starting from 2013 to 2022 February containing articles, books and reviews from 57 different sources.

Table 3. Main information about the data (for Documents: 94; Sources: 57, from: 2013 to 2022 February.)

Description	Results
MAIN INFORMATION ABOUT DATA	
Timespan	2013:2022
Sources (Journals, Books, etc)	57.00
Documents	94.00
Average years from publication	1.96
Average citations per documents	3.07
Average citations per year per doc	0.95
References	3,764.00
DOCUMENT TYPES	
Article	32.00
Book chapter	6.00
Conference paper	39.00
Conference review	9.00
Review	8.00
DOCUMENT CONTENTS	
Keywords Plus (ID)	554.00
Author's Keywords (DE)	287.00

3.1.1 Overall Citation Analysis Results from Sources

The most cited reference clustering was figured out based on the local citation score as the reasons briefly defined in the study of Chung (2007). The parameters used; sources as unit of analysis; in the coupling measured by references; local citation score as impact measure; keyword plus as cluster labelling in all sources with a 1% minimum cluster frequency, since the number of units (sample size) are relatively small (Gao et al., 2021). Screening Fig. ***2***, the most-cited sources between the selected years, are mapped as there built a core for the sustainable digitalization in the construction industry. The sources have centrality in their impact measure together. Sustainability-related sources are dominant within the field, and frequently these sources rank digitalization studies.

Table 4 lists the top 5 references used in the construction industry's digital transformation and sustainability studies. Since these three keywords are newly prominent in the research, citation counts are relatively low. The most used reference is the journal article of Oesterreich & Teuteberg (2016). This study was an early Industry 4.0 paper analysing the literature and identifying the technologies for Industry 4.0 in construction industry, distilling the most frequent terms as of that time and constructs, and applying their own PESTEL analysis through different case studies. The earliest paper seen in the reference's table was produced in 1997. It was about the digitized design and calculations of sustainable construction materials and proposed bamboo because of its texture and mechanical characteristics.

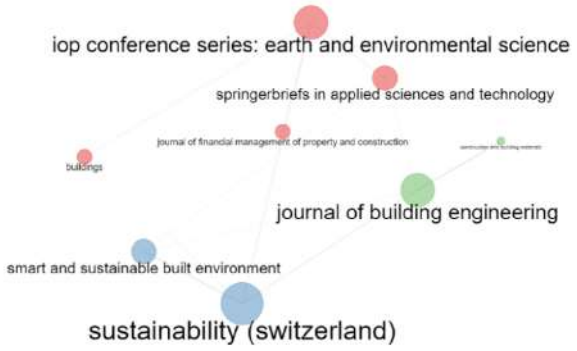

Fig. 2. Full Picture of Most-Cited References between 2013-2022

Table 4. Top 5 References in the context of Sustainable Digital Transformation in Construction Industry Studies (listed according to the top cited).

Document Type	Author/Editor	Year	Source
Journal Paper	Oesterreich and Teuteberg	2016	Computers In Industry
Journal Paper	Alaloul and Zawawi	2016	Alexandria Engineering Journal
Journal Paper	Amada et al	1997	Composites Part B: Engineering
Journal Paper	Azhar and Brown	2009	International Journal Of Construction Education And Research
Journal Paper	Blismas et al	2009	Construction Innovation

3.2 Most-Cited Journals

To clarify the quality of the papers, the citation indexes are informative, as indicated in bibliometric studies such as Zhang et al (2017)'s study. To enlighten, the top most cited journals are analyzed as in Fig. ***3***. It shows that sustainability and digital transformation-related research in the construction industry are attracted to the field. The list

emphasizes that there is a rising awareness among scholars. Automation in Construction, one of the most influential journals in the construction industry, has the most-cited studies in the field, paying the most attention to the new developments and research trends in the construction industry as sustainability and digital technologies. The sustainability and construction materials-themed journals indicate that the recent developments in the new era have effectiveness in the construction management field. The digital technologies-themed journals such as "Sensors" also have a powerful landing for the scholars of the construction management field.

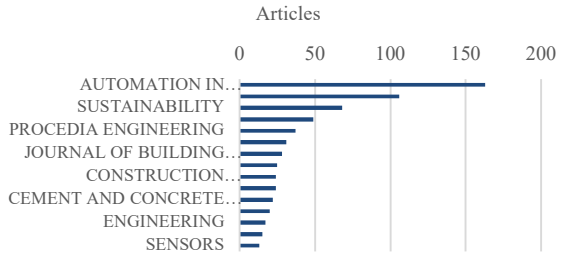

Fig. 3. Most-Cited Sources

3.3 Co-word Network of Keywords

The co-occurrence network of keywords is a powerful content analysis technique used in research to conceptualize and visualize the structure of the most spoken research areas and groups (Zhang et al., 2017). Indicating this map, we used the Co-occurrence network of the conceptual structure of Biblioshiny visualization, R bibliometrix package. Since this is a niche field, we consider selecting 50 keywords to see the individual conversations in and in between groups. We chose the association technique for normalization algorithm since many scholars revealed that the association algorithm is a probabilistic method that best represents a probabilistic based co-occurrence network, providing a powerful support (Van Eck & Waltman, 2009).

Fig. ***4*** shows the dominant subjects of sustainability and digital technologies in the construction industry field. For that analysis, "sustainable development" and "construction industry" are mostly spoken in the field, and a strong relationship between sustainable development and the construction industry is seen. Within that group, there is a sub-group related to the digital technologies separately, such as 3d printers, the internet of things etc. with embedded systems. Climate change, environmental sustainability, and life-cycle analysis are the subjects closest to sustainable development. The "environmental technology" is a confounding area that scholars are using the term, related to both sustainable development and industry 4.0 technologies. Another implication is that instead of the term "sustainability" which seems more popular to most fields, "sustainable construction" has a stronger link. The second outstanding cluster is "architectural design" with building information modelling. The digital devices are linked to "information management" related subjects within that group. It is also implied that the environmental impact, energy efficiency and utilization of the construction projects link to building information modelling in the project management context.

There are two mini-groups within these two dominated ones. The first one is mostly around digital technologies, digital transformation in the built environment, and the closest relationship between the two main groups. The other one is mostly around building materials and intelligent buildings.

Fig. ***5***, below shows the annual growth of the words used in the field. According to the yearly graph based on the cumulative usage of the keywords, the construction industry and sustainable development are discrepantly most used keywords starting from 2018. There is also a dominance of architectural design and Building Information Modelling – BIM with Building Information Model, was on the stage since the beginning, 2013. Recently there are also, industry 4.0 and digital transformation spoken in the researches with environmental impact and sustainability.

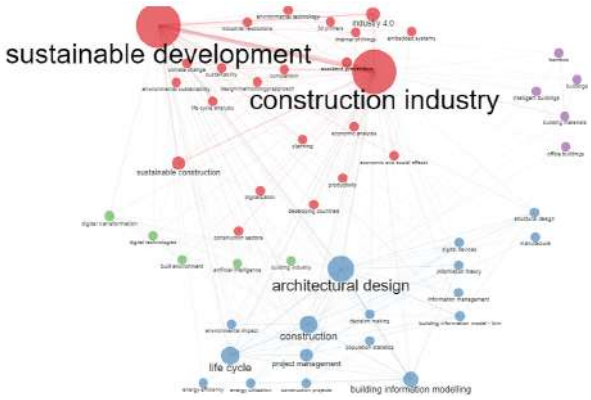

Fig. 4. Co-Word Network of Top 50 Keywords in sustainability and digital technologies research in the construction industry.

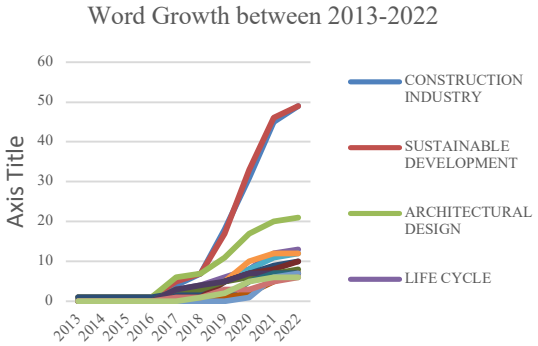

Fig. 5. Top most used words and their growths per year in the field

In Table 5, the centrality values of the most co-occurred keywords are listed. Regarding this, the dominance of the sustainable development and construction industry has highlighted values as seen in the co-occurrence network figure.

3.4 Research Topics of Recent Studies

Fig. ***6*** shows the trend topics from starting the sustainability and digital technologies in the construction industry field. There are recent trends in sustainability-related subjects and around building information that is ultimately used for digital transformation in the construction industry. There also seems offsite construction in the abstracts, which is also researching digitalization in the supplemental construction activities such as warehousing, inventory and logistics. The cost estimation effect in the field was a trend at the beginning of the field; however, it waned as time passed. Sustainable development, sustainable development goals, green construction, and environmental sustainability are still trending and finding their places in the field in the construction sector as a whole.

Table 5. Conceptual Structure Analysis of Top 15 Co-Occurred Keywords

Node	Cluster	Betweenness	Closeness	Page Rank
sustainable development	1	478.59	0.02	0.15
construction industry	1	424.71	0.02	0.15
architectural design	2	51.18	0.01	0.07
construction	2	19.27	0.01	0.04
building information modelling	2	8.29	0.01	0.04
industry 4.0	1	6.13	0.01	0.03
project management	2	6.08	0.01	0.03
life cycle	2	4.82	0.01	0.04
digital transformation	3	3.03	0.01	0.02
construction projects	2	2.50	0.01	0.02
sustainable construction	1	2.41	0.01	0.03
decision making	2	1.39	0.01	0.02
digital technologies	3	0.83	0.01	0.02
building materials	4	0.81	0.01	0.02
environmental impact	2	0.69	0.01	0.02

Table 6 is a comprehensive grouping of the publications by their authors, publication time slice and contributions to the sustainable and digitalized construction industry literature. Papers are grouped as Digital Transformation and Sustainability General Concepts, Requirements of digitalization & sustainability, Sustainable Development Goals and digital transformation, Sustainable and Digital Technologies and Construction Materials, Trends in Sustainability and Digitalization of Construction Industry as an output of the intensive analysis of the papers.

There are 27 papers in the field on “Digital Transformation and Sustainability General Concepts”. The dominant focus is on BIM-related studies in the field, starting from 2017 with sustainability and digital transformation keywords. One of those is the study of having the highest total citation score (32) in this subject group focuses on the general concepts of BIM and general system concepts and layouts by the mean of facility management (Araszkiewicz, 2017). It adverts sustainability as practising innovative and sustainable digital solutions in BIM by solving sustainability requirements. Rahmayanti et al. (2019) is another most cited publication in this subject group that focuses on sustainable urban development in the built environment. It reveals the harmfulness of the construction activities to the environment and how this damaged environment can be recovered with digital and sustainable solutions (Rahmayanti et al., 2019).

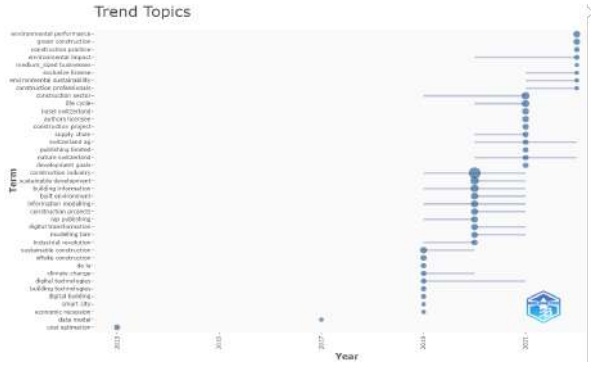

Fig. 6. Trend Topics in the abstract fields from 2013 to 2022, produced from biblioshiny.

The study of Fokaides et al. (2020) puts front the energy efficiency assessment methodologies through BIM and digital solutions (Fokaides et al., 2020). It also summarizes the Sustainable Development Goals' general concepts. Going through yearly top-cited papers, highlighting the importance of cloud computing and BIM implementation in the construction industry by studying Nigerian cases (Oke et al., 2021). Through questionnaires and literature reviews, they listed and verified the benefits of cloud computing and digitalized solutions in the construction industry in sustainability (Oke et al., 2021). For the general concepts and digital transformation, there seems to be a study leap most recently, in 2022. Currently the integration of BIM in the industry with sustainable and digitalized solutions (Quevedo-Martínez et al., 2022), green construction adoptions by energy management and waste management have been published. Sustainable development goals are also the current studies’ core as pointed out by Orzeł & Wolniak (2022). Safety and risk in sustainability and digitalization are still the most spoken subjects (Tender et al., 2022). Decision and information support studies (Grishkina et al., 2022) are on the current subjects.

Subject group of “Sustainable and digital technologies and construction materials” has the wood and robotic study by Aagard and Larsen (2020), bamboo and building element studies by Lorenzo et al. (2020) and Setiyowati & Mappaturi (2020), safety and robotic rechnologies by Zhu et al, (2020), digital twin technologies (Teisserenc & Sepasgozar, 2021), IoT with sustainability studies (Turner et al., 2021), blockchain in construction industry (Balasubramanian et al., 2021), sustainability and digital innovation approaches in construction industry (Dalla Valle, 2021a)(Dalla Valle, 2021b); (Adeosun & Oke, 2022) and 3D printing production for sustainability and

digitalization in construction industry (Amran et al., 2022) are the technologies in construction industry for sustainability.

Table 7 groups the research papers by their contribution to the sustainable and digital construction industry field. 33 papers propose a design, on-site construction activities and management methodologies, 22 papers put out for policymaking, framework development, strategy setting and decision-making for the construction practitioners, and 9 papers' scholars reviewed the literature well and highlighted the general field descriptives.

Table 6. Contribution of the papers in sustainable and digital construction industry research field.

Contribution Subject Group of Publication	Paper #	Major contributions and research topics of publications in sustainable, digital construction industry
Digital Transformation and Sustainability General Concepts	27	Smart Facility Management and BIM implementations (Araszkiewicz, 2017); BIM and drivers and barriers in the industry (Dubas & Pasławski, 2017), (Olanrewaju et al., 2021), (Keogh & Smallwood, 2021); Digital Technologies, BIM and sustainability strategies (Meuer et al., 2019); Energy efficiency assessment methodologies with BIM (Fokaides et al., 2020); Sustainability assessment and BIM (Hadi Ahamad et al., 2020); Sustainability and digital transformation of the industry through BIM (Nölle, 2020); Operational management and BIM crossing in the industry (Dmitry et al., 2021); Green BIM approaches (Dalla Valle, 2021a); Sustainability and BIM integration for digital transformation (Marzouk et al., 2021); BIM implementation and integration (Quevedo-Martínez et al., 2022); Digital technologies with BIM approaches (Santiago, 2022); Information support systems (Grishkina et al., 2022); Additive layer technologies (Medici & Codarin, 2018); Digital twin and sustainable technologies (Mêda et al., 2021); Cloud Computing in construction industries (Oke et al., 2021); Smart city and sustainable city concepts (Rahmayanti et al., 2019), (Safiullin et al., 2019); Construction management, planning and innovation concepts (Giraldo & Palacio, 2020), (Gusakova & Pavlov, 2020); (Morozova et al., 2020); (Yevu et al., 2022); Quantity surveying approaches in digitalization and sustainable construction (Tunji-Olayeni et al., 2019); Digital construction delivery methods for sustainability (Knutt, 2020); Safety and Risk approaches in sustainable and digitalized construction industry (Tender et al., 2022); Sustainable development (Handryant et al., 2020); Green construction approaches (Owusu-Manu et al., 2022).
Sustainable and Digital Technologies and Construction Materials	15	Woodwork and robotic technologies (Aagaard & Larsen, 2020); Prototyping in housing industry (Tahmasebinia et al., 2020); Bamboo and building element technologies (Lorenzo et al., (2020a/2020b), (Setiyowati & Mappaturi, 2020), Safety and robotics technologies (Zhu et al., 2020); Optimization for circular economy in construction industry (Parigi, 2021); Augmented Reality technologies in construction industry (Oke & Arowoiya, 2021); Digital twin technologies in construction industry with BIM and sustainability (Benjamin Teisserenc & Sepasgozar, 2021), (B Teisserenc & Sepasgozar, 2021a); IoT in construction industry (Turner et al., 2021); Blockchain in construction industry (Balasubramanian et al., 2021); Sustainability and digital innovation approaches in the construction industry (Dalla Valle, 2021b), (Adeosun & Oke, 2022) 3D printing production for sustainability and digitalization in construction industry (Amran et al., 2022).
Trends in Sustainability and	5	Novice business model developing, planning and construction management implementations in sustainable and digitalized construction industry (Ghosh et al., 2021), (Alaloul et al., 2018)

Digitalization of Construction Industry		Novice circular production and construction 4.0 trends (Nagy et al., 2021), (Norouzi et al., 2021).
Sustainable Development Goals and digital transformation	9	Sustainable Development Goal Achievement Studies with Digitalization in construction industry (Esetova et al, 2019); (Ryzhkova & Ginzburg, 2020); (Lekan et al., 2020); (Vite & Morbiducci, 2021); (Ebekozien et al., 2021); (Yousif et al., 2021), (Weber-Lewerenz, 2021); (Rooshdi et al., 2021); (Orzeł & Wolniak, 2022).
Requirements of digitalization & sustainability	8	Optimization and BIM implementation requirements in the industry (Iyer-Raniga, 2019), (Gautam et al., 2018); Skill requirements for construction professionals for digitalization and sustainability (Akyazi et al., 2020); (Ginigaddara et al., 2021); (Al Amri et al., 2021); Interdisciplinary work requirements in construction industry practitioners (Andersson & Eidenskog, 2020); Safety and hazardous status detection and requirements for sustainable digital construction (Slivkova et al., 2021); Digitalization and sustainability requirements for strategy implementations (Nikmehr et al., 2021).

Table 7. Major methodology of publications to industry in sustainable, digital construction industry

Contribution to Industry	**Paper #**	**Major methodology of publications in sustainable, digital construction industry**
Design, Construction methodology, Management	33	Dubas and Paslawski, (2017); (Araszkiewicz, 2017), Medici and Codarin, (2018); Gusakova and Pavlov, (2020); Fokaides et al, (2020); Hadi et al, (2020); Giraldo and Palacio, (2020); Handryant et al, (2020); Mêda et al, (2021); Dmitry et al, (2021); Oke et al, (2021); Dalla, (2021); Quevedo-Martínez et al, (2022); Owusu-Manu et al, (2022); Grishkina et al, (2022); Tender et al, (2022); Santiago, (2022); Iyer-Raniga, (2019); Vite and Morbiducci, (2021); Ebekozien et al, (2021); Orzel and Wolniak, (2022); Aagaard and Larsen, (2020); Tahmasebinia et al, (2020); Lorenzo and Mimendi, (2020); Setiyowati and Mappaturi, (2020); Lorenzo et al, (2020); Zhu et al, (2020); Parigi, (2021); Oke and Arowoiya, (2021); Amran et al, (2022); Adeosun and Oke, (2022); Olanrewaju et al, (2021); Nagy et al, (2021)
Policy Making & Framework & Strategy Setting & Decision Making	22	Meuer et al, (2019); Nölle, (2020); Morozova et al, (2020); Knutt, (2020); Keogh and Smallwood, (2021); Marzouk et al, (2021); Yevu et al, (2022); Pavan et al, (2019); Akyazi et al, (2020); Slivkova et al, (2021); Nikmehr et al, (2021); Ginigaddara et al, (2021); Esetova et al, (2019); Ryzhkova and Ginzburg, (2020); Lekan et al, (2020); Weber-Lewerenz, (2021); Rooshdi et al, (2021); Teisserenc and Sepasgozar, (2021); Teisserenc and Sepasgozar, (2021); Turner et al, (2021); Balasubramanian et al, (2021); Dalla, (2021)
Literature Review	9	Rahmayanti et al, (2019); Tunji-Olayeni et al, (2019); Safiullin et al, (2019); Andersson and Eidenskog, (2020); Al et al, (2021); Yousif et al, (2021); Alaloul et al, (2018); (Norouzi et al., 2021), Ghosh et al, (2021).

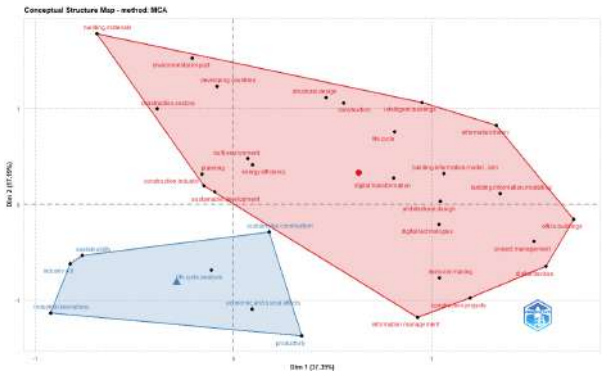

Fig. 7. Conceptual structure map with Multiple Correspondence Analysis of Keywords on sustainability and digitalization in construction industry research.

Fig. *7* represents the conceptual structure mapping based on keywords as the unit of analysis with the multiple correspondence analysis (MCA) executed by biblioshiny. Selecting keywords as the unit of analysis is for visualizing the common concepts in the field as many scholars also use (Huang et al., 2021). The reason for choosing MCA is encountering the dimensionality problems and clustering and hierarchical category purposes for the most common concepts (Greenacre & Blasius, 2007). MCA is an extension of correspondence analysis, which is based on an explanatory multivariate technique, categorizes the data based on their numerical analysis and allows for analyzing the pattern in the data (Abdi & Valentin, 2007). For an unsupervised learning algorithm, the number of clusters wasn't set manually and remained as automatic and top 30 terms were searched within the documents. Conceptual structure has a superiority because it shows the connections, themes, topics and trends contented in the research documents. Seen in the figure, digital transformation and sustainability are spoken widely in the construction industry. Building information modelling and sustainable development has an importance in the field while there is also decision-making approaches and project management principles. The second cluster mostly on the life-cycle analysis and productivity as well as sustainable construction and industry 4.0 norms.

For a deeper analysis of the major research topics and contribution subjects, 64 papers are labeled for focused understanding. Scimago 2020 ranking list was used, and publications (Journal, Conference paper, Book) with top h indexes were filtered. All qualified publications were read firstly by their titles and abstracts and then by full text. Rests were analyzed just by their abstracts, titles and keywords.

3.5 Cross-Country Comparisons

Analyzing the country contributions of corresponding authors gives the results based on both intra-country (SCP) and also inter-country (MCP) article counts (Aria & Cuccurullo, 2017). The sustainability and digitalization in the construction industry field produce the researches mainly from Australia, Italy and Malaysia in the top three and Spain and the United Kingdom following them as seen in Fig. ***8***.

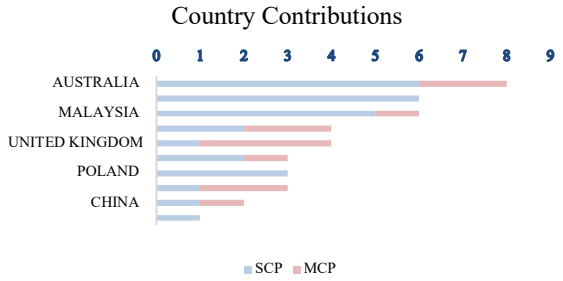

Fig. 8. Country contribution clusters of papers.

Based on the "association" normalization technique (because of its probabilistic measurement calculations, Van Eck & Waltman (2009) and Louvain clustering algorithm (because of it has a superiority by covering most of the data over the samples (Šubelj et al., 2016). Fig. ***9*** lists the most occurred keywords. Not surprisingly, the term "construction industry" and "sustainable development" have been studies farly ahead of the "architectural design", "life cycle", "industry 4.0", "building information modelling" and "sustainable construction".

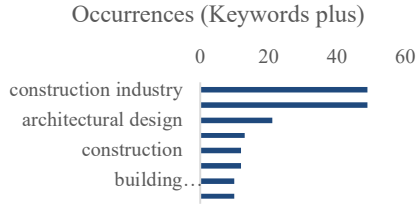

Fig. 9. Keyword occurrences in the publications.

Table 8 lists the total keyword usages grouped by their concepts (digitalization, sustainability or construction industry, as well as the general concepts and strategies). Not surprisingly, for indicating the digitalization, scholars are mainly using the term "industry 4.0", building information modelling and digital transformation. This output was also initially resulted in the study of Xu et al., (2013) as mentioned above also. The term "digitalization" is rather less used to indicate that it is not in the list of descending order. For indicating the construction industry, as seen in the table, the "construction industry", "construction", and "project management" are the most used ones. Under the sustainability concept, "sustainable development", "life cycle", and "sustainable construction" are the top three keywords of which are used by scholars in the field. There are other keywords of which are indicating the building design, materials and procurement and also other general concepts and strategies which there primarily express "economic and social effects", "planning" and "productivity". These results also show the importance of planning and productivity in the construction industry.

Fig. ***10*** shows the word cloud based on the most frequent occurrences, as Lantz (2015) suggested. It was generated via biblioshiny package with top 50 keywords. The dominance of building information modelling, industry 4.0, life cycle, and sustainable construction is seen in the literature after using the term "architectural design". Another implication of the word cloud is digital

transformation, information theory, and digital technologies, which are the developing subjects in the field.

Table 8: Total number of keywords, grouped by their concepts (>5 occurrences shown in the table, values are for total, written in descending order).

Concepts	Keywords (Occurrences (> 5))	# of keyword usage
digitalization	industry 4 0, building information modelling, building information model - bim, digital transformation, digital technologies, information theory	209
construction management & industry	construction industry, construction, project management, construction projects, construction sectors	197
sustainability	sustainable development, life cycle, sustainable construction, environmental impact, sustainability, energy efficiency	184
design & building materials & procurement	architectural design, structural design, building materials	161
general concepts & strategies	economic and social effects, planning, productivity	109

Fig. 10. Word-cloud based on keyword plus of data, word occurrences calculated by most frequency

Fig. ***11*** is the thematic map of the data by their density and centrality in the field. Visualized by biblioshiny, thematic mapping is a sociogram of Social Network Analysis (SNA) (Wasserman & Faust, 1994). It shows the concepts and interconnections in a network graph (Chen et al., 2011). Density, and development degree is the strength of the internal ties among all keywords in the research theme and centrality (Xiao et al., 2022). It is the number of links occurrences within each node (Wasserman & Faust, 1994) and is found by the number of links divided by the total possible number of links in the environment. Every node is interconnected. Relevance degree is the external ties strength to other themes by author's keywords (Pryke, 2012). Motor themes in the upper right corner, which indicate high density and strong centrality, are the well-developed and essential themes of the field. These are environmental impact, structural design, and building materials, and the results indicate that developing countries are studied in the field.

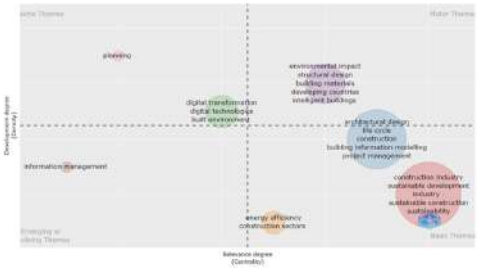

Fig. 11. Thematic map and themes by their density and centrality with the spread of the themes.

Niche themes in the upper left indicate well-developed internal ties but not vital external ties in the field (Xiao et al., 2022). These are digital transformation, digital technologies and built environment close to the motor themes and planning in the most corner position. For the sustainability and digitalization in the construction industry, it seems planning is not a vital pioneer however it was spoken in the field and has not grown at all. The ones close to motor themes find their places in the field and are prominently studied by scholars. The lower left quadrant is the emerging or declining theme in the field with lower centrality and density in the sustainability and digitalization in the construction research field. This is only information management in this study which shows that it was a short-time fad in the literature then sentenced to decline or evolve to another concept in the field indicating the same manner. Basic themes are crucial for sustainability and digitalization in the construction industry but not well developed. They require a comprehensive and continuous incline in the field, with high density and low centrality degrees. These are the construction industry, sustainable development, sustainable construction, architectural design (which is in the centre between motor and basic themes), life cycle, building information modelling, and project management. On the left-hand side of the quadrant, close to the declining themes, there are energy efficiency studies indicating the industry with the term "construction industry. These clusters show a strong relationship between the construction industry and sustainability, too.

Biblioshiny enables the thematic evolution mapping by the sub-themes of the time slices. There are primary and niche themes around building information modelling and architectural design. The building information modelling studies primarily study the life cycle and structural design and the paradigm of information theory. The ISO standard (ISO 19650) for building information modelling seems as entered in the field.

4. Discussion and Conclusions

As construction industry requires effective management with highly collaborative information-based and workmanship focused virtually organized approaches. To

succeed this, digitalization is one of the key strategic activities proven in all industries with use cases, on-site case scenarios, academic research and public, private partnerships, and construction as seen in the papers that there are limited publications. This specifies also the limitations of this paper that there are limited case studies in the total paper collection (94 papers) and another limitation is by conducting the analysis on Scopus database with the concepts identified in the boolean logic (digitalization, digital transformation, digitization, industry 4.0, sustainability, sustainable development, sustainable construction) and other concepts are out of this study limits.

Success in effective construction management can decrease wastages, and a sustainability strategy can be well managed and applied. This study presents a literature review by bibliometric analysis with various techniques to show this intention. A total of 94 papers searching for sustainability-related terms and digitalization related terms in the construction industry were analyzed from 2013 to 2022. Since both digitalization and digital transformation and sustainability approaches are relatively new to practice in the industry, academic studies are also small in quantity. The acceleration of publications by 2017 reveals that sustainability and digitalization are developing research fields in the construction industry.

Results show that Australia is the top country among the all-collaborated and contributed scientific productions (with a 15.38% rate). However, as a developing country, Malaysia has also an increasing trend in the last years. In terms of the total number of publications, Malaysia (38), Australia (28) and Italy (20) are the top three countries. Results show that both developing and developed countries rank the sustainability and digitalization subjects. Studies have been published primarily on construction industry-related sources. They are clustering around the environmental impacts and material, manufacturing processes and modelling with strategic approaches and digital technologies in the field.

The Co-citation network of references revealed that “Automation in Construction” citations are at the core of the field and create dominance in the network. Co-word network of the keywords shows the most used terms for an indication as “sustainable development” and “construction industry” as the most burst keywords in the field. And these two words are used together in the literature with “Industry 4.0” and “Sustainable construction”. Sustainability related terms are settled around “sustainable development” as referred above and sustainability, energy efficiency, life cycle analysis, and sustainable construction. “Digital technologies” and related technology names also appear in the studies with “building information modelling”. Those form another group and are used in the literature mostly together. There have been building materials-related studies that are forming another study group altogether. By grouping the keyword occurrences based on their concepts, digitalization, construction management and sustainability studies are the most frequent ones.

In recent years, as adverted above, “sustainable development” has been used widely to refer the sustainability studies in the construction industry. The steady increase in “building information modelling” studies, Industry 4.0 and digital transformation research continues. “Environmental performance” and “green construction” are seen recently together with “sustainable development” and “sustainable development goals”, “building information modelling”. There produced digital transformation and sustainability general concept studies and sustainable and digital technologies research primarily related to design, construction methodology and management, and policymaking & framework & strategy setting and decision-making studies.

Consequently, outputs of the paper imply that the construction industry has a rising trend in producing digital transformation and sustainable development studies. And analyzing the conceptual structures, the subject results have revealed that there is digitalization application in construction industry by occuring an evolution from digitization to digitalization and sustainability to sustainable development in the industry. Building information modelling has taken its place in the construction industry for encountering digital solutions, and sustainable development has been taking its place for sustainable attempts. However, for statistically generalizability, eventually there needs further and more studies in this field. In further studies, authors' co-citation and co-occurrence analysis can be explored. Case studies can also be added to the keyword for including qualitative studies.

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Ceren Sahin - Istanbul Technical University (ITU), Management Engineering Department, Ayazaga Campus, Istanbul. She is studying Management Engineering with digitalization, machine learning, sustainability and construction management domain.

Nihan Yildirim – Istanbul Technical University (ITU), Management Engineering Department, Ayazaga Campus, Istanbul. She is Associate Professor in ITU, has many researches in management, management and organization, production management, management of enterprises, entrepreneurship and

innovation management and social sciences and humanities. She is also participated in various management consultancy projects. She is participating and board member of many organizations such as ITU Center for Social Innovation.

Paper no. 87

The Potential of Concrete 3D Printing in Construction

Joshua Gilmore[1], Katharina Crafford[2] and John Smallwood[3]
[1,2,3]Department of Construction Management, Nelson Mandela University, South Africa, E-mail: john.smallwood@mandela.ac.za

Abstract: The construction industry requires higher productivity, reduced wastage, and enhanced quality. Additive manufacturing, known as 3D printing, in this case, concrete 3D printing, has the potential to contribute to performance improvement compared to other construction methods. The construction industry has always had an issue with conventional in-situ concrete and masonry methods, which result in excessive concrete and masonry waste, slow progress, time-overruns, and quality non-conformances. Given the issues of conventional concrete and masonry and the advent of Industry 4.0, a study was conducted to determine the potential of concrete 3D printing to resolve the issues of poor productivity, wastage, and quality non-conformances. The qualitative method was adopted, and data was collected through semi-structured interviews conducted with professionals involved with concrete 3D printing and conventional construction expertise based in Dubai, Thailand, and The Netherlands. Findings include the potential of concrete 3D printing to solve conventional concrete and masonry issues through increased construction speed, reducing of labor-intensive activities, automation, and the achievement of quality walls. Conclusions include the need to implement concrete 3D printing to improve cost, quality, and time overruns. Recommendations include: a designer shift to 'designing for concrete 3D printing', investment in developing concrete 3D printing expertise and plant and equipment; re-training of concrete crews; inclusion of concrete 3D printing in tertiary built environment education programs, and 3D concrete printing continuing professional development (CPD). The paper will contribute to the related body of knowledge due to the limited amount of concrete 3D printing-related research conducted in the construction industry.

Keywords: 3D Printing, Concrete, Construction, Quality, Wastage.

1. Introduction

The world's population is increasing by 200 000 a day. This rapid population increase has escalated the demand for housing, putting pressure on the construction industry to evolve faster, more effective delivery methods that are also more environmentally friendly and cost-efficient (Maskuriy et al., 2019). With all these simultaneous, competing objectives, there is a real need to advance innovative technologies.

Currently, structures are primarily built using concrete, with over 20 billion tons being used per annum worldwide. However, the construction industry is beset with poor productivity, a high level of accidents on sites, quality non-conformances, high levels of waste and pollution, cost blow-outs, and a scarcity of skilled workers (Sanjayan, 2018).

The emergence of technological innovations, such as 3D printing, has offered possible solutions to this problem during recent years. 3D printers use digital programs to process the specifications of a project and create 3D objects. In addition to enhancing the typical construction process, this technology allows for creating various geometric shapes that would be difficult to construct using conventional concrete construction methods (Balletti et al., 2017).

The world's first 3D printed commercial building was created in Dubai within seventeen days. Furthermore, the use of 3D printing required 50% less labour and generated 60% less waste than conventional methods of construction would have (Kaddoura, 2010; Alexander, 2020).

While there are significant plant and setup costs, the material prices of 3D printing are relatively low compared to conventional, site mixed or ready-mixed concrete (Balletti et al., 2017). This, combined with the gains observed by Kaddoura (2020) and Alexander (2020), indicates that 3D printing is a promising field of exploration for the construction industry.

There is a paucity of 3D printing-related literature as 3D printing is still a relatively new form of construction, and therefore, to date, limited research has been conducted.

2. Aim and objectives

The study reported on aimed to examine the extent to which concrete and masonry conventional construction methods result in cost, quality, and time overruns, and concrete 3D printing's potential to minimise these. The objectives of the study are to:

- Determine why construction sites experience concrete and masonry wastage:
    - Determine why concrete and masonry wastage occur on construction sites using conventional masonry and in-situ concrete construction methods, and
    - Determine the potential of 3D printing to mitigate concrete and masonry wastage compared to using conventional masonry and in-situ concrete construction methods.
- Determine why construction sites experience slow progress and time-overruns:
    - Determine why the progress on construction sites is slow and time overruns occur using conventional masonry and in-situ concrete construction methods, and
    - Determine the potential of 3D printing to accelerate construction progress and eliminate time-overruns compared to using conventional masonry and in-situ concrete construction methods, and
- Determine why construction sites experience quality non-conformances:
    - Determine why quality non-conformances occur on construction sites using conventional masonry and in-situ concrete construction methods, and
    - Determine the potential of 3D printing to mitigate quality non-conformances compared to using conventional masonry and in-situ concrete construction methods.

3. Review of the Literature

3.1. The potential of concrete 3D printing to mitigate wastage arising from conventional in-situ concrete and masonry construction methods

Wastage arising from conventional in-situ concrete construction is mostly mitigated through concrete 3D printing due to the need for less labour, and precise concrete placing. Concrete as a material is well suited for 3D printing as it has low production costs, high durability, and high thermal resistance. Furthermore, such printing does not require formwork to mould and shape the concrete. Concrete 3D printing's precise nature of placing allows for little to no concrete wastage, and the quantity of concrete, mixed and printed, is precisely measured. It uses fewer materials, produces less waste, and mitigates the need for rework and its associated wastage (Paul et al., 2010; Skitmore, 2015). Labour and supervision can be replaced by the design and construction phase of 3D printing as it is integrated and managed by a digital fabrication supervisor for the design and construction (Hossain et al., 2020).

3D printing can contribute to resolving the challenges related to monitoring and control, including cost control, and communication on projects relative to in-situ concrete and masonry construction as this form of automation does not require intensive management and supervision (Schober and Hoff, 2016).

3.2. The potential of concrete 3D printing to accelerate the construction process and eliminate time-overruns on conventional construction sites

3D printing allows for an increase in construction speed and the maintenance of a consistent pace, contrasting with conventional construction methods, where workers require breaks, and concrete requires curing between pours (Skitmore, 2015). It would accelerate the construction process by allowing for a layer-by-layer deposition of in-situ concrete (Skitmore, 2015). In contrast, Hossain et al. (2020) found that this form of additive manufacturing of concrete allowed for a layer-on-layer extrusion of concrete without the need for the conventional method of using formwork, which enables saving of time.

Each site project that uses a concrete 3D printer would have diverse needs uniquely programmed into the machine. The programming results in additional costs and time. Skitmore found that the machine would print in the outside environment, and often require regular downtime to clean and maintain (Skitmore, 2015).

Concrete 3D printing does not require any significant time for curing while printing, the only time needed for a 3D printer is the initial start-up time. After that, the 3D printer will print concrete at a constant rate, allowing the lower layers to cure enough to support the new layer (Skitmore, 2015).

The implementation of 3D printing reduces the number of labourers required on-site resulting in a small labour team. Every site has unique implications in terms of setting up a 3D printer, however, once the 3D printer is set up on a site, it can start printing immediately, thus reducing the lead time for setting up the printer (Skitmore, 2015).

3.3. The potential of concrete 3D printing to mitigate conventional masonry and in-situ concrete quality non-conformances

Hoffman et al. (2020) state that a 3D printer automatically regulates the fresh concrete mix, intended to be in actual time, and it will change the rate at which the concrete flows and the overall speed at which it prints. Furthermore, this form of automation creates a method of printing quality walls without stopping or creating voids or holes.

Concrete mix consistency is crucial for a structure's quality when 3D printing, and therefore, it requires continuous monitoring. A slight increase in concrete viscosity leads to the overall quality and extrusion of concrete being affected. A few methods can be implemented to ensure that viscosity conforms mixing and producing concrete at a constant rate; using small concrete batches, and protecting the concrete batches from extreme moisture loss (Hoffmann et al.,2020).

Li et al. (2020) state that voids in concrete prints are due to the layer-by-layer extrusion of concrete without concrete vibration as in conventional methods. Voids influence the concrete's strength; however, these voids are reduced through the pump's pressure during the extrusion process. The voids are associated with the print quality and the pump pressure, which will determine the strength of printed objects. Therefore, the print quality can be characterised by the surface quality, dimension steadiness, and binding quality of the printer's concrete material. These characteristics depend on the freshness of the materials and printing restrictions.

Moelichet et al. (2020) state that concrete prints are exposed to environmental factors such as temperature, wind, and humidity, unlike conventional methods in which concrete is initially protected by formwork. These environmental factors control water evaporation and accelerate hydration's reaction rate, resulting in quality non-conformances.

Ortega et al. (2020) determined that once a print is completed, it must go through a quality control protocol to ensure that the quality complies with the required standard.

An important issue is that currently there are no design standards for 3D printed concrete structures (Diks, 2019).

4. Methodology

4.1. Research Approach

The research was conducted with a combination of inductive and deductive approaches. Semi-structured interviews were used to collect qualitative data across a cross-sectional time horizon regarding the common causes of conventional concrete and masonry wastage, slow progress, time overruns, quality non-conformances, and the potential of concrete 3D printing to minimise these. Qualitative data was selected to understand conventional concrete and masonry, and concrete 3D printing.

4.2. Population and Sample

The study population consisted of four professionals involved with concrete 3D printing with knowledge of conventional construction methods – based in Dubai (civil engineer), The Netherlands (two interns), and Thailand (researcher). Homogenous purposive sampling was used to recognise and select participants for interviews due to the population's requirements. Given that the study was conducted during the Covid-19 pandemic, it was challenging to conduct interviews, even online.

4.3. Thematic Analysis

Thematic analysis is a qualitative data analysis method used to search for themes or patterns throughout the data. Thematic analysis entails a researcher coding their qualitative data to recognise themes or patterns to further investigate their research. Thematic analysis allows for detailed descriptions, explanations, and theorising (Saunders et al., 2019). All transcripts were coded into the main themes and sub-themes by grouping themes related to each objective. Initial coding was conducted to find common themes from which six themes and eighteen sub-themes were chosen to be further examined. Each transcript was re-coded, keeping in mind the themes and sub-themes, to characterise all important data. The most important extracts of the interviews for each main theme and sub-theme were then analysed.

5. Findings

The thematic analysis produced three themes and five main sub-themes from the participants for the potential for concrete 3D printing.

The identified sub-themes are the following:

- Costs related to the:
    - Advantages of the 3D printing process, and
    - Labour advantages of 3D printing.
- Time related to the advantages of the 3D printing process, and
- Quality related to the:
    - Advantages of the 3D printing process, and
    - Quality monitoring.

5.1. Potential of Concrete 3d Printing to Mitigate Concrete and Masonry Wastage

5.1.1. Advantages of the 3D printing process

The process of 3D printing was one of the advantages to mitigate concrete and masonry wastage identified by the interviewed participants. As reported by the participants interviewed, it is worth mentioning that these advantages were related to additive fabrication, material optimisation, complex geometries, and mitigation of conventional installations. Participants 2 and 3 referred to additive fabrication and the effect it had on minimal wastage of concrete. Participant 1 underscored participant 2's and 3's cited advantages with additive fabrication and referred to the use of additive manufacturing. Furthermore, participants 2 and 3 referred to material optimisation and hollow shape and their effect on concrete material usage compared to conventional construction. Participant 4 underscored participant 2's and 3's cited advantages with material optimisation and referred to 3D printing of walls.

Participants 2 and 3 referred to complex geometries and multiple shapes and the effect they had on mitigating masonry wastage. Participant 4 underscored participant 2's and 3's cited advantages of multiple shapes and referred to the shape optimisation of walls.

Participants 1 and 4 cited eliminating formworks in terms of realising cost savings. The participants' comments correlated with the literature review. Paul et al. (2018) and Skitmore (2015) found that 3D printing delivered precise concrete placing, thereby mitigating unforeseen wastage and that 3D concrete printing can print multiple shapes eliminating the need for formwork. Furthermore, they found that a 3D printer's precise nature of additive fabrication enabled this technique to generate little to no concrete wastage. The method used fewer materials and produced less wastage.

These findings were evident in the participants' statements recorded verbatim below:

- "…starting a new element so you will always have a waste but in kg and not in tons like in conventional construction." (Participant 2 and 3);
- "…mostly hollow on the inside, so it has been optimised to the point where you only need the bare minimum of material use compared to conventional methods." (Participant 2 and 3);
- "This is because of how a 3D printer is setup and we are able to print very complex large shapes." (Participant 2 and 3);
- "…you do not need formwork." (Participant 4);
- "…if you to print something unusual, yeah, it's in that case you will spend much much more material for such type of wall and in that case it will be more reasonable to use concrete printing." (Participant 4);

- "You can also optimise form by Optimising the shape of the walls and save." (Participant 4);
- "…benefit of 3D printing building, that we can make some reductions of the formwork" (Participant 1), and
- "3D printing to reduce the risk more than the traditional because it's the additive manufacturing." (Participant 1).

5.1.2. Labour advantages of 3D printing

The labour used relative to concrete 3D printing was one of the advantages to mitigate concrete and masonry wastage identified by the interviewed participants. As reported by the participants interviewed the advantages were related to automation, minimal labour, and mitigating of poor organisation and communication. Participants 2, 3 and 4 referred to the minimal amount of labour required and its effect on reducing concrete and masonry wastage. Participant 1 underscored participant 2's and 3's cited advantage in the form of minimal labour and referred to the shortages of labour experienced in the industry.

Participants 2 and 3 added a valid point, namely the automation aspect of 3D printing, which has the effect of reducing concrete and masonry wastage.

Participant 4 underscored participant 2's and 3's cited advantage of automation and referred to the mitigation of poor organisation and communication.

The participants' comments correlated with the literature review. Hossain et al. (2010) found that the design was programmed and transferred into the 3D printer to print. In doing this, the labour required relative to conventional construction were replaced with the process of 3D printing. Schober & Hoff (2016) found that 3D printing automation did not require much communication and mitigated poor organisation. Furthermore, Paul et al. (2018) and Skitmore (2015) found that 3D printing minimised the need for manual labour.

These findings were evident in the participants' comments recorded verbatim below:

- "…we have only minimum amount of labour." (Participant 2 and 3);
- "…using a 3D printing, is that we almost have it fully automated." (Participant 2 and 3);
- "…you reduce the human factor." (Participant 4);
- "…you reduce the mistakes of supervisors in the case the concrete as you need only two people or maybe three people to control a printer." (Participant 4), and
- "…we can reduce the problems of labour shortages." (Participant 1).

5.2. Potential of Concrete 3D Printing to Accelerate the Construction Process and Eliminate Time-Overruns

5.2.1. Advantages of the 3D printing process

3D printing was one of the advantages of accelerating the construction process and eliminating time-overruns identified by the interviewed participants. As reported by the participants interviewed, the advantages were related to labour, construction speed, and process. Participants 2 and 3 referred to construction speed and the effect it had on the acceleration of the construction process. Participant 4 underscored participant 2's and 3's cited advantage of construction speed and referred to the constant rate of printing. Furthermore, participant 1 underscored participant 2's and 3's cited advantage of construction speed and referred to controlling the printer's speed. Participants 2 and 3 added the advantage of additive manufacturing eliminating formwork and saving time.

Participant 4 referred to the construction process and installation time and its effect on eliminating time overruns. Participant 1 underscored participant 4's cited advantage related to the installation time and referred to a 3D printer's setup time.

Participant 4 referred to the process and the minimal amount of labour required, and the advantage of accelerating the construction process and eliminating time overruns.

Participants 2 and 3 maintained the completed programmed geometry had an advantage in accelerating the construction process and eliminated time overruns. The participants' comments correlated with the literature review. Skitmore (2015) found that 3D printing allowed for increased construction speed and maintenance of a consistent pace, contrasting with conventional construction methods, where workers required breaks. Hossain et al. (2020) found that this form of additive manufacturing allowed for a layer-on-layer extrusion of concrete without the need for conventional methods of using formwork, which saved time. Skitmore (2015) stated that 3D printing would accelerate the construction process by allowing for a layer-by-layer deposition of in-situ concrete.

Furthermore, Skitmore (2015) found that concrete 3D printing only needed time for the initial start-up and then printed concrete at a constant rate. The implementation of 3D printing would reduce the number of labourers required on-site and only require a small labour team. Skitmore (2015) also found that once a structure was programmed, it would start printing immediately, thus reducing the lead time for setting up the printer.

These findings were evident in the participants' statements recorded verbatim below:

- "…pumping which is moving as fast as it can." (Participant 2 and 3);
- "We don't work this way but if we received a geometry in the morning and after discussion, then by mid-day we can start printing. This is the ideal situation as we usually take 2 to 3 weeks then we start working." (Participant 2 and 3);
- "There is no formwork to be considered." (Participant 2 and 3);
- "…you can print for 24 hours and print and night." (Participant 4);
- *"...like I said in our case we need to install it differently this time is for the installation." (Participant 4);*
- *"3D printer can work like 15 hours with no problem only and you only need 2 people and*

make 2 shifts, which you only need 4 people for the shifts in total." (Participant 4);

- *"We can make the speed faster." (Participant 1), and*
- *"So 10 square meter. One square meter. We can make only 20 minutes for the 3D printing. Sorry I have to calculate this as well. So, it's taken about two hundred minutes for the 3D printing. Yeah. But if you include the set-up time, let's say 4 hours. About 4 hours." (Participant 1).*

5.3. Potential of Concrete 3D Printing to Mitigate Concrete and Masonry Non-Conformances

5.3.1. Advantages of the 3D printing process

The 3D printing process was one of the advantages of mitigating concrete and masonry non-conformances identified by the interviewed participants. As reported by the participants interviewed, it was worth mentioning that these advantages were related to automation and flowability. Participants 2 and 3 referred to automation and concrete mix and their effects on mitigating quality non-conformances relative to conventional concrete and masonry. Participant 1 underscored participant 2's and 3's cited advantage in the form of the concrete mix and the regulation of mixture.

Participant 4 cited the pump's flowability, which positively affects concrete quality. The participants' findings correlated with the literature review. Hoffmann et al. (2020) found that the machine's automation would regulate the fresh concrete mix and change the rate of concrete flow in the 3D printer. Furthermore, Li et al. (2020) found that controlling the pump's pressure affected concrete quality.

These findings were evident in the participants' statements recorded verbatim below:

- "Concrete does mix and produce at a constant rate." (Participant 2 and 3);
- "…mixing and producing concrete at a constant rate is an advantage and a disadvantage because if you maintain your mixture in the machine properly all what you are going to you just need is to control the pressure in the hose." (Participant 4), and
- "…we do the automatic system, so we do not have inconsistences of the mixing process." (Participant 1).

5.3.2. Quality monitoring

The quality monitoring of 3D printing was one of the primary mitigations of quality non-conformances in concrete prints identified by the interviewed participants. As reported by the participants interviewed, it was worth mentioning that this was related to the quality control of 3D prints. Participants 2 and 3 referred to quality control and the protocols and their effects on monitoring the quality of concrete. Participant 4 underscored participant 2's and 3's references to quality control and referred to the evaporation of water from the concrete.

The participants' findings correlated with the literature review. Ortega et al. (2020) found that once a print was completed, it had to go through a quality control protocol to ensure that the quality was up too standard. Moelich et al. (2020) found that extreme water evaporation resulted in cracking of the concrete and quality non-conformances.

These findings were evident in the participants' statements recorded verbatim below:

- "…we try implement the production report all these 3 elements - structural, measurements and aesthetical failure – are part of 1 quality norm that we prescribe at the factory." (Participant 2 and 3), and
- "…cracks due to the shrinkage this is the most common problem of concrete printing is cracks." (Participant 4).

6. Conclusions

Given the findings in terms of the advantages of concrete 3D printing to mitigate concrete and masonry wastage, quality non-conformances, accelerate slow progress and eliminate time overruns, it can be concluded that there is a need to implement concrete 3D printing technology. Furthermore, it can be concluded that there is a need for the construction industry to integrate concrete 3D printing into conventional construction methods.

Overall, it can be concluded that there is a need to implement concrete 3D printing in construction due to the potential of 3D printing technology to improve cost, quality, and time overruns related to traditional concrete and masonry construction.

Given concrete 3D printing's potential to improve conventional concrete and masonry cost, quality, and time overruns, it can be concluded that there is a need for the implementation of concrete 3D printing in terms of: reducing material wastage, reducing material usage, reducing labour and supervision required; increasing the construction speed, reducing labour-intensive work and attaining complex shapes, and printing of quality conforming walls.

Concrete 3D printing 4.0 technology has the potential to contribute to solving conventional concrete and masonry challenges experienced on construction sites.

Given that only four interviewees participated in the study, the study can best be described as a pilot study, and the findings as indicative of an agenda for an in-depth qualitative study.

7. Recommendations

Architectural and engineering designers will have to make a paradigm shift in terms of 'designing for concrete 3D printing.

The construction industry should invest in concrete 3D printing in terms of developing the necessary expertise, which will require training and the acquisition of plant and equipment, to be able to construct the new era of 3D printed buildings.

Existing concrete workers should be retrained to enable their participation in the new era.

Tertiary built environment education should integrate concrete 3D printing into designer, construction management, construction project management, and quantity surveying programmes as a matter of urgency.

Professional associations and statutory councils should promote and facilitate concrete 3D printing-related CPD.

The Construction Industry Development Board (cidb) should evolve a position paper relative to concrete 3D printing.

In-depth qualitative research should be conducted relative to concrete 3D printing to

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Joshua Edward Gilmore, Graduate, Department of Construction Management, Nelson Mandela University, South Africa.
BSc (Honours) (Construction Management). 3D Printing, Concrete, Construction, Construction Management.

Katharina Nicole Crafford, Department of Construction Management, Nelson Mandela University, South Africa.
Dipl.-Ing., ICIOB.
Green Retrofitting, Women in the Built Environment, Teaching and Learning.

John Julian Smallwood, Department of Construction Management, Nelson Mandela University, South Africa.
PhD (Construction Management), Pr CM Pr CHSA CMSaiosh FCIOB MACHASM MACPM MARCOM MESSA MICOH MIOSH.
Construction, Construction Management, Health and Safety.

Paper no. 88

Novel Framework for Contract Awarding Process for Public Construction Projects in Sri Lanka: Learning From a Systematic Literature Review

Nuwantha Lasitha Sampath Uduwage-Don[1] and Kriengsak Panuwatwanich[2]
[1]School of Civil Engineering and Technology, Sirindhorn International Institute of Technology, Thammasat University, E-mail: nuwanthauduwage@gmail.com
[2]Associate Professor, School of Civil Engineering and Technology, Sirindhorn International Institute of Technology, Thammasat University, Pathum Thani, Thailand, E-mail: kriengsak@siit.tu.ac.th (corresponding author)

Abstract: The construction industry is unique due to numerous factors such as consumer-led, one-off nature, procurement arrangement, mode of investment, and technology. Therefore, selecting a contractor who is aligned with the uniqueness or subject matter of the project is vital for better completion of the project. In the bid evaluation process, at first, the bidders are eliminated based on the financial, technical, and managerial aspects which are focused only on the bidder's status, and then the selected bidders are evaluated based on the contract awarding criteria, which focuses on the status of the bid. However, due to public accountability, project bid price becomes the most concerning factor in public construction procurement. Therefore, bid price has become the most popular criterion worldwide for awarding construction contracts. Yet according to many researchers, this practice does not guarantee the successful delivery of the project to meet cost, time, and quality constraints. Moreover, the performance of a contractor can be different in dissimilar atmospheres due to the nature of the construction project. Cost overruns, extensive delays in completion, inferior quality, and an increased number of disputes are some recurring issues due to awarding contracts based on the lowest bid price criterion. These issues are present in Sri Lanka where the contract awarding in the public procurement process still very much relies on the lowest bid price. With the grave economic challenges being faced, there is a demand for Sri Lankan public construction procurement to have a novel framework for the contract awarding process which can be configured to best suit the subject matter of the contract. This paper systematically reviewed the academic research in the area of tender evaluation which was published between 1990 and 2022 with the main aim to compile the necessary knowledge in building a novel framework to overcome the issues that occurred with the lowest bid price awarding method and align the contract awarding process with the subject matter of the contract.

Keywords: public construction procurement, tender evaluation, contract awarding process, awarding criteria

1. Background

The construction industry is one of the key industrial contributors to the economy of any country in connection with Gross Domestic Products (GDP) and the employment rate (Alzahrani and Emsley, 2013). The government of any country is the most significant construction client, which plays a major role to acquire construction projects known as infrastructures (Dlungwana et al., 2002) through a public procurement process. Through the public construction procurement process, governments mainly expect "the development of the basic infrastructure such as roads, dams, irrigation works, schools, houses, factories and other physical foundations on which development effort is poured in establishing the living standard of the public" (Jatarona et al., 2018). Al-Zahrani and Emsley (2012) state that, "the success of construction projects is a fundamental issue for most governments, users and communities" and Yaweli et al. (2005) states, construction projects and their success are heavily reliant on contractors and awarding the contract to the right contractor will not only confirm the overall quality of the project but also ensure the opportunity of saving on costs. Thus, selecting the best-suited contractor during the period of evaluation is vital to the project. The selection of construction contractors is very often conducted using the bidding process which uses bids submitted by the potential bidders according to the set-out criteria (Puri and Thiwari, 2014).

In Sri Lanka, the Contract Awarding Process (CAP) in public procurement still very much relies on the lowest bid price as the main criterion. National Procurement Agency (NPA) guideline and manual are the two main documents that formulate mandatory rules and regulations for the public procurement procedure in Sri Lanka. According to NPA (2006) sub-clause 7.7.1 (a), mentioning "the purpose of the bid evaluation is to determine the lowest evaluated substantially responsive bid out of the bids received". Yet

many researchers have highlighted awarding the contract to the lowest cost is likely to be of poor quality or poorly executed (Lee et.al, 2020; Marzouk, 2008; Topcu, 2003). Therefore, this practice does not guarantee the successful delivery of the project to meet cost, time, and quality constraints. Additionally, cost overruns, extensive delays in completion, inferior quality, and an increased number of disputes are some recurring issues due to awarding contracts based on the lowest bid price criterion. Currently, researchers have recognized, that evaluating to get the lowest bid is not certainly the most economical solution in the long run period (Lambropoulos, 2013; Tucker, 2019) and instead depend on the lowest bid price, some countries are moving to more proactive approaches to award a contract to a contractor such as adopt most economical advantageous tendering method (Ballesteros-Perez, et al., 2015), considering average bid (Kumaraswamy,1996), incorporate sustainable construction practices to the evaluation process (El-Sayegh et al., 2021), etc due to advantages of those approaches.

1.1. Objectives

The objectives of this study are three-tier,

1. Systematically review the academic research in the area of tender evaluation, which was published from the year 1990 to 2022, to identify the exchange of views that has been related to the tender evaluation process and extract the discussions related to the CAP.

2. Precisely defining the significant areas in the integral mechanism of the CAP and alternative mechanisms can be used in each of these areas.

3. Develop a novel framework to determine the CAP for public construction projects in Sri Lanka.

2. Theoretical Background

Yilmaz and Ergonul (2011) stated that the notion of project success does not have a common and firm explanation due to different views of parties involved in the project and each party will have their judgment of success and the definition of success, which vary from project to project. Generally, a project is considered successful if it is delivered at the right time, price, and quality (Skitmore et al., 1995). Thus, the selection of a suitable contractor is a very significant task as the contractor plays a crucial role in the progress and success of the project. There are many downsides when the unsuited contractor gets selected for a particular project. According to Eriksson and Westerberg (2009), the selection of an unsuitable contractor for a construction project can affect the project budget, scheduled time for completion, quality, environmental balance, day-to-day life of the inhabitant, health and safety of the work environment, benefits received after completion of the project.

2.1. Contractor Selection Process

Contractor selection is a strategic question for the construction industry since the suppliers have an important role in project performance (Araujo et al., 2015). Generally, the bidding/tendering process (see **Figure 1**) is used to select the contractor (Dave et al., 2017) in most project delivery methods (see **Figure 2**). Contractor selection is one of the major processes in the project delivery systems which takes a considerable time gap in the timeline of the whole procurement process and the areas caged in red color in **Figure 2** depict this properly. Two main areas of the contractor selection process are the prequalification process and the Contract Awarding Process (Hatush and Skitmore 1998).

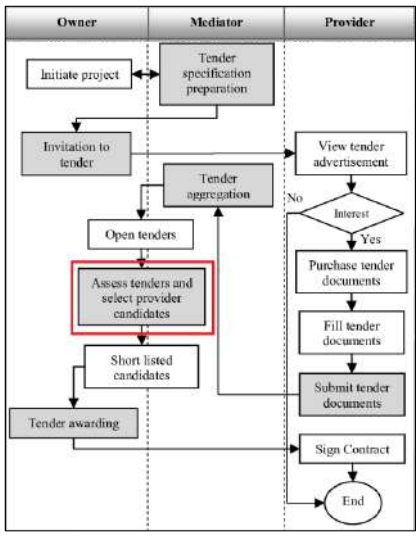

Fig. 1. General Bidding/Tendering Process (Source: Mohammed et al., 2011)

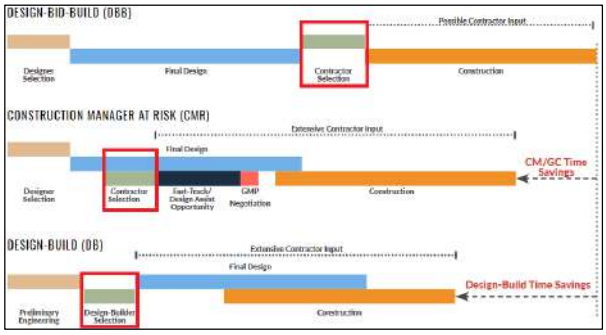

Fig. 2. Contractor Selection Phase in Different Project Delivery Systems (Source: Mccarthy, 2020)

Tucker (2019) states the tender procedure to award a contract is a three-stage process,

1. Firstly, submitted bids are scrutinized to confirm compliance with specifications and conditions set out in the bid documents.
2. Secondly, bids that are accepted in the first stage, are then evaluated based on “functionality” to confirm that bid is fulfilling the technical specifications objectively.
3. Finally, bids that meet requirements for functionality are evaluated against the estimated price.

Stage 1 discusses the prequalification process whereas stages 2 and 3 are discussing the contract awarding process. The pre-qualification process aims to reduce the cost of bidding by sorting according to fixed nonprice criteria while keeping the competitive advantage (Ng and Skitmore 2001). The criteria used in the prequalification process are commonly known as “selection criteria” (Brownejacobson, 2012) and they only focus on "the bidder" (Government of Scotland (GoS), 2020). i.e., bidder’s organization capacity; experience; grading,

machinery, and equipment; management and technical skills; qualifications; past performance; environmental compliance; litigation history; financial stability, and the annual turnover (ADB, 2018; Dave et.al 2017; GoS, 2020; Government of Tasmania, 2020; Mangitung, 2010). After the prequalification process, all the suitably qualified bidders are direct to the contract awarding process to evaluate against the awarding criteria (Mateus et al., 2010). Then the contractor who is best fitted with the awarding criteria gets the project (see **Figure 3).** The procurement entity must accurately define the contrast between selection and award criteria, to have unprejudiced competition and transparency in the procurement procedure (Lambropoulos, 2013). Most of the time contract awarding process in public construction procurement solely depends on the lowest bid price (Lambropoulos, 2013). Finally, the bidder who is selected from the prequalification process and achieves the requirements in the contract awarding process will be awarded the contract to complete the construction project as per the given requirements. In a normal context, the bidder who submits a bid that materially complies with the terms and conditions of the bidding document and achieves the lowest bid price is awarded the contract (Deep et al., 2017).

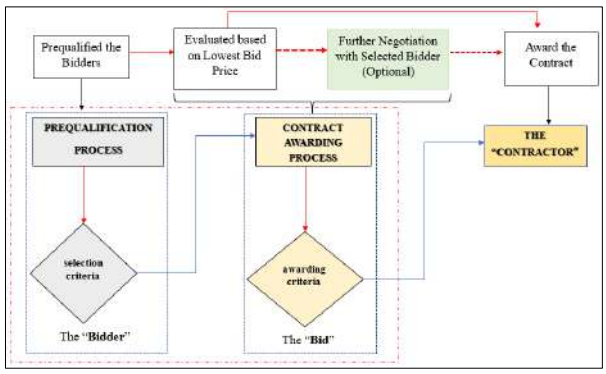

Fig. 3. Tender evaluation process
(Source: Authors' construct, 2022)

2.2. Importance of Contract Awarding Process

The contract awarding process evaluates the bids filtered during the prequalification process, based on the selection criteria (Construction and Procurement Delivery (CPD), 2020). Normally at this stage bidder's eligibility has been already concluded and the remaining is to confirm the compatibility of the selected bids with the subject matter of the contract. As an example, the public procurement process in countries such as the United Kingdom (UK), Ireland, and South Africa defines two stages before awarding the contract. i.e., In the first stage, checking the formal compliance of the bid with the specifications set out in the bidding documents, and in the second stage evaluated screen bids based on "functionality and price" (whether, objectively, the bid fulfills the technical specifications with the price) (CPD, 2020; Office of Government Procurement (OGP)- Ireland (2019; Tucker, 2019). The contract awarding process will undertake in the second stage. An improper contractor can jeopardize the quality and finally the success of the entire project. For example, in some building projects, such as office schemes, the mechanical and electrical (M&E) components can be as much as 50% of the total project cost, and the M&E works are considered very high-risk items (Ng and Skitmore, 2001). The risk of awarding the contract to a contractor who has a lack of capability in M&E areas shall need to be borne by the employer (Hanna and Brusoe, 1997). The contract awarding process is built around the contract awarding criteria. Selecting the contractor who gives the overall best value for a particular project may vary according to the perception of the procuring party and thus awarding criteria should closely match the employer and the project requirements (Palaneeswaran et al., 2003). Thus, in the contract awarding process, the most significant factor is contract awarding criteria. The award criteria are linked with the subject matter of the project to select the best bid among the capable tenderers (Lambropoulos, 2013).

According to the Procurement Guidance Note 04/16 (PGN, 2020) in the United Kingdom (UK), awarding criteria must be linked to the subject matter of the contract and focused on **"the bid**" instead of the "**bidder**". Nevertheless, contract awarding criteria shall have the consent of the procurement entity; it should: meet the significant requirements of the contract; not attract one or selected individual suppliers; be precise; and encourage competition (GoS, 2020; CPD, 2020). There are two main award criteria: the price only and the Most Economically Advantageous Tender (MEAT)/ Best Value Procurement (BVP) (Ballesteros-Perez, et al., 2015; CPD, 2020; Lambropoulos, 2013; Tucker, 2019).

The CAP (i.e. weighting factors; formulas; parameters) shall be precisely defined (Chen, 2008) to implement the bidder's strategies to submit a responsive bid in line with the subject matter of the project. Further, a transparent CAP can aid the bidders to calculate the score they are getting for their bid during the evaluation and improve the responsiveness of their bid during the bidding period (Soudry, 2004). Therefore, the CAP performs the central role in public procurement (Chen, 2008).

2.3 Contract Awarding Process (CAP) in Sri Lanka

In Sri Lanka, the government stipulates specific procedures that need to be followed in consulting, contracting, procurement, and supplies in government projects (Mohammaed, 2017). National Procurement Agency (NPA) guideline and manual published by the National Procurement Agency of Sri Lanka in the year 2006, outlines the terms and conditions that need to be followed when procuring any kind of public sector development. Though the NPA guideline/manual shall specify the CAP in identified chapters, there is no indication about the precise CAP. Nevertheless, there are places in which mentioned contract shall be awarded to the lowest evaluated responsive bidder related to the bid price. e.g. According to NPA Manual (2006)a which refers to Procurement Guideline Reference: 3.8;

"For Works contracts not exceeding SLR 25 Million: provisions to meet the emergency Procurement requirements:

(c) the lowest Bid price is selected as the winner provided the Bid is substantially responsive otherwise"

According to this subclause, the substantially responsive bidder who achieves the lowest bid price will be the winner for the contracts which has a contract value below 25 million Sri Lankan Rupees. Not only the above type of contracts but almost all types of contracts specified by the

NPA guideline and manual is subject to the bid price criterion. This shows NPA guideline and manual imply the awarding criteria should be bid price and yet it does not directly specify an evaluation mechanism for assessing responsiveness of bid price that can be used for it. As a common approach being practiced in Sri Lanka, the evaluation mechanism can be understood as the lowest bid evaluation method.

2.4. Demand for a Novel Framework to Contract Awarding Process in Sri Lanka

Reforming the public procurement process is one of the main priorities of the Government of Sri Lanka (GOSL) and the requirement of improving Sri Lanka's public sector governance system to accomplish continuing developments in both economic and social areas has become a more stressing concern now than ever before (Raza, 2015). Moreover (Raza, 2015) states a small development in the efficiency of the public procurement system which is achieved through procurement reform can retain millions of tax rupees and those savings can be used for the benefit of the public. Procuring construction projects plays a vital role in the public procurement process and therefore reforming the activities in the public procurement process related to the construction industry provides direct benefits to the nation to enhance the living standards of the community (Gunawardhane and Karunasena, 2014). There are projects which were failed due to awarding the contract using the traditional tendering process by ignoring its specific nature. i.e. ***Flyover at Rajagiriya, Sri Lanka which commenced in 2016.*** According to Wijenayake (2018), the Rajagiriya flyover is 533 m long, 3.5m-wide, two-lane fly-over in two parallel bridges and is expected to be completed in two stages. The project was near the parliament of Sri Lanka and by its nature, the project demanded the shortest construction time to complete the project to avoid the heavy traffic on the parliament road. However, the contractor has taken an undue lengthy period (28 months) to complete the flyover. Compared with another similar project in Sri Lanka which is the Kelaniya flyover, which commenced in 2008, a dual lane flyover, 325 m long and 7.5 m in width and located in a heavy traffic area similar to the Rajagiriya flyover, was allowed to complete only 9 months (Newsonprojects, 2008). In contrast to the Kelaniya flyover, the Rajagiriya flyover is 1.64 times large and should have been completed within the maximum of 14 months (regardless of technological developments during construction periods which is almost 8 years), but it was extended for 28 months which is almost double. Wijenayake (2018) further stated in the article, that during the construction period vehicle drivers complained of additional delays with lane restrictions due to construction needs, and meanwhile, there were complaints about the quality of construction. Wijenayake (2018) questioning in his article, why Sri Lanka does not have a process to select the contractor who completes the construction project with a lead compared to its schedule time by keeping its quality, which might also allow the contractor to get incentive and if so, the outcome of public construction projects would have been changed.

In the view of the public procurement process of Sri Lanka, if relevant government authorities had a way to award a contract to a contractor who is a better fit with the subject matter of the contract, this failure might be averted and the project could have been successful. Even though Sri Lankan public procurement process discusses a substantially responsive bidder who is eligible to award the contract, it has a lacuna of precisely define CAP that addresses the subject of the contract. This has been a reason to practice bid price as an awarding criterion and the lowest bid price method as an evaluation mechanism to award any public construction project to a contractor irrespective of the subject matter of the project. Following a similar process for each contract awarding will not give the best-suited contractor every time and introducing a framework to configure the CAP according to subject matter based on the outlined CAP above will provide more favorable conditions for Sri Lankan construction projects.

According to Raza (2015), based on recent conversations with the donors like World Bank, USAID, and the French Aid Group, the GOSL has shown reforming procurement as one of the foremost activities in the GOSL reform plan to improve good governance in the medium term. So, improving the CAP also be a highlighted area, regardless of depending on the stereotypes process in the future. Thus, there is a demand for a novel framework for CAP using outlined CAP for public construction projects in Sri Lanka.

3. Methodology

The study was focused on a systematic literature review combined with a bibliometric analysis, which was carried out using the source as academic literature published in Scopus. Scopus is an Elsevier's abstract and citation database launched in 2004. Burnham (2006) mentioned Scopus is the "largest single abstract and indexing database ever built" since it claims to have indexed over 14,000 Science, Technical, and Medical (STM) and social science papers from 4000 publishers. Scopus maintains a high-level quality assurance process by continuously monitoring and advancing all the data in it while having enriched metadata track records of authors and affiliations, and scientific articles, attained using advanced profiling algorithms (Baas, 2020). Due to this, the credibility of Scopus has the character to use as a bibliometric database for wide-ranging analyses in research reviews (Baas, 2020). Thus, Scopus has been chosen as the database for this study.

In the data collection phase, Boolean operators were used to search and extract the data from the Scopus database. The study is focusing on the CAP which is one of the main components of the tender evaluation process and research foci on tender evaluation in the construction industry were decided to choose for the analysis. Thus, search keywords were limited to "Tender Evaluation", and "Bid Evaluation". Normally, the terms "Tender" and "Bid" are used interchangeably in the construction industry to refer to a similar process. To extract all the papers relevant to these two terms, both the terms were connected using the "OR" operator and to limit the study to the field of construction the term "construction" has been used with the "AND" operator. The period for the search was set from the year 1990 to 2022. Journal articles ("ar"), conference paper ("cp"), review ("re") and conference review ("cr") were considered as the type of documents. Search has been done using respective documents' "Article Title", "Abstract" and "Keywords". Based on the above criteria, the following search query was built to search and extract the information from the Scopus database.

TITLE-ABS-KEY (("Tender Evaluation" OR" Bid Evaluation) AND "construction" And PUBYEAR>1989 AND (LIMIT-TO (DOCTYPE,

"ar") OR LIMIT-TO (DOCTYPE, "cp") LIMIT-TO (DOCTYPE, "re") LIMIT-TO (DOCTYPE, "cr"))

Search and extract the required information from Scopus, the study was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 flowchart. VOSviewer V.1.6.18 (Centre for Science and Technology Studies, Leiden University, Leiden, The Netherlands), which is a software tool for constructing and visualizing bibliometric networks among authors, countries, co-citations, and the terms used in articles had been used analyze and create the network visualization map related to results of bibliometric analysis.

4. Analysis Results

According to the results found using the search query, the analyses are organized under each of the following areas: "Intellectual structure of knowledge and stated key research areas" based on the tender evaluation process (to observe the contribution of the studies and understand the exchange of views by different authors); "Outline the CAP" (define the precise flow of CAP); "Develop a novel framework for CAP ".

4.1. Intellectual structure of knowledge and stated key areas

To analyze the growth of publications between the year 1990 - 2022, data extracted from the search query was sorted properly to retrieve the data related to attributes "**Year**" and "**Cited by**". The data in the attribute "Year" gives the number of documents published in that year whereas the data in the attribute "Cited by" shows the number of citations for a document in each year. The excel function **"COUNTIF"** was used to obtain the number of documents published from 1990 to 2022 linked to the tender evaluation process. The results were shown in a 2D column chart (see **Figure 5**). The chart shows the dispersion of the publications which discuss the tender evaluation process over the past three decades. The chart exhibits that the tender evaluation process has become a more prominent discussion from the year 2004 to current. In the years 2011 and 2021, the number of documents published has risen to its highest which is 16 publications. Even nine (9) documents were published within the first half of the year 2022, related to the tender evaluation process. This infers tender evaluation process has been one of the leading discussions among construction-related researchers around the globe, since there are one or more publications linked to the tender evaluation process each year from the 1990 to current, except in the year 1993.

Perceive further intellectual structure knowledge in the area of discussion of the Co-citation analyses done using the VOSviewer. Co-citation analyses track two papers that are cited together in another source article. Below parameters were selected in the VOSviewer to carry out the Co-citation analyses and constructed "scores file" and the network visualization map based on the results.

Type of analyses "Co-citation"; Counting method "Full counting"; Unit of analysis "Cited authors" and **Minimum number of citations of an author** set to **"10" of the 6206 authors, 88 meet the threshold. Number of authors selected to calculate the total strength of the co-citation link is set as "88"** and no author has been removed from the **verify selected authors** list.

According to the network visualization map (see **Figure 4**) there are 5 clusters (Red, Green, Blue, Green, Gold, and Violet) with 2071 links. Links and Total link strength attributes in a scores file ("Scores file" generated by the VOSviewer which is a text file that contains scores of documents) for a given item indicate, the number of links of an item with other items and the total strength of the links of an item with other items and when working with, the "Citations" attribute in Co-citation analysis show the number of citations received by a cited source, a cited reference, or a cited author (VOSviewer Manual, 2022). Data available in the scores file was used to identify the weight (Total link strength) and weight (Citations) of each cluster in network visualization map. The data in each cluster were sorted in the scores file based on the data in citation attribute from largest to smallest value and the general research areas related to the first two authors appeared after sorting were further analyzed and results were tabulated (see Table 1).

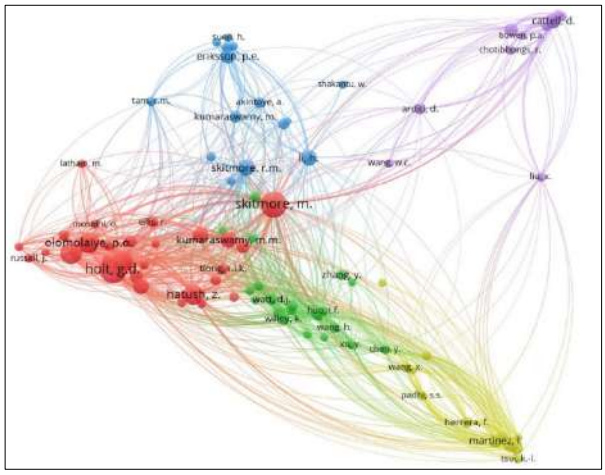

Fig. 4. Co-citation network visualization map
(Source: Authors' construct, 2022)

According to **Table 1**, the column named "General area of research interest" shows the common trend of each cluster in the network visualization map. i.e. original documents of Co-cited papers related to the first two authors in Cluster 1 are mainly focused on Contractor Selection, Tender Evaluation, Procurement Route, and Balanced/Unbalanced Bidding. Except for the 5th cluster, all other clusters discussed the contractor selection and/or tender/bid evaluation. This indicates the information available in those clusters tends to focus on optimizing the existing process of procuring a contractor. Yet narratives of the documents linked to each cluster do not mention details about optimizing or improving the CAP as a separate study. All the time, the focus of the documents in each cluster was to improve the existing process as a whole. Mostly applying various distinctive techniques to optimize the inside mechanisms of the existing process, without improving or changing the existing process, is another commonality that can be seen within these clusters. Thus, there is a requirement of making changes to the existing CAP to make it more effective and able to select the best-suited contractor for a specific project.

To examine the key areas discussed in the selected timespan related to the tender evaluation process, Co-occurrence analysis was done using the VOSviewer. Co-occurrence analysis is a method to analyze text that

includes a graphical visualization of possible interconnection among the set of units i.e, people, organizations, and concepts (VOSviewer Manual, 2022). Below parameters were selected in the VOSviewer to carry out the Co-occurrence analyses and constructed "scores file" and the network visualization map based on the results.

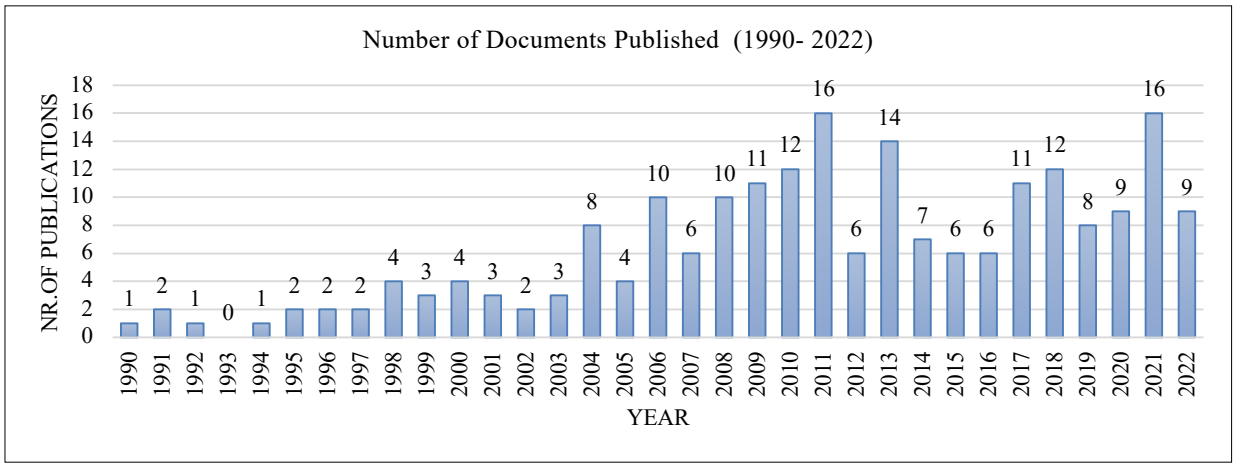

Fig. 5. Number of Documents Published (1990-2022)
(Source: Authors' construct, 2022)

Table 1. Data retrieved from scores file related to each cluster (Co-citation Analysis)

Cluster		Author[a]	Weight (Total link strength)[a]	Weight (Citations)[a]	General areas of research interest[b]
Number	Color				
1	Red	Holt, G.D.	2978	107	• Contractor Selection ▪ Factors • Performance evaluation of Contractors • Alternative Practice for Tender Evaluation
		Skitmore, M	2248	96	• Procurement path selection • Balanced and unbalanced bidding • Contractor Selection ▪ Evaluating Prequalification ▪ Criteria
2	Green	Willey, K.	618	22	• Key factors in tender evaluation • Importance of tender evaluation criteria
		Kayis, B.	552	20	
3	Blue	Skitmore, R.M.	926	38	• Procurement path selection • Contractor Selection: ▪ Cost-benefit analysis ▪ DSS for prequalification ▪ Selection Criteria
		Li, H.	513	35	• Balanced and unbalanced bidding • Green Supply chain management • Contractor selection ▪ Analytic Network Process
4	Gold	Martinez, L.	1268	25	• Bid Evaluation ▪ Using expertise-based model
		Chen, Z.-S.	1169	23	• Bid evaluation ▪ Under uncertainty
5	Violet	Cattell, D.	612	34	• Balanced and unbalanced bidding • Mark-Up distribution in quotation • Pricing Ethics
		Bowen, P.	403	25	• Balanced and unbalanced bidding • Mark-Up distribution in a quotation • Ethics in construction

Notes: [a] Using the scores file related to the Network visualization map; [b] subjectively chosen - refer to the narrative of paper
(Source: Authors' construct, 2022)

Type of analyses "Co-occurrence"; Counting method "Full counting"; Unit of analysis "All keywords" and **Minimum number of occurrences of a keyword** set to **"5" of the 1443 keywords, 71 meet the threshold. Number of Keywords to be selected to calculate the total strength of the co- occurrence link set as "71"** and no keyword has been removed from the **verify selected keyword** list.

According to the network visualization map (See **Figure 7**) there are 7 clusters (Red, Green, Blue, Gold, Violet, Yellow, and Orange), 71 key terms, and 904 links can be identified. Key terms like "construction industry", "project management", "bid evaluation" and "tender evaluation" can be clearly visible on the map due to the high scale of visualization in those terms. It means those terms appeared many times in the studies compared to the other terms. According to the Vosviewer Manual (2022), an attribute called "Weight" in the scores file indicate the weight of an item gets higher, the more prominently the item is shown in the visualization of a map.

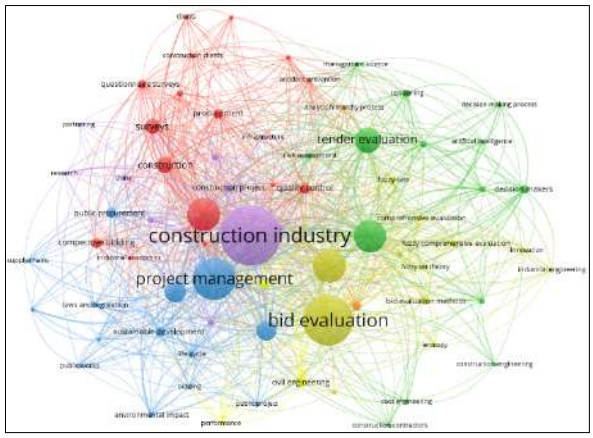

Fig. 6. Co-occurrences network visualization map (Source: Authors' construct, 2022)

Data available in the scores file was used to identify the weight (occurrences) cluster in the network visualization map. The data in each cluster were sorted in the scores file using the data in weight (occurrences) attribute from largest to the smallest amount and the first two key terms under the "label" column appeared after sorting were further analyzed and the results were tabulated to understand the general pattern of each cluster. VOSviwer manual (2022), define the **Normalized citations, Average normalized citations** as follows,

Normalized citations: The normalized number of citations received by a document.

Average normalized citations: The average normalized number of citations received by the documents in which a keyword or a term occurs.

After analyzing **Table 1**, except for four keywords (construction, tender evaluation, construction industry), and civil engineering), all other keywords have scored above 1.0 for average normalized citations. This infers if a document (which contains keywords), has a high

$$Ct_{nn} = \frac{Ct_{nr}}{Ct_{avg}} \quad (1)$$

Where:

Ct_{nn}: Normalized number of citations of a document

Ct_{nr}: Number of citations of a document

Ct_{avg}: Average number of citations of all documents published in the same year according to the data provided to VOSviewer

Equation 1: normalized number of citations of a document (Ct_{nn})

occurrence and score above 1.0 for average normalized citation then it has a higher number of citations for the document (Ct_{nr}) compared to the average number of citations of all documents published in the same year according to the data provided to VOSviewer (Ct_{avg}).

If $Ct_{nn} > 1.0$ then $Ct_{nr} > Ct_{avg}$

It conveys, that if a specific document is highly cited, then it can be concluded that these key terms have been frequently cited by the other researchers for their study. In simple terms, keywords which are having a score for an average normalized citation of more than 1.0 were cited frequently by the authors of this Scopus database. After refining the identified keywords in all 7 clusters based on the number of times appeared, the combination of a few main keywords was disclosed as "construction industry", "contractor selection", "tender/bid evaluation", and "decision making", "mathematical models", "project management". Once these keywords were arranged in a meaningful manner, the general idea in the combination of keywords can be identified as using models to make decision making during the bid/tender evaluation to select the contractor in the construction industry, and the selection of the contractor will impact on the project management concepts. So, this refining process explains the highly important areas has been aimed at during the studies of tender evaluation over the past three decades. But there is no indication about the keywords related to the CAP, which gives a conclusion there is a lacuna in a discussion about the CAP, throughout the past three decades, though it's a vital topic to focus on.

Table 2. Data retrieved from scores file related to each cluster (Co-occurrences Analysis)

Cluster		Label[a]	weight (occurrences)[a]	Score[a] (Average normalized citations)
Number	Color			
1	Red	contractors	57	2.0873
		construction	38	0.8227
2	Green	decision making	40	1.0665
		tender evaluation	31	0.5477
3	Blue	project management	53	1.5191

		contracts	26	1.2298
4	Gold	bid evaluation	63	1.223
		construction projects	41	0.8147
5	Violet	construction industry	76	1.3922
		construction project	10	0.3049
6	Yellow	civil engineering	11	0.857
		mathematical models	10	1.6175
7	Orange	analytic hierarchy process	28	1.9522
		contractor selection	54	2.3751

Notes: [a] Using the scores file related to the Network visualization map
(Source: Authors' construct, 2022)

4.2. Outlining the contract awarding process

"Unquestionably there is no 'best overall' contract award process has emerged; the most appropriate way depends on the specific conditions at the time and place of tender of each particular project, as well as on the characteristics of each client" (Lambropoulos, 2013). Even though there is a high demand for improving the tender evaluation process to procure a suitable contractor, previous analysis shows, that there are no specific details about the inside mechanism of the contract awarding process and thus, it is important to scrutinize the outline of the contract awarding process to identify the key areas in it. Moreover, identification of key areas can help to improve the contract awarding process by optimizing those areas instead of focusing on one stereotypical contract awarding process.

An effective contract awarding process will ensure the contractor will meet the significant areas of the contract (GoS, 2020; CPD, 2020; Tucker, 2019) by evaluating the contractors against the awarding criteria, who were screened out during the prequalification stage (Hatush and Skitmore, 1998). This infers the contract awarding process shall first be initiated with "**contract awarding criteria**". **Table 2** depicts one of the general interest areas of the clusters as "**evaluation**" of a specific context i.e., Performance evaluation of Contractors; Evaluating Prequalification; Bid Evaluation: Using an expertise-based model. This hinders an "**evaluation mechanism"** that shall be implemented to assess the awarding criteria. The contract awarding process should have an objective evaluation other than the bid price (GoS, 2020; Lambropoulos, 2013; Palaneeswaran et al., 2003; CPD, 2020; Tucker, 2019). The outcome of this process (see **Figure 7**) can be further improved with the discretion of the procuring entity.

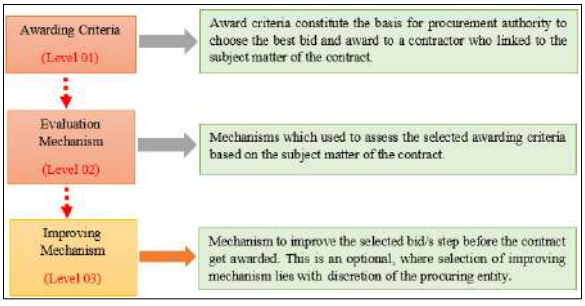

Fig. 7. Outlined Contract Awarding process
(Source: Authors' construct, 2022)

Most of the time, the expectations of both procuring party and the contractor get differ once the contract started to be processed. Often the drawings and specifications at the bidding time are altered once the contract is awarded if procurement is complex and hard to lay down (Asner, 2001; Bajari et al., 2008) and due to that, there will be ex-post changes (Bajari and Tadelis, 2001; Bajari et al., 2008; Chakravarty et al., 2004). Nevertheless, solutions for many critical problems are hard to decide until procuring entity examines the contractor's bids (Asner, 2001). Thus, having a mechanism to improve bid/s, one step before awarding can ensure the contract is awarded to the best-suited contractor who addresses the subject matter of the contract. After scrutinizing the extensive literature review, the contract awarding process can be outlined as awarding criteria, evaluation mechanism, and improving mechanism (optional) and these three steps shall execute one after another. Thus, these stages were identified starting from level 1 to level 3. Level 1 shall execute first to start the process and level 3 is the last to execute before awarding the contract. The integral mechanism of CAP is shown above (see **Figure 7**).

Scrutinizing literature aided to identify the alternative approaches at each level of this integral mechanism of CAP. Many articles were discussing the use of Most Economical Advantageous Tender (MEAT) over the bid price as the awarding criteria (Ballesteros - Perez et al. 2015; IBRD 2011; Jaskowski et, al, 2018) and some legislation has made it mandatory to consider both MEAT and bid price as possible alternatives for contract awarding criteria i.e., EU Directive 2004/17/EC and 2004/18/EC), Visegrad group countries. To evaluate the awarding criteria non-weighted/weighted method, cheapest/average methods have been introduced by many researchers (Awwad and Ioannou, 2010; Herbsman and Ellis 1992; Lahdenpera 2013; Marcarelli and Nappi 2019; Shrestha 2014). The weighted/nonweighted method is suited to evaluate the MEAT criteria where there are one or more parameters along with the bid price to select the contractor. In the weighted method, all the input values will be converted to the weighted values (nonmonetary terms) using a weight factor, and non-weighted method all the input values will be converted to monetary terms. The cheapest/average method is suited to evaluate the bid price criteria where price will be the only parameter considered in the CAP. The cheapest (lowest) bid price evaluation is the traditional way of evaluating the bidders. In average

bid price evaluation, the bid which has a price near to the average price of all submitted bids will be selected to award the contract (Awwad and Ioannou 2010). i.e., the Taiwanese use close to the average bid method and Italy is using closest to but below the average value (Shrestha, 2014). Finally, as improvement mechanisms, negotiation with the highest score bidder method and Best And Final Offer (BAFO) method were mentioned by many researchers (Asner 2001; Bajari, Houghton and Tadelis 2006; Bauld 2015). Negotiation with the highest scored bidder is practiced by many countries where negotiation is only carried out with the final selected bidder to further clarify the areas which didn't comprehensively address during the tendering process. In contrast, the BAFO method call for the bidders who had minor deviations during the evaluation and were not selected as the final bidder in the first round, to resubmit the corrected bids in the second round (Asner 2001). Alternatives for each level have been identified through the literature review and the findings are depicted in **Table 3**.

Table 3. Alternatives in each level

Level	Alternatives
Awarding Criteria	Bid Price / Most Economically Advantageous Tender (MEAT)
Evaluation Mechanism	Nonweighted/weighted Cheapest / Average
Improving Mechanism	Negotiated with highest score bidder/ Best and Final Offer Method (BAFO)

(Source: Authors' construct, 2022)

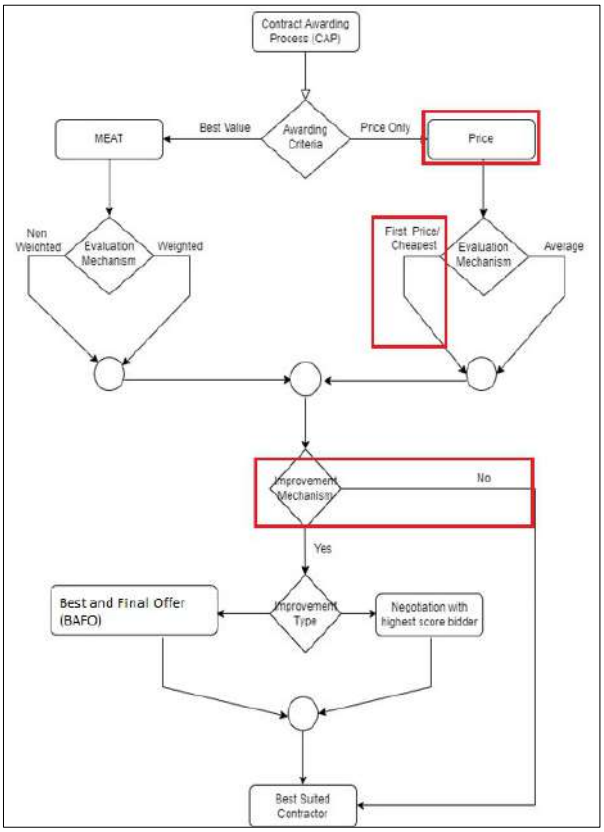

Fig. 8. Proposed Novel framework for CAP
(Source: Authors' construct, 2022)

By utilizing these literature findings novel framework shown in **Figure 8** has been developed to identify the best CAP related to any construction project. This novel framework can show the alternatives which can be chosen at each level (decision phase) based on the procuring entity's requirements and finally provide a distinct path for each project's CAP. The red colored path illustrates the current CAP in Sri Lanka to select a contractor for public construction project according to the NPA manual/ guideline which always relies on the combination of the bid price awarding criteria and the cheapest/lowest bid price evaluation method. As discussed previously lowest bid price does not guarantee the best-suited contractor and thus procuring entity can customize their CAP based on this framework.

5. Discussion

Analysis shows the term tender evaluation process has been popular among researchers in the past few decades even though there is low interest at the beginning of the year 1990. Narratives of the studies found through Co-citation analysis show the authors of those studies were studying key areas connected to the tender evaluation process and attempting to improve the shortcomings of internal mechanisms that process by applying the different techniques or models. In most of the cases, the authors were trying to improve the shortcomings of specific models introduced by another author by applying a distinctive mechanism. This can be considered an "evolution" of the tender evaluation process in the past three decades. Co-occurrence analysis indicates the boundary of discussion of the tender evaluation process by bringing the mostly appeared key terms within this exchange of views in the past three decades. Demand expedites the evolution of a process. This means the demand for the evolution of the tender evaluation process was constant for the last few decades within the identified boundary. CAP is a significant part of the tender evaluation process. But according to both Co-citation and Co-occurrence analysis, it was convinced the CAP has not focused to advance within the discussion of tender/bid evaluation. Co-citation and Co-occurrence analysis illustrates, that most of the time, the improvement or the modification has been done to the whole existing process of the tender/bid evaluation. The foci of those researches were to improve the internal mechanism of the existing process by applying different techniques or a decision-supporting model. There were few studies demarcated the perspective of "the bidder" and "the bid", when improving the existing process but did not investigate in the depth of that. But recurring demand for advancing the tender evaluation process impulsively produces the demand for studying the CAP. As discussed at the initial stage of this study, CAP is mainly looking at the perspective of "bid" or in other ways looking at the subject matter of the specific project. Therefore, it's vital to study the CAP, if the ultimate goal is to select the most suited contractor for the project. Proper understanding of the integral mechanism in the CAP allows for determining the alternatives that can be used in each critical phase of the process. The proposed new framework shows that distinct alternatives can be chosen at each level based on the procurement entity's requirements. As mentioned earlier according to the NPA guidelines and manual, in Sri Lanka the traditional way of awarding the contract always depends on the Bid price. During the evaluation process, if

a bidder meets the bidding requirements along with the lowest bid price, the contract will be awarded to the particular bidder without having a second thought. But new framework enlightens a different path where CAP can be designed based on the actual requirements of the project. This approach can eliminate most of the disadvantages due to the lowest bid price awarding methods which discuss earlier in this paper and give new insight to the procuring entities to design effective CAP based on the actual requirements of the project. For an instance, if the project is looking for more sustainable construction practices, evaluating based on the MEAT will produce more effective results compared to the bid price. This new framework would be one distinct answer to a recurring demand for procurement reformation in Sri Lanka.

6. Conclusion and way forward

According to the literature, the Sri Lankan contract awarding process is solely based on the bid price criteria, regardless of the subject matter of the contract. Literature mentions that Sri Lanka expects to undergo reform in its public procurement process to advance the public governance system and to achieve essential economic and social development. Procuring public construction projects is also one of the major areas in the public procurement process and introducing reformations for the contract awarding process to reap the benefits starting from large-scale mega infrastructure projects to small-scale constructions is vital. Thus, there is a demand in Sri Lanka for implementing a novel framework for CAP based on the subject matter of the contract.

The article explains there is a lacuna in the discussion of the CAP during the past decades and it provokes the demand to improve the integral mechanism of the CAP by adopting possible alternative mechanisms at each level in **Figure 7**. The novel framework for CAP in **Figure 8**, has been developed in a manner where procuring entities have distinct options at each level (decision phase)) instead of picking the lowest bid price method in the CAP all the time. Improving this novel framework further by incorporating more alternatives except mentioned in this paper, will be a way forward in this research area. The focus of this research is confined to the tender/bid evaluation process of the public sector in Sri Lanka. The proposed framework can only be used with the bidding process of competitive nature and the unsolicited bidding process or Swiss challenge method is not considered in this research.

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Nuwantha Lasitha Sampath Uduwage-Don is currently a full-time doctoral student at School of Civil Engineering and Technology, Sirindhorn International Institute of Technology (SIIT), Thammasat University, Pathumthani, Thailand. He holds a BSc. in, Quantity Surveying and MSc in Construction Law and Dispute Resolution from the University of Moratuwa, Sri Lanka. He is a Chartered Quantity Surveyor of Institute of Quantity Surveyors Sri Lanka (IQSSL), Corporate member and Certified Quantity Surveyor (CQS) of Australian Institute of Quantity Surveyors (AIQS). He has been working in the construction industry as a contract/procurement specialist for nearly 8 years. His areas of research interest in concisely, public procurement, contract management, blockchain, and value engineering.

Kriengsak Panuwatwanich, Ph.D. is Associate Professor at Sirindhorn International Institute of Technology (SIIT), Thammasat University. He holds a B.Eng. in Civil Engineering from SIIT, M.Eng.Sc. from the University of New South Wales, and Ph.D. from Griffith University, Australia. His research interests include engineering and construction management, with a specific focus on the applications of digital technologies in construction, safety and innovation management, as well as sustainability.

Paper no. 90

Flexural Strengthening and Repairing of Reinforced Concrete Beams by Using Textile Glass Fabric

Raed Abendeh[1], Hesham Rabayah[1], Rana Alhourani[2] and Donia Salman[3]
[1]Associate Professor, Department of Civil and Infrastructure Engineering, Al-Zaytoonah University of Jordan, Amman, Jordan, E-mail: r.abendeh@zuj.edu.jo; h.rabayah@zuj.edu.jo
[2]Assisstant Professor, Department of Civil and Infrastructure Engineering, Al-Zaytoonah University of Jordan, Amman, Jordan, E-mail: r.alhourani@zuj.edu.jo
[3]Ph.D. Student, Department of Civil Engineering, University of Mississippi, Oxford, MS, USA, E-mail: dgsalman@go.olemiss.edu (corresponding author)

Abstract: Textile reinforced concrete (TRC) is emerged recently as an attractive substitute for traditional composite materials. There is a growing interest in repairing, retrofitting, and strengthen existing concrete structures with various materials, and the use of textile fabric made of high strength materials such as AR-glass, carbon, or basalt for those problems gains acceptance in civil engineering. The effectiveness of alkali-resistant glass fiber (AR-glass) in strengthening reinforced concrete beams is investigated in this study. A total of four large scale reinforced concrete beams with dimensions of 150x200x2000 mm are experimentally tested under four-point loading to exploit the potential strengthening of glass textile (GT) fabric. Two types of glass textile-reinforced concrete (TRC) beams with integrated internal and external fabric layers as supplemental flexural reinforcement are investigated: two beams of internal GT fabric, one with one layer of textile and one with three layers, and one beam of external GT layer. In addition, a control beam specimen is cast with no GT textile. Monitoring the load-deflection curves, crack pattern, and strengthening layer behavior revealed that using GT as an internal and external layer increased the flexural strength of beams. However, using three internal textile layers provided greater flexural strength than using one internal layer; additionally, using one layer of external textile provided greater flexural strength than using one or three internal layers.

Keywords: Textile reinforced concrete, AR-glass fiber, flexural strengthening, reinforced concrete beams.

1. Introduction

Natural events such as earthquakes, fires, and chemical attacks cause reinforced concrete structures to deteriorate over time and fail to perform as expected. Several ways for repairing, assessment, retrofitting, and reinforcing existing concrete structures have been proposed in the literature (Ingham, 2009; Trapko and Musia, 2011; Tran et al., 2015; Haddad and Almasaeid, 2016; Almasaeid et al., 2022).

The use of fiber-reinforced polymer (FRP) fabrics is a common method for strengthening and rehabilitation of damaged concrete, and the FRP fabrics are becoming more popular due to their low thermal conductivity, lightweight, high strength-to-weight ratio, adequate performance, simple and quick application, and durability in harsh environments (Hamilton et al., 2009). Numerous studies have been conducted on the performance of FRP for wrapping heat-damaged columns (Bisby et al., 2011; Yaqub et al., 2011; Al-Nimry and Ghanem, 2017), as well as its effectiveness in the rehabilitation of chemically deteriorated concrete columns (Alzeebaree et al., 2019; Mohammedameen et al., 2019; Gulsan et al., 2018). It was reported that the FRP confinement method was efficient since it increased the load-carrying capacity while also increasing ductility. However, this technique has some disadvantages, such as poor performance at high temperature, difficulty of application on wet surfaces, high material, labor, and application costs, and lack of integration of the binder and the concrete surface.

To overcome these disadvantages, textile reinforced concrete (TRC) is now gaining popularity in civil engineering as an alternative to FRP. Textiles are often made up of fiber that have been woven or stitched in at least two orthogonal orientations, resulting in an open-mesh structure, and are made of high-strength materials such as AR-glass, carbon, or basalt (Triantafillou, 2016; Peled et al., 2017) embedded in inorganic materials like

cement-based mortars if to be used as external strengthening on the concrete surface. TRC material is also known as textile reinforced mortars (TRM), fabric reinforced cementitious matrix (FRCM), or glass fiber grids (GFG).

Various studies have been carried out to compare TRC and FRP systems for external strengthening the flexural and shear capacity of reinforced concrete beams. Elsanadedy et al., 2013 concluded that the use of TRM system was less effective in terms of increasing flexural capacity by 7.2% when compared to FRP system, but it provided higher ductility by 61% when compared to FRP. This was reported based on a comparison of the behavior of two beams: one strengthened with five layers of basalt fiber-TRM in a u-shaped pattern, and the other with one layer of basalt FRP. Raoof et al., 2017 found that the use of a textile system to increase the flexural capacity of retrofitted beams was less effective than that of FRP, but the effectiveness of the textile was sensitive to the number of layers applied. Triantafillou and Papnicolaou, 2005 noticed that TRM was 30% less effective than FRP based on two specimens, with fiber rupture for the FRP-strengthened beam and interlaminar debonding for the TRM-strengthened beam. Tetta et al., 2015 also compared TRC and FRP systems for shear strengthening of reinforced concrete beams, concluding that TRM was generally less effective than FRP in increasing shear capacity, but TRM was more effective in increasing beam deformation capacity. Furthermore, the behavior and effectiveness of both systems are affected by both the strengthening configuration and the number of layers.

The flexural strengthening of beams using TRC has been conducted by different studies with the goal of investigating various parameters such as the material of the textile fiber, including carbon fiber textile (Triantafillou and Papanicolaou, 2005; Dambrisi and Focacci, 2011; Ebead et al., 2017), polyparaphenylene benzobisoxazole (PBO) fiber textile (Ombers, 2012; Dambrisi and Focacci, 2011; Ombers, 2012; Ebead et al., 2017), and basalt fiber textile (Elsanadedy et al., 2013); the number of textile fiber layers used (Ombers, 2012; Dambrisi and Focacci, 2011; Elsanadedy et al., 2013; Babaeidarabad et al., 2014; Ebead et al., 2017; Raoof et al., 2017); the strengthening configuration (Dambrisi and Focacci, 2011); and the compressive strength of concrete (Babaeidarabad et al., 2014). It was concluded that the use of textile for reinforced concrete beams improved their flexural capacity, and increasing the number of textile layers increased flexural capacity and changed the mode of failure.

Different researchers also investigated the use of glass-textile as an internal strengthening of reinforced concrete beams and slabs; it was concluded that the use of bidirectional glass grid improved the flexural capacity of reinforced foam concrete prisms under three point bending test (Falliano et al., 2019), as well as using glass grid as lateral reinforcements under four point loading procedure enhanced the shear resistance of the polypropylene fiber reinforced foam concrete beams (AL-Kasasbeh and Allouzi, 2020). The application of glass fiber grids and polypropylene grid for concrete slabs improved the punching capacity, and also a better behavior at the interface between concrete and GFG compared to the glued fiber-reinforced polymer plates on the surface of the slab were noticed (Bouzeboudja and Ahmed, 2018).

According to the literature, there has recently been a surge of interest in researching the retrofitting and strengthening of reinforced concrete structural elements using advanced composite materials. The potential enhancement of flexural capacity using TRC as internal and external fabric layers of reinforced concrete beams under four-point flexural load is investigated in this study.

2. Experimental Program

2.1. Test Specimens

In this study, an experimental program was conducted on a total of four large-scale simply supported reinforced concrete beams (150x200x2000 mm) under four-point test setup. On the top and bottom sides, the beams were reinforced with 2ϕ10 longitudinal rebars with a 25 mm cover to the center of the bars. The shear reinforcement consisted of ϕ8- 150 mm-spaced stirrups.

A control beam specimen was prepared as shown in Fig. 1 where the reinforcement details of the control beam are illustrated. To exploit the potential strengthening of glass textile (GT) fabric with integrated internal and external fabric layers on the flexural capacity of RC beams, three beam specimens were also prepared: two beams of internal GT fabric, one with one layer of textile (INT1L) and one with three layers (INT3L), and one beam of external GT layer (EXT1L). All specimens had the same dimensions, concrete properties, flexural and shear reinforcements, and loading protocol. The only difference is the strengthening procedure applied. Fig. 2 illustrates the details of all tested specimens.

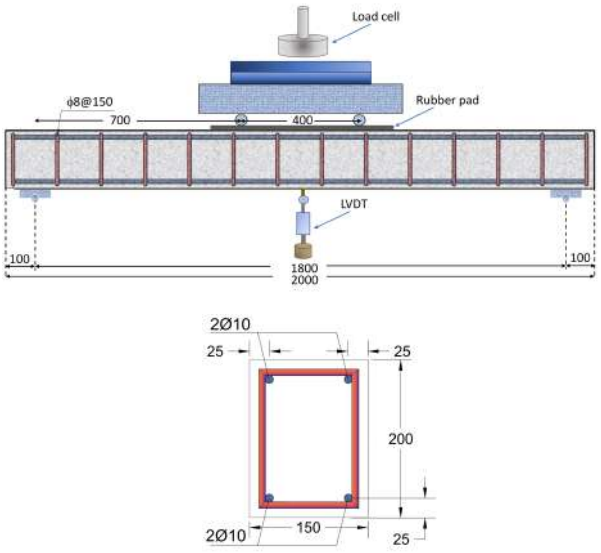
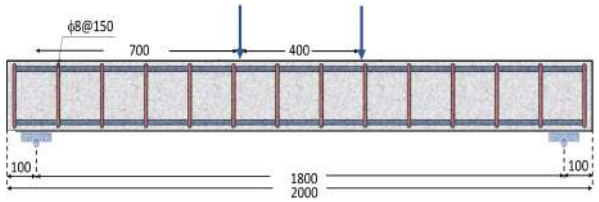
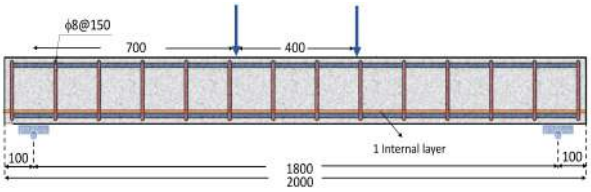


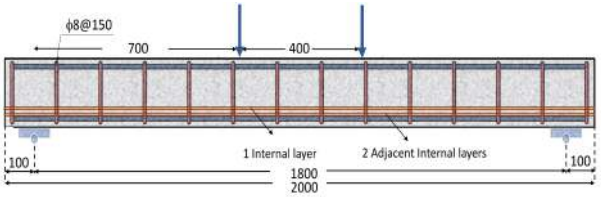
Fig. 1. Beam details



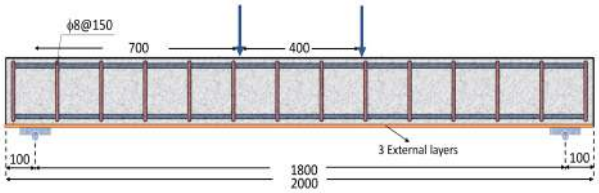
(a) Control



(b) INT1L



(c) INT3L



(d) EXT3L

Fig. 2. Details of tested beams

2.2. Materials and Methodology

The specimens were all made with the same ready-mixed concrete mixture. The compressive strength and tensile splitting strength of the concrete were experimentally determined after 28 days of testing by conducting standard tests: three 150x150x150 mm cubes were tested for compressive strength, yielding an average value of 50 MPa, and two 150 mm diameter and 300 mm height cylinders were tested for splitting strength, yielding an average value of 4.5 MPa. Fig. 3 depicts compressive and tensile testing details. For the steel bars reinforcement, the measured yield strength of the main reinforcement (ϕ10 mm) and the shear reinforcement (ϕ8 mm) were 517 and 280 MPa respectively.

The strengthening material used was a mesh woven made of high-quality fiberglass yarns impregnated with a special treatment to make the mesh alkali resistant, the characteristics of the AR-glass textile as given in the manufacturer data sheet are presented in Table 1. Fig. 4 also shows the AR-glass textile fabric used for strengthening.

The mortar (255 StarFlex LD) used was a grey powdered-cement-based, with a high polymer content, selected silicon/quartz mineral charges, and specific additives. The mortar had a fresh density of 1.6 kg/l and an initial bond strength of 2.1 N/mm^2 that can be applied up to a thickness of 15 mm.

(a)

(b)

Fig. 3. concrete specimen testing (a) tensile splitting test and (b) compressive strength test

Table 1. Components as per technical data sheet of AR-textile glass

Component	Details
Fiber glass	81%
Alkali resistant treatment	19%
Width of the mesh (warp)	4.15 mm ± 5%
Width of the mesh (weft)	3.8 mm ± 5%
Tensile strength (warp)	>35 N/mm
Elongation (warp)	5%
Tensile strength (weft)	>35 N/mm
Elongation (weft)	5%

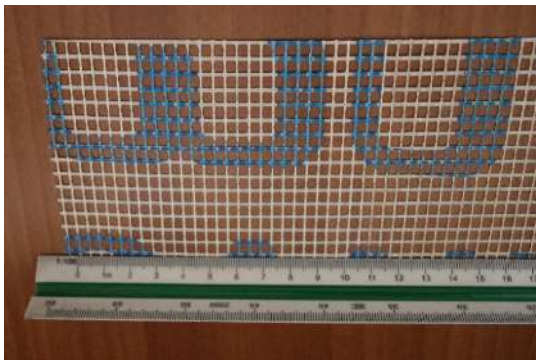


Fig. 4. Glass fabric textile

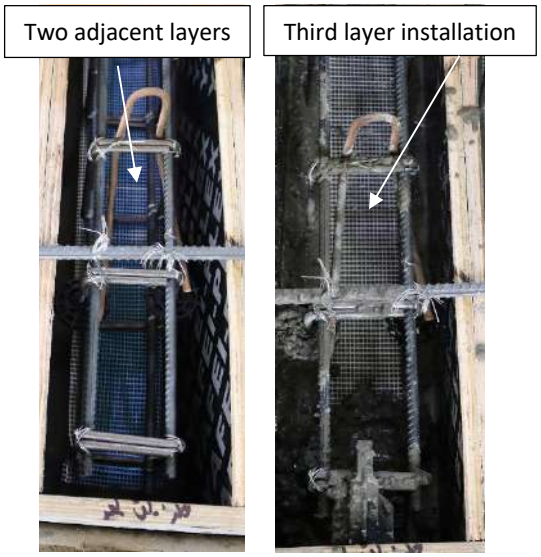
2.3. Fiber Glass Installation

The mortar mixture for the specimen with one layer of external glass textile was prepared by mixing 0.483 L of water for each 1 kg mortar in a clean bucket with an electrical mixer. The product was allowed to sit for 5-10 minutes after mixing before being re-mixed for application. Then, using a trowel, the initial layer of mortar was spread in 3 mm thickness all over the bottom surface of the beam, and the textile glass fabric was gradually placed above the mix, while troweling above the fiber glass to ensure straightness. The textile fabric was then covered with a second layer of the mixture, 2-3 mm thick. Fig. 5 shows the stages of the external glass textile fabric application.

Fig. 5. Installation of external textile fabric

The textile glass fabric was installed directly under the stirrups for specimens with one layer of internal glass textile fabric. For specimen with three internal layers of textile, on the other hand, had two layers installed above each other under the stirrups first. Following that, a 3 cm concrete layer was poured, then a third layer of textile was installed directly above the poured layer, just above the main bottom reinforcement bars. The distance between the two adjacent layers and the third layer was determined to be 1.8 cm. Fig. 6 depicts the installation of the internal textile.

(a) beam with one internal layer



(b) beam with three internal layers

Fig. 6. Installation of internal textile fabric

2.4. Testing Set-up

The beam specimens were supported on each side. The center line of the supports was placed 100 mm from the edge of the beam; thus, the center-to-center supported distance was 1800 mm. The supports were placed on rigid concrete blocks at the two edges. The load was applied gradually through a heavy-duty load cell, and deflection values were recorded every 5 kN increment. The deflection measurements were taken with a linear variable differential transformer (LVDT) placed beneath the center of the specimen. Fig. 7 shows the experimental setup of the specimens, a schematic representation of the testing setup is also shown in Fig. 1.

Fig. 7. Experimental setup of beam specimens

3. Test Results and Discussion

Fig. 8 depicts the load-deflection curves of the INT1L, INT3L and EXT1L specimens along with the control specimen. The behavior of the plotted curves differs due to the use of the AR-glass textile fabric, which affected the flexural performance of the beams. The maximum recorded load and its corresponding deflection value are presented in Table 2. Fig. 9 illustrates the failure pattern of the beam specimens observed through testing. A schematic representation of the recorded failure patterns is also shown in Fig. 10.

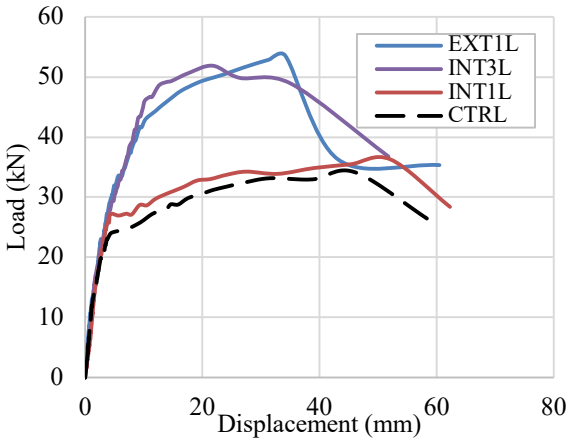


Fig. 8. Load vs. deflection curves of specimens

Table 2. Maximum load and its corresponding deflection values for specimens

Specimen	Max. Load (kN)	Deflection (mm)
Control	34.13	46.13
INT1L	36.28	52.14
INT3L	51.87	21.78
EXT1L	53.52	34.19

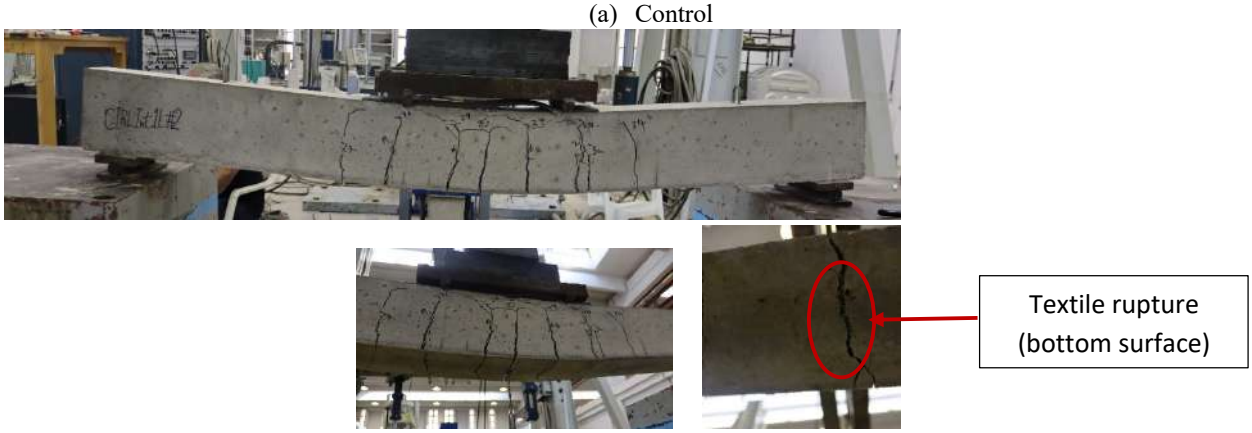
It is worth noting that the control beam specimen failed with an ultimate load of 34.13 kN and a mid-span deflection of 46.13 mm. This specimen failed in flexure after large flexural cracks formed at the constant moment region; the failure was caused by tensile reinforcement yielding followed by concrete crushing at the compression zone (Fig. 9(a)). All textile-reinforced specimens also failed under flexure at loads that were higher than the control beam specimen. The ultimate load recorded for specimens INT1L, INT3L and EXT1L was 36.28, 51.87 and 53.52 kN respectively, resulting in a flexural capacity enhancement of 6.3, 52 and 56.8% respectively, with respect to the control specimen without textile.

The maximum load recorded for specimen with one internal layer of textile (INT1L) was 36.28 kN with a 6.3% enhancement of the flexural capacity in comparison to the control beam specimen. This specimen had nearly the same load-deflection performance as the control specimen, and it was observed in the areas of maximum moment through the flexural cracks that the textile fabric ruptured (Fig. 9(b)). This indicates that using a single internal layer of textile had little effect on the beam's flexural performance or load-deflection response. On the other hand, when three layers of fibers were used (INT3L), the load-deflection curve in Fig. 8 shows that the flexural capacity increased to an ultimate load of 51.87 kN, resulting in a 52 % increase in the flexural capacity with respect to the control beam specimen. Upon failure, the flexural capacity of INT3L specimen dropped down gradually. Otherwise, the mode of failure in this specimen was else observed to be rupture in the textile fabric (Fig. 9(c)), as seen through the cracks that formed in the area of maximum moment. Thus, it can be concluded that the number of textile layers influences the flexural capacity.

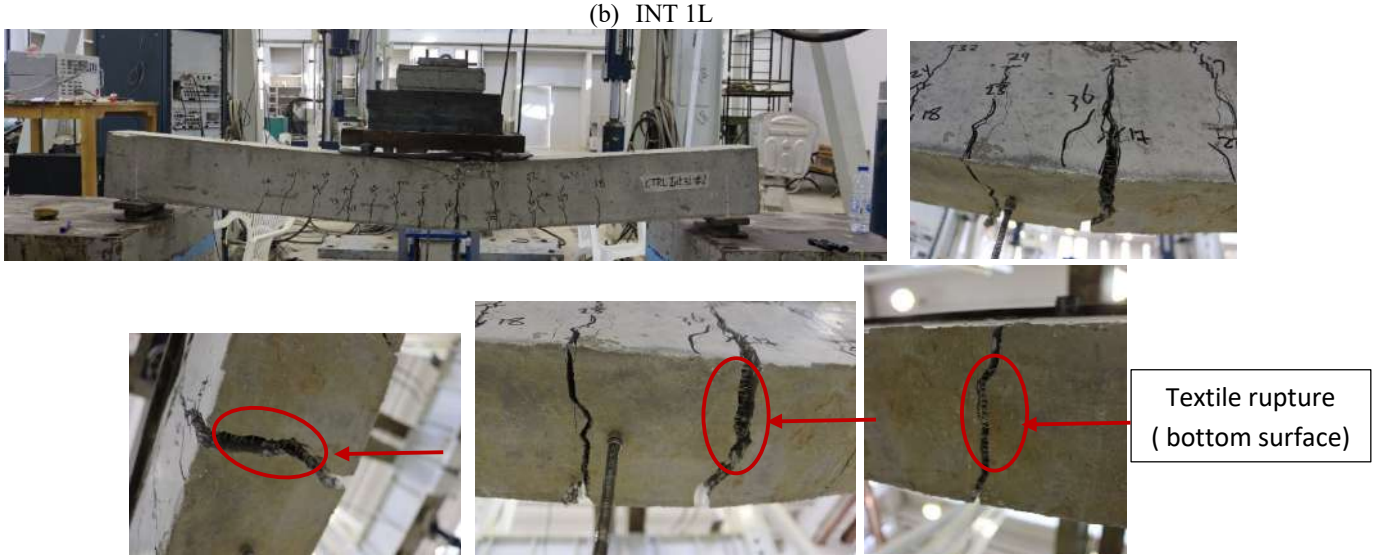
The specimen with one layer of external textile (EXT1L) recorded the highest flexural capacity of all the specimens, which was 53.52 kN with a 56.8% enhancement of the flexural capacity in accordance to the control beam specimen, however it was only 2 kN greater than the specimen with three layers of internal textile. Once reaching the maximum capacity, the flexural capacity dropped down suddenly. The failure mode reported for this specimen was fibers rupture in the region of maximum moment (Fig. 9(d)), with no debonding observed between the textile layer and the concrete surface or in the textile-mortar interface.

It can be further noticed from Fig. 8 that the load-deflection response of the specimen strengthened with external textile differs from the behavior of the specimens with one internal texile layer or more, as a significant drop in capacity was observed upon reaching the ultimate capacity for the specimens with external textile. Other studies in the literature have found a similar pattern in the load-deflection curves of externally retrofitted beams with textile fabrics under flexural loading (Elsanadedy et al., 2013; Raoof et al., 2017). Furthermore, Koutas et al. (2019) summarized different failure modes of beams strengthened in flexure with external TRM, and the load-deflection response for beams with textile where the fibers were observed to rupture has the same response as what was reported in this study for EXT1L beam.

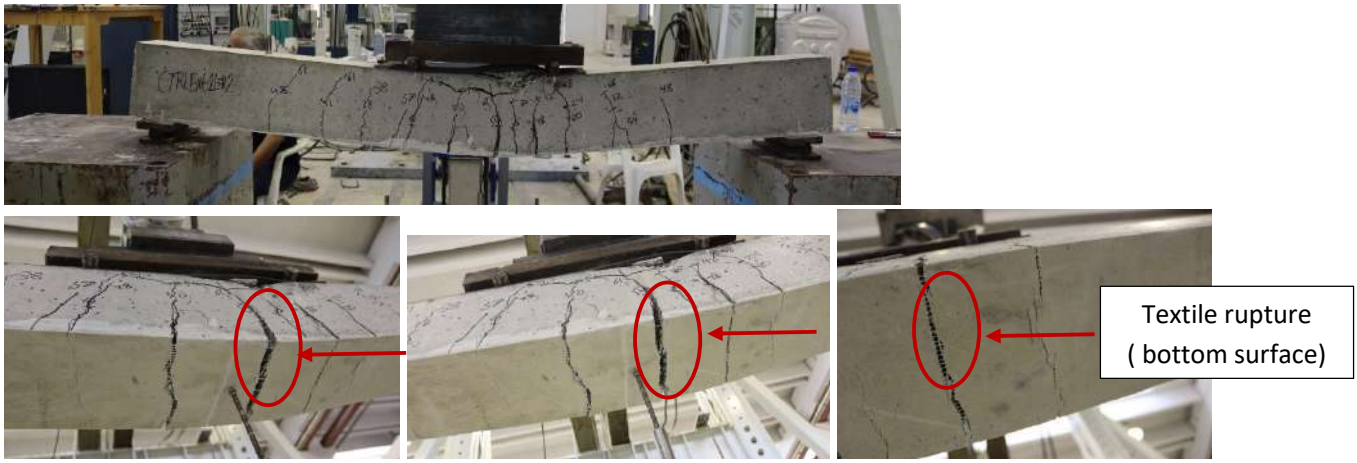
(a) Control



(b) INT 1L



(c) INT 3L



(d) EXT 1L

Fig. 9. Failure pattern of specimens

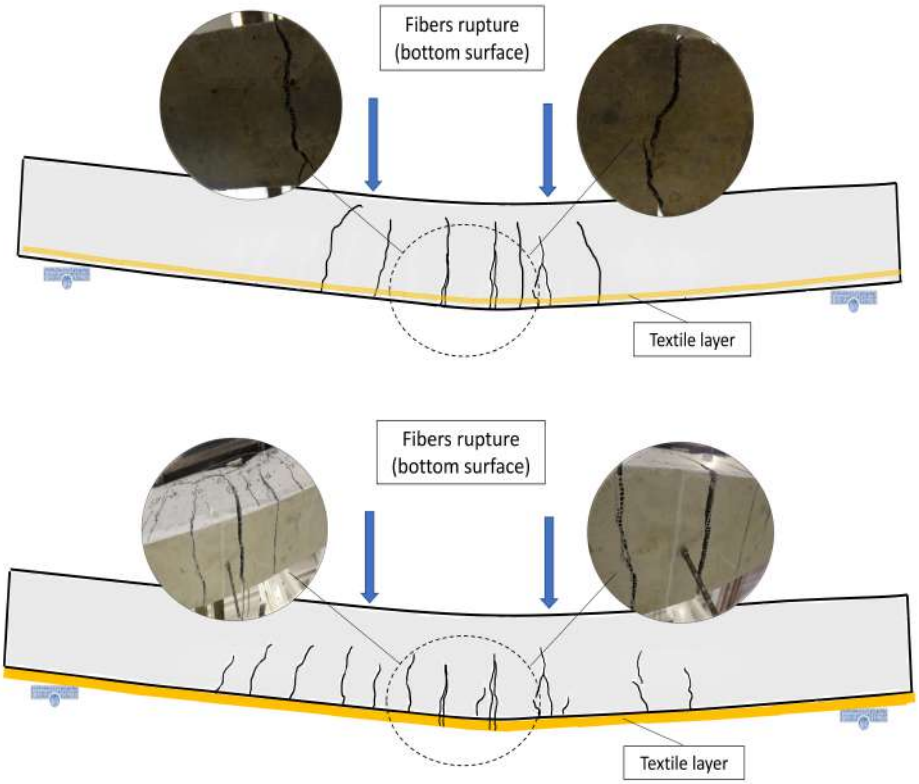


Fig. 10. Schematic of specimens failure modes

4. Conclusions

A total of four full-scale reinforced concrete beams were tested under four-point flexural testing setup. The goal of the experimental program was to investigate the potential beam strengthening using alkali-resistant glass textile fabric. Based on the load-deflection curves, mode of failure, and strengthening layer behavior, the following conclusion can be drawn:

- The use of AR-Glass textile fabric as internal beam reinforcement increased flexural capacity. However, when compared to the control specimen, using one layer resulted in an enhancement percentage of only 6.3%, whereas increasing the number of layers to three resulted in an enhancement percentage of 52%. This demonstrates that flexural capacity is sensitive to the number of layers used for internal strengthening.
- The use of AR-Glass textile fabric as external strengthening also increased flexural capacity; the beam specimen with one external layer displayed a 56.8% increase in flexural capacity when compared to the control specimen.
- The load-deflection response of the two specimens with internal textile was similar to that of the control specimen, indicating that the textile layer acted with the main steel reinforcement bars, as it was almost at the same level of the reinforcement bars. When textile fabric was used as external strengthening, the load-deflection behavior was different because the textile worked as additional tensile resisting reinforcement with larger lever arm.
- The modes of failure shapes for the beams with one external layer and with three internal layers showed similar trend, with higher bearing load capacity and less deflections compared to other beams.

Author Contributions

Raed Abendeh contributes to specimens design and preparation, experimental program, conceptualization, methodology, visualization, manuscript editing, supervision, project administration, and funding acquisition. Hesham Rabayah contributes to experimental program, conceptualization, methodology, analysis, investigation, and visualization. Rana Alhourani contributes to experimental program, conceptualization, methodology and visualization. Donia Salman contributes to specimens preparation, experimental program, conceptualization, detailing, methodology, draft preparation, and coordination. All authors have read and agreed with the manuscript before its submission and publication.

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Institutional Review Board Statement

Not Applicable

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Raed Mohammad Abendeh is Associate Professor in the department of civil and infrastructure engineering at Al-Zaytoonah University of Jordan, Amman, Jordan. He received his BS and MS from Jordan University of Science and Technology, Irbid, Jordan, in 1998 and 2001, and his Ph.D. from Technical University of Hamburg, Hamburg, Germany. His research interests include construction and building materials and finite element analysis.

Hesham Saleh Rabayah is Associate professor in the department of civil and infrastructure engineering at Al-Zaytoonah University of Jordan, Amman, Jordan. He received his MS from Jordan University of Science and Technology, Irbid, Jordan, in 1997, his MS from Amman Arab University for Graduate Studies, Amman, Jordan, in 2005, and his Ph.D. from University of Birmingham, Birmingham, West Midland, England, UK, in 2010. His research interests include sustainability, construction materials, and management. He was EPPM association president from 2020-2022.

Rana Abdelrahman Alhourani is Assisstant professor in the department of civil and infrastructure engineering at Al-Zaytoonah University of Jordan, Amman, Jordan. She received her BS from Jordan University of Science and Technology, Irbid, Jordan, in 1992, and her MS and Ph.D. from the University of Jordan, Amman, Jordan, in 1994 and 2002. Her research interests include construction and building materials and finite element analysis.

Donia Ghnayem Salman is a Ph.D. Student in the department of civil Engineering at the University of Mississippi, Oxford, MS. She received her BS from Hashemite University, Zarqa, Jordan, in 2014 and her MS from the University of Jordan, Amman, Jordan, in 2018. Her research interests include construction and building materials, materials modeling, and finite element analysis.

Paper no. 92

Pathogens and Time Overruns in Power Construction Projects in South Africa

Xola Nazo[1] and Fidelis Emuze[2]
[1]Masters Student, Department of Construction Management, Nelson Mandela University, Gqeberha (Port Elizabeth), South Africa 6031, E-mail: s198164090@mandela.ac.za
[2]Professor, Department of Built Environment, Central University of Technology, Free State, Bloemfontein, South Africa, 9300, E-mail: femuze@cut.ac.za (corresponding author)

Abstract: The demand for power plants is due to the upward need to meet electricity needs in South Africa. To meet the market, the state-owned entity, Eskom, has been developing two power stations, Kusile and Medupi, which are identical in design. However, the construction of the power plants faced difficulties that resulted in cost and time overruns. The reported study in this paper focuses on time overruns by addressing the pathogens, how they appear, and what should be done to prevent them on power projects. The adopted research strategy was case-based to allow the collection of both statistical and textual data from the two projects. The collected data established the existence of pathogens in the two projects, the extent to which the pathogens affected productivity, who was involved in enabling pathogens, what stages of the power projects were affected the most and the impact of pathogens on the projects. Post-project analysis shows the need to address pathogens with best practices related to design management, social relations, procurement, and competencies.

Keywords: Construction, management, pathogens, projects

1. Introduction

1.1. Overview of study

Pathogens in megaprojects are situations often identified as non-existing or of less importance but grow in time to be the centres of project failures. These pathogens are usually not identified due to the lack of risk analysis and management. Contractors often put themselves at risk due to bias toward similar projects and not prioritising the new project and its challenges. Love (et al., 2009) state that individuals may repeat practices, such as taking shortcuts by not following due processes in projects. When an approach provides an outcome deemed satisfactory by the individual, this practice is used on future projects, even if it is unsuitable. For example, the decision by designers to shun audits, checks, and reviews before releasing documentation for pricing or construction always led to errors and rework. Despite the importance of such activities, this practice has become a norm due to the financial and time pressures imposed upon design firms by clients. In power projects, several subcontractors are performing different work packages. If not appropriately coordinated, these entities risk non-conformance on the project. Noganta (2019) states that coordination is crucial in the management process of interdependent parties and their activities. In major construction projects with many actors, the principal contractor is faced with coordinating the interdependent subcontractors to ensure cost, quality and time requirements are achieved.

The study seeks to identify situations (pathogens) that occur during the construction of power projects in South Africa. South Africa has loaned billions from the World Bank. The biggest problem is that the power projects take longer than scheduled and cost more than planned. This creates a problem with the SOE (state-owned enterprise) having problems paying the loan and making it impossible to be profitable. Tshidavhu and Khatleli (2020) state that cost and time overruns are prevalent challenges in mega construction projects worldwide, and South Africa is no different. Although small, mega-projects have excessive project failures due to progress slippage. Megaprojects are still a phenomenon globally as they are always on budget while not meeting completion deadlines. Pathogens occur in all project phases, including proposal, design, construction, and handover. The study focuses on the construction of Medupi and Kusile power stations. The two power projects cost more than estimated and took longer to finish. This study assessed the inconsistency in the

planning and development of power projects. This will help understand the situations professionals such as project managers and engineers face in coordinating work on complex projects. The study addressed three questions:

- What are the pathogens in power project construction?
- How do pathogens appear in power project construction?
- What should be done to prevent pathogens in power project construction?

2. Method

2.1. Research design

The research method that fits the study is a qualitative study. The case study design was used in the study as it allowed direct observations and interactions with the subject. This research method creates an opportunity to compare the two cases individually with the problems and extent of problems for each case study. Lune et al. (2017) describe why most researchers that are using qualitative research use a case study method. The authors explain that scholars use the case study method to guide their research. This is achieved by concentrating on a single phenomenon, individual, community and institution. This qualitative research method used a descriptive research design to identify the actions that led to the lack of progress. Akhtar (2016) says that descriptive research aims to identify a particular situation's characteristics, such as pathogens in projects. The direction of the reported study is illustrative.

2.2. Sampling

The researcher selects the most suitable participants to interview, the type of questions to be asked, and the questions to achieve credible outcomes. Flick (2014) explains sampling as a relation to an array of matters for the whole path of the analytical process, from initial questions about the topic of study to the presentation of your work. There are several types of sampling: convenience, purposive, snowball, and theoretical. Purposeful sampling is ideal for this study as the interviews are conducted with personnel involved in Medupi (case study 1) and Kusile (case study 2) power projects.

2.3. Data collection

The sources of data were primary and secondary. The primary data were from interviews based on a semi-structured questionnaire, and the secondary data were collected from articles and newspapers. This allows the research to develop a better conclusion on the problem. Kabir (2016) explains that primary data are data that have been collected first-hand and not been published; the data have not been changed or altered. Primary data sources are experiments, interviews, surveys, questionnaires, and observations. The secondary data is explained as already published data that is used to develop a literature review; examples are books, records, biographies, newspapers, and journals.

2.4 Data analysis

The study compared the results from both case studies. A cross-case analysis is used in this study as it helps to compare the results from both cases, the differences, and the similarities. Khan and Wynsberghe (2008) explain that cross-case analysis is a research method that mobilises knowledge from individual case studies. The authors explain that mobilisation of case knowledge occurs when researchers accumulate case knowledge and compare cases; this opens room to produce new knowledge.

3. Results

3.1. cross-case analysis

Interviews with ten personnel at Kusile and ten who worked at Medupi were conducted and compared to the reports from newspapers and articles. In case study 1, the Medupi project, four senior management, four middle management and two artisans were interviewed. In the case study, one contract manager, one project commercial manager, one operations manager, and one head of department were interviewed. The middle management interviewees on the project include a civil engineering estimator, a piping supervisor, a foreperson, and a quality control inspector. The artisans that were interviewed in the project were two boilermakers. As shown in Table 1, these interviewees 1 have varying years of experience in coal power projects. The interviewees with the most experience were the project commercial manager (15 years), the operations manager (nine years), and the head of the department (eight years). Similarly, eight middle management and two artisans were interviewed in case study 2, which is the Kusile project. The interviewees in the Kusile project also have varying job roles, which include one rigging supervisor, one foreman, one welding supervisor, two quality controllers, one quality inspector, two engineers, and two boilermakers. All the interviewees in the Kusile project have been exposed to coal power projects for more than six years, as shown in Table 1. The demographic data thus show that the interviewee was able to respond to pathogen-related questions based on their lived experiences on the two power projects. The interviewees are deemed experienced in coal power project construction as their years of active service in the sector range from three to 15, as shown in Table 1.

Table 1. Profile of interviewees

	Years of experience in coal power projects	
S/N	Medupi	Kusile
P1	3	8
P2	15	9
P3	9	10
P4	8	7
P5	6	11
P6	5	7
P7	6	5
P8	3	10
P9	4	7
P10	7	8

When asked about the pathogens encountered in the two projects, the 20 interviewees provided responses outlined

in Table 2 (a and b). Notably, 15 interviewees affirmed that poor design is a pathogen they have seen on both sides of the power projects. Lack of practical project scoping and management, lack of experienced project experts, and strategic cost misrepresentation are notable pathogens in both projects, with more than 14 interviewees flagging them. The interviewees have experienced these pathogens on Medupi and Kusile power projects. These much was also highlighted in newspapers during and after the projects.

Table 2a. Pathogens in case studies

Pathogen	Medupi Responses		
	Yes	No	Unsure
Poor Design	7	3	0
Social relation issues	8	2	0
Late or incorrect procurement of material	8	1	1
Late or incorrect procurement of specialised equipment	5	4	1
Appointment of contractors	7	3	0
Planning fallacy	8	2	0
Lack of experienced experts in projects	9	1	0
Inadequate quality management	8	1	1
Inadequate project risk management	9	1	0
Inaccurate project costing	7	2	1
Lack of practical project scoping and management	9	1	0
Strategic misrepresentation in costing and budgeting	8	2	0

Table 2b. Pathogens in case studies

Pathogen	Kusile responses		
	Yes	No	Unsure
Poor Design	8	1	1
Social relation issues	5	1	4
Late or incorrect procurement of material	8	2	0
Late or incorrect procurement of specialised equipment	6	1	3
Appointment of contractors	7	3	0
Planning fallacy	5	2	3
Lack of experienced experts in projects	8	1	1
Inadequate quality management	5	2	3
Inadequate project risk management	5	4	1
Inaccurate project costing	8	0	2
Lack of practical project scoping and management	7	1	2
Strategic misrepresentation in costing and budgeting	8	0	2

Table 3 (a and b) show that pathogens can be encountered during the project planning and execution stages. The proportion of pathogens in the execution stage is more than in the planning stage. Except for the planning fallacy, the interviewees on the Medupi project believed that most pathogens occur during project execution (i.e. when construction is on). Tables 3a and 3b thus suggest that pathogens are more likely to feature at the execution stage of the case studies.

Table 3a. Stage in which pathogens are encountered

Pathogen	Medupi response		
	Planning	Execution	Handover
Poor design	2.5	7.5	0
Social relation issues	1.5	8	0.5
Late or incorrect procurement of material	0	10	0
Late or incorrect procurement of specialised equipment	0	8	0
Appointment of contractor	5	5	0
Planning fallacy	6.6	1.7	1.7
Lack of experienced experts in projects	4.83	4.83	0.34

Table 3b. Stage in which pathogens are encountered

Pathogen	Kusile response		
	Planning	Execution	Handover
Poor design	5.5	3.5	1
Social relation issues	4	5	0
Late or incorrect procurement of material	5.5	4.5	0
Late or incorrect procurement of	6.5	2.5	0

specialised equipment			
Appointment of contractor	4.5	5.5	0
Planning fallacy	4.5	3.5	0
Lack of experienced experts in projects	5	5	0

Social relations issues, however, occur during project execution on both projects. Table 4 illustrates the impact of the pathogens on progress. The interviewees were asked to rate pathogens' possible effect on on-site work progress, from minor to moderate to major. Notably, all the pathogens were rated to have either moderate or major consequences. When pathogens occur, their impact on work progress is not marginal or minor.

Table 4a. Extent of pathogen impact on projects

Pathogen	Medupi responses		
	Minor	Moderate	Major
Poor design	0	2	8
Social relation issues	2	3	5
Late or incorrect procurement of material	0	4	6
Late or incorrect procurement of specialised equipment	3	4	3
Appointment of contractor	4	5	1
Planning fallacy	2	4	4

Table 4b. Extent of pathogen impact on projects

Pathogen	Kusile responses		
	Minor	Moderate	Major
Poor design	0	3	7
Social relation issues	2	4	3
Late or incorrect procurement of material	1	5	4
Late or incorrect procurement of specialised equipment	2	3	4
Appointment of contractor	2	3	5
Planning fallacy	1	4	4

Project design-related problems have a significant impact in both case studies. The planning fallacy also has a major impact on the projects. In effect, these pathogens could derail the progress of a power project. When pathogens are encountered, some effects include strikes by workers, conflicts between contractors, and revision of designs due to errors or scope changes, as outlined in Table 5. The data further shows that project actors may be responsible for pathogens or allow them to occur. Table 6 shows that clients, designers, and contractors must look at pathogens that could emerge from their decisions and actions.

Table 5a. Pathogen effects in case studies

Pathogen Effect	Medupi responses		
	Yes	No	Unsure
Section of work placed on hold	8	1	1
Strikes	9	1	0
Conflicts between contractors	8	2	0
Change of scope	8	2	0
Revisions to drawings	8	2	0
Errors in drawings	8	2	0
Inconsistency in delivery of specialised equipment	6	3	1
Delay in delivery of material	9	1	0
Irregularities in contracts administration	5	2	3

Table 5b. Pathogen effects in case studies

Pathogen Effect	Kusile response		
	Yes	No	Unsure
Section of work placed on hold	8	1	1
Strikes	8	1	1
Conflicts between contractors	5	1	4

Change of scope	9	0	1
Revisions to drawings	9	0	1
Errors in drawings	9	0	1
Inconsistency in delivery of specialised equipment	8	0	2
Delay in delivery of material	9	0	1
Irregularities in contracts administration	5	1	4

The newspaper articles and journals often speak about Medupi and Kusile power projects at the same time as the same occurrences occurred at both power projects. The same companies run them, and the disputes are between the same parties. The media cited delays in the delivery of general or locally supplied building material and the non-availability of specialised equipment. The secondary data also underlined that pathogens have led to time overruns at Medupi and Kusile power projects.

Table 6a. Responsible actors for pathogens

Pathogen Effect	Medupi response		
	Client	Designer	Contractor
Section of work placed on hold	7.5	2.5	0
Strikes	4.5	0	5.5
Conflicts between contractors	4.83	1.33	2.83
Change of scope	6	3	1
Revisions to drawings	2.33	5.83	1.84
Errors in drawings	0.5	9	0.5
Inconsistency in delivery of specialised equipment	1.5	0.5	5.5

Table 6b. Responsible actors for pathogens

Pathogen Effect	Kusile response		
	Client	Designer	Contractor
Section of work placed on hold	4.66	4.66	0.66
Strikes	2.5	0	5.5
Conflicts between contractors	4.83	0.83	2.83
Change of scope	6.83	2.33	1.33
Revisions to drawings	4.19	4.66	1.16
Errors in drawings	2.33	6.33	1.33
Inconsistency in delivery of specialised equipment	5.5	1	2.5

4. Discussion

At the Medupi power project, the interviewees were four senior management, four middle management and 2 Artisans. This type of spread in the person giving information creates a more informed knowledge as the options on the matter may differ due to the difference in qualifications and experience. However, at Kusile, the interviewees were eight middle management and two artisans, which was also fair as the information is from reliable sources. Even though they are not senior management, middle management forms an integral part of the decision-making. At Kusile as well, the interviewees were reliable sources for valid information.

Poor design management contributes to the time overruns at Medupi and Kusile power projects. Hogg (2019) and Yelland (2021) explain the wrong decision-making in the design by Eskom and the main contractor. The authors describe the terrible decision-making on the design for fast-burning coal, yet the coal in South Africa is slow-burning. The authors use a letter from a senior engineer at Eskom for about 30 Years. It is further explained in the two documents that Eskom had to undergo modification for all the 12 boilers of the two power projects. With this information alone, there are errors in drawings, and there will be revisions. Errors in drawings and revisions in drawings are directly related to poor design. According to the data, seven interviewees at Medupi experienced poor design, which they experienced during the second project. According to interviewed persons, the poor design was experienced during the execution phase at Medupi, while Kusile experienced poor design during the planning phase. The personnel felt that poor design significantly impacted Medupi and Kusile. Both Medupi and Kusile encountered errors in drawings. The interviewed personnel also experienced revision of drawings at both Medupi and Kusile.

Social relations were an ongoing problem in both case projects. Poor social relations lead to strikes and rebellion. Strikes are directly related to social relations. For example, Pombo-van Zyl (2015) reported a strike at Medupi in 2015, while Polity (2011) also reported another strike at Kusile. The main reasons for these strikes are the proportion of expatriate employment compared to locals, wage increases,

allowances, and accommodation. According to interviewees, social relations were experienced in both Medupi and Kusile. The phase of the construction process where both Medupi and Kusile experienced social relations issues was execution. Five interviewees at Medupi thought social relations significantly impacted the construction process, but four interviewees at the second project viewed it as having a moderate effect. In general, on both projects, there was the view that contractors shoulder the blame for most contestations and strikes. The strikes affected the execution phase of the two case projects. The strikes on the projects had a significant impact.

The data also shows that delays in the delivery of material may stem from late or incorrect procurement of material. The interview data for late or inaccurate material procurement establish that both projects experienced the pathogen. The phase in which this pathogen was encountered differs. At Medupi, most responses agreed that they see this at execution, while the answers for the second project flagged the planning phase. The impact on the construction process was significant in case study 1 and moderate in case study 2. The interviewees perceived that the contractor was responsible for the delay in the material delivery in case study 1. At the same time, the client was cited as the party that created the situation in case study 2. Nine interviewees confirmed that this pathogen was experienced during the execution phase, while half of the interviewees from case study 2 experienced it during the project's planning phase. In both case projects, the interviewees thought that delay had a significant impact on work progress.

The boilers and turbines for both power projects were designed internationally, and the equipment supply was also international. This led to late procurement of materials and a shortage of parts. Molekoa (2011) reported on the late delivery of boilers and turbines, which led to the construction of the boilers being delayed from 2010 to 2012 at power project 1. Yelland (2019) reported on the shortage of parts for the boilers in case study 2, which led to parts of unit 6 being used for units 1,2 and 3. These statements by the two reporters suggest there was incorrect procurement of specialised equipment, which led to inconsistent delivery of specialised equipment. The interviewees experienced the wrong procurement of material for both projects. This pathogen was encountered in the execution phase of case study 1 and the planning phase of case study 2. The impact of incorrect procurement of specialised equipment was moderate for case study 1 and major for case 2. The inconsistency of delivery of technical equipment was experienced in both projects. Most interviewees perceived that the contractor was responsible for this effect of the pathogen, while a few flagged the client's actions in case study 2. Both project interviewees perceived this was experienced during the execution phase of the projects. The impact created by the inconsistency in the delivery of both projects was major.

There were several issues in both case projects where contractors were dismissed or contracts terminated due to underperformance. A Staff Writer (2021) on mybroadband.co.za discusses the switching of tenders between contractors on the projects. This occurred when a contractor tendered for boilers and another (with the knowledge of the first) for turbines. The awarding tender for boilers came to pass; the turbines were awarded to the aligned contractors. The author claims the switch was because external entities, investment houses for a political party, had shared at the contracting firms. This proves that there were irregularities in the appointment of contractors. This led to several other issues that led to time overruns. Interviewees for both case studies agree that the work of contractors was an evident pathogen that created chaos on-site. This pathogen was experienced in planning and execution in case study one and the caution phase for case study 2. The impact on case study 1 was moderate but major for case study 2.

Baloyi (2020) reports on a statement by Eskom on inadequate time for Kusile and Medupi power projects. "Given the inadequate time to plan, absence of suitable resources in the country (in quantum and skill) and other consequential issues, Eskom in overly optimistic way endeavoured to manage a programme of this magnitude for the country's benefit." This statement states that Eskom was never ready to partake in such a project, let alone plan for it. The planning fallacy is directly related to a lack of practical project scoping and management. Due to planning fallacy and lack of adequate project scoping and control, a change in scope occurred during construction. Therefore, there are so many issues with planning for this project. The interviewees agree that they experienced planning fallacy in case studies. The interviewees for both projects opined the planning fallacy was evident in the planning phase for both projects. The impact of the planning fallacy was from major to moderate for both projects. The interviewees experienced a lack of practical project scoping and planning. The phase of construction where this pathogen was notable is execution for case study 1 and planning for case study 2. The impact was major for case study 2. Eight interviewees agree the change in scope to have occurred in case study 1, and nine interviewees in case study 2. Notably, the interviewees held the client responsible for the change in scope in both projects, which experienced changes in work at the execution phase. The impact on the construction process major for se study project was said to be major.

Yelland (2021) reports on the defects of boilers and that these defects were created by poor workmanship. The failure to manage the quality of the welding for the boilers was due to the inexperience of the senior management. The interviewees in case study 2 and case study 1 agree that the pathogen of lack of experienced experts was experienced in the projects. It was mostly experienced at the execution phase of the projects, and it is reported to have a significant impact on the work progress.

Lindeque (2018) reports on Eskom's findings of the poor quality of work by contractors at Kusile. The power utility employed ten internationally recognised contractors to work in case study 2 for an extended period but continued to deliver substandard work. This led to some of the contractors being fined and some contracts being terminated. The report suggests that even though the contractors had experience and reputation, the contractors had inadequate quality management standards. According

to the interviewees, bad quality management was experienced in both projects. The phase of construction where this pathogen was notable was execution. The impact of the pathogen on construction was moderate in case study 1 and major in case study 2.

Ayvazoglu et al. (2019) explain that technical risks are related to the project's technological, administrative, and technical aspects. The technical risks are divided into three parts operational and maintenance risk, design risk and construction risk. In both case study projects, the risks that were ignored were design risk and construction risk. Due to defective design, confusion and rework were experienced in the construction process. The interviewees agree that inadequate risk management was evident in both projects. The stage of construction affected by this pathogen was planning for both case studies. The impact on the construction process was significant for case study 1 and moderate for case 2.

Khatleli et al. (2020) discuss the escalated prices in the case studies due to the changes in the design and modifications, as illustrated in Table 7.

Table 7. Illustration of cost escalations

Medupi Costing in Rand		
Planned cost 2007	Actual cost 2019	Percentage increase
79 billion	234 billion	66.24%

Kusile Costing in Rand		
Planned cost 2007	Actual cost 2019	Percentage increase
69 billion	452 billion	84.73%

The literature has cautioned scholars that incorrect project costs may be due to costing the project wrong from the start, the contract's time frame where prices change over time, thus creating claims with different costs and the dispute due to contracts administration due to claims. Several authors report on several companies' claims of over 4 billion Rand on construction projects. The escalation of costs or confusion in claims resulted from several defects and variations encountered by contractors due to defective design. The interviewees agree that they experienced costs for both projects. The interviewees opined that this pathogen was experienced at execution in case study 1 and the planning in case study 2. The impact of this pathogen was moderate for case study 1 and significant for case 1. Strategic misrepresentation of costing and budgeting was experienced in both projects. In case study 1, the interviewed persons suggest that this pathogen was experienced in the execution phase, and in case study 2, it was encountered in the planning phase. The impact of strategic misrepresentation of costing and budgeting was moderate on the construction process. The interviewees experienced irregularities in contract administration for both projects. They suggest that the client was responsible for this effect of the pathogen. Most data for case study 1 indicates that this effect of the pathogen was manifesting at execution and the planning phase in case study 2. The impact on the construction process was major for both projects.

There are so many issues that can be stopped on site. These are not limited to strikes, errors in drawings, incomplete work to allow another contractor to take over and changes in scope. The interviewed persons who worked in the case of studies 1 and 2 experience work sections were placed on hold because of the effects of pathogens. In case studies 1 and 2, the client is held responsible for this effect of the pathogen. This effect was experienced during the execution phase of both projects, and the impact was often major.

Contract conflict occurs mainly when they are scheduled to start their work section, but the predecessor has not completed it (during handover). This pathogen effect is experienced in the case of studies 1 and 2. While not in the immediate scene, the contributions of the clients to conflict manifestation were also mentioned by the interviewees.

5. Conclusion

The descriptive study on pathogens and time overruns herein reported seeks to make contractors, engineers, subcontractors, and investors aware of the developments of undesirable working outcomes. The study has emphasised the importance of a thorough capability investigation of the feasibility of projects. Several considerations at the inception stage of a project should not be overlooked. For instance, the planning of a project should be scrutinised in all respects, studying the new and old trends in the project scope to avoid misconceptions of ideas. The study of pathogens in mega projects identifies the lack of prioritisation in projects due to fast-tracking of the project and therefore making mistakes that will be evident later in the project life cycle. The source of these pathogens is human error developed by the pressures of a complex project and the fact that people are always trying to take shortcuts.

Tables 2 and 5 provide answers to the pathogens in power project construction. The tables highlight significant pathogens. In response to pathogens, Table 3 shows how they appear in projects. Their impact is also highlighted in the paper. Using the case study approach to assess pathogens and time overruns uncovers many problems that may be avoided on projects. The study highlights the level of inexperience at the planning stage of the project that can lead to more significant issues during the execution and handover of the project. The two fundamental aspects of the project were ignored. Firstly, the client employed an experienced contractor that is internationally recognised, having worked on similar projects in Australia. The client also employed a reputable company to design and supply

boilers. But the company's area of expertise was in the development of turbines, not boilers. And so, the design did not incorporate the performance facilitation of slow-burning coal produced in South Africa. This mistake created more significant problems and further delays as the boilers failed when tested. Secondly, gaps were flagged with environmental impact assessment (EIA). The main issue was established at the EIA level, where suggestions were made to preserve a healthy atmosphere when the power project is fully functional. The flue gas desulphurisation plant was not included in the design for case study 1 and was later incorporated into case study 2. This creates time overruns in the project.

The client and the contractors should invest a lot of time in project management training for the engineers and management. The project management training will inform them of the project's organising, directing, planning and control. In this study of two power projects, the research suggests that the primary source of pathogens was the bias of using an experienced contractor without monitoring the firm's design. This led to time overruns leaving the client with a substantial financial burden. However, other factors developed pathogens in the two power projects. These include the lack of experienced experts in power projects, procuring of material, suboptimal risk analysis of power projects, suboptimal total quality management, inaccurate estimating and contract understanding and adherence. These pathogens are somehow related; total quality management is directly linked to defective design, and inaccurate estimating is, to a certain extent, developed by defective design. A pathogen may create a situation that develops another pathogen as the construction process continues.

Ignorance and taking situations lightly were the major downfall for the client in both case power projects. The information and reports from newspapers and articles declare that the two projects have been delayed by seven years. This is appalling as it suggests that these two projects' participants are incompetent. The primary instigators of delay were the boilers' design and welding. The issues with the design morphed into commissioning failures as the power utility had no information about the sub-optimal design they implemented and the fact the contractors did not have enough artisans who could perform the welding required for the boilers that were developed. There were several other issues, such as the late delivery of boilers and turbines, which led to a delay in case study 1 for two years, the late incorporation of changes to the design and shortages of parts for boilers in case study 2. It did not end there; the social issues also came to play, leading to strikes and work being placed on hold. The study declares the inconsistency in the development and planning process of the two cases as a primary problem in the development of the projects. Part of the planning process, which in most projects is ignored, is the implementation of social-related parameters that the contractors must adhere to for that country's laws and regulations for the employment of the people in projects. The pathogens led to time overruns in these two projects as the problems were only picked up at the execution phase. This became a big problem as it also created conflicts between contractors; this is merely evident when work sections were placed on hold due to inadequate quality, thus delaying the successor's progress. Projects like these involve many contractors responsible for a particular area of work. As with all case studies, the results presented in this paper can only be transferred to a similar context as it does not provide opportunities for statistical generalisations.

Author Contributions

Xola Nazo contributes to conceptualisation, methodology, analysis, investigation, data collection, and draft preparation. Fidelis Emuze contributes to conceptualisation, methodology, analysis, investigation, data collection, manuscript editing, supervision, and project administration. Both authors have read and agreed with the manuscript before its submission and publication.

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Xola Nazo, PGDip, is an MSc Built Environment candidate at the Nelson Mandela University (NMU), South Africa. Project management, construction estimating, and procurement is his area of research and undergraduate qualifications.

Fidelis Emuze, PhD, is a Professor and Head of the Department of Built Environment at the Central University of Technology, Free State (CUT), South Africa. Lean construction, health, safety, and sustainability constitute the primary research interest of Dr Emuze, who is a National Research Foundation (NRF) C-rated researcher that has published over 250 research outputs and received over 25 awards and recognitions. Dr Emuze is the editor of *Value and Waste in Lean Construction*, *Valuing People in Construction*, and co-editor of *Construction Health and Safety in Developing Countries*. Dr Emuze authored *Construction Safety Pocketbook for South Africa* in 2020. Dr Emuze is the International Coordinator of CIB W123 – People in Construction Working Commission.

Paper no. 98

Mechanical Perefeormance of Cellular Concrete Incorporating Silica Fume and Polypropylene Fibers

Raed Abendeh[1], Mousa Bani Baker[1] and Donia Salman[2]
[1]Associate Professor, Department of Civil and Infrastructure Engineering, Al-Zaytoonah University of Jordan, Amman, Jordan; E-mail: r.abendeh@zuj.edu.jo; Email: m.banibaker@zuj.edu.jo
[2]Ph.D. Student, Department of Civil Engineering, University of Mississippi, Oxford, MS, USA, E-mail: dgsalman@go.olemiss.edu (corresponding author)

Abstract: Cellular concrete, often known as lightweight concrete, has been widely employed in construction. Despite its advantages in terms of weight, thermal insulation, and fire resistance, its relatively low strength is a major concern to be used in structural applications. Thus, three different groups of cellular concrete are prepared for a possible increase in the cylindrical compressive strength of more than 17 MPa with dry density of less than 1900 kg/m^3 to be used structurally based on ACI 213R. The first group included five mixes with 0.84, 1.05, 1.16, 2.1, and 2.76% silica fume (SF) addition, the second group included two mixes with 0.2 and 1.16% polypropylene (PP) fiber addition, and the last group included two mixes with 0.65 and 0.87% of both SF and PP fibers respectively. The effects of foam agent content, water cement ratio, sand size and content, and SF and PP fiber as additives on the density and compressive strength of cellular concrete are investigated in this study. The fresh and dry densities, as well as the compressive strength, are recorded for each mix. The results revealed that the introduction of SF and/or PP fibers in cellular concrete mixtures increased the density and compressive strength. Moreover, some cellular concrete mixtures are feasible to be used in structural applications.

Keywords: Cellular concrete, Silica fume, Polypropylene fibers, Compressive strength, Density.

1. Introduction

Cellular concrete is typically made up of cement-based material and sometimes lime additives, with or without sand, and pozzolanic materials can be used to partially replace the binder to improve its properties (Dolton and Hannah, 2006). A void system matrix is generated in cellular concrete by the addition of a physical or chemical expansion agent that includes air in the mortar, the application of foaming agents to the mixture, or by vacuum curing, which results in the formation of pores owing to internal strains induced in the paste.

The use of cellular concrete dates back to the early 1920s, when it was used for insulation (Sach and Sefert, 1999). Axel Eriksson patented the first cement-based cellular concrete, known as Ytong (Amran et al., 2015), in 1923. However, in the 1950s and 1960s, a detailed investigation of the composition, physical characteristics, and manufacturing of cellular concrete was first conducted (Valore, 1954; Valore, 1954; Rudnai, 1963). In the late 1970s and early 1980s, additional admixtures were created as a result of this research, leading to the commercial usage of cellular concrete in construction projects. Foam concrete, lightweight cellular concrete (LCC), and low-density cellular concrete (LDCC) are all terms used to describe cellular concrete.

Foaming agents based on hydrolyzed proteins first appeared on the market in the late 1950s, allowing air cells to be more stable while maintaining adequate density control. Around 1990, synthetic foaming agents were developed, which led to highly stable air cells with a longer life in the concrete plastic state, resulting in more durable concrete (Gomez, 2015). In the last two decades, advances in the production of superplasticizers and the development of hybrid foaming agents (a mix of protein and synthetic agents) have enabled the widespread use of foamed concrete, and significant efforts have been made to investigate the characteristics and mechanical behavior with the goal of using cellular concrete as a primary construction material. The effects of agent concentration in cellular concrete have been shown to be primarily on pore distribution and size, which determine final strength (Kuzielová et al., 2016).

Because of the entire material volume savings, cellular concrete offers a low-density material that makes it an attractive, cost-effective option to conventional concrete (Alamayreh et al., 2022). This lightweight classified concrete has recently been produced with a wide variety of

densities (300-1600 kg/m^3), compressive strengths (0.3-30 MPa), and thermal conductivities (0.2-0.8 Wm-1 K-1) (Sun et al., 2018; Gokce et al., 2019; Khan et al., 2019; Xie et al., 2018). The air content also ranges from 10% to 70% in cellular concrete (Panesar, 2013).

The main advantages of cellular concrete over traditional concrete are weight savings of up to 80%, high strength-to-weight ratio, excellent acoustic and thermal isolation, high fire resistance, lower raw material costs, high energy absorption, easier pumping, and application due to its self-flowing behavior in its fresh state, and the fact that it does not require compacting, vibration, or levelling. As a result, this form of concrete is commonly utilized for building panels, fire protection walls, and energy absorption pads (Panesar, 2013; Tikalsky et al., 2004; Jones and McCarthy, 2006), as well as a construction material for impact-resistant protective structures (Deng et al., 2016; Nian et al., 2016). It is also used to create masonry units such as bricks, floors, and trench filling. However, the loss in density caused by the addition of foam is accompanied by a decrease in strength and heat conductivity (Legatski, 1978). The porosity of foamed concrete, which is governed by air voids, are considered to also have a substantial impact on the concrete's compressive strength and durability (Hoff, 1972), limiting its practical applicability (Panesar, 2013).

Silica fume (SF) is a powdered form of amorphous silicon oxide that can be used as a supplement component to replace some of the cement in cellular concrete. Because of the filler properties and pozzolanic behavior, SF is currently used to strengthen foamed concrete in a short amount of time (Jones and McCarthy, 2005; Nambiar and Ramamurthy, 2006). In addition, SF is basically inorganic silica particles ranging in size from nano to microns. As a result, it can be utilized to stabilize foam by adsorbing particles onto liquid-gas (bubble) interfaces in an irreversible and spontaneous manner (Muth et al., 2017).

Various studies on the use of SF in cellular concrete have been conducted; Gokce et al., 2019 investigated the mechanical performance of foamed concrete by testing a total of forty-five specimens with varying replacement levels of fly ash and SF (0, 10 and 20%, by weight of cement) at three foam contents (0, 31 and 47%, by volume), cured under three conditions (7 and 28-days standard water curing and autoclave curing). It was concluded that SF enhanced the density of foamed concrete by up to 55% for specimens with constant foam content, also SF inclusion lowered the water absorption value by up to 67%. In high fly ash mixtures, the reduction in compressive strength produced by foam addition was more pronounced (up to 97% reduction). However, using SF increased the compressive strength of foam concrete by up to 4.4 times at the same foam level; this impact was more significant in mixtures with higher foam contents. Furthermore, increasing the foam content increased the compressive strength- to-thermal conductivity ratios of SF mixtures by up to four times. While fly ash incorporation decreased the compressive strength-to-thermal conductivity ratios of combinations with high foam concentration (47%) up to 38%, also it increased this ratio by around 33% in mixtures with low foam level (31.4%). In this regard, the authors concluded that SF outperforms fly ash.

Fani et al., 2020 studied the influence of SF and polyurethane on the density and strength of cellular concrete subjected to varied curing conditions of 28, 65, and 90 days. The specimens were prepared with varying SF as a partial substituent of cement ranging from 0-20% by weight of cement and polyurethane (0-20% by volume). The results revealed that the absence of SF and the presence of polyurethane in mixtures resulted in a decrease in the density and strength of cellular concrete. However, the addition of SF resulted in increased density and strength, demonstrating the usefulness of the pozzolanic action in SF as well as its ability to introduce homogeneity in the pore structure.

Fibers can be natural or synthetic in origin, and they enhance the strength of foam concrete. Alkali resistant fiberglass, kenaf, steel, palm fiber, and polypropylene (PP) fiber are some of the fibers being utilized. Because fiber introduces a ductile elastic-plastic zone, it can alter the typical behavior of cellular concrete (Chica and Alzate, 2019). However, studies have found that foamed concrete reinforced with PP fibers has improved mechanical properties (Rasheed and Prakash, 2015).

Hamad (2015) investigated the impact of adding PP fiber on the mechanical properties of foamed concrete. By total volume of concrete, the percentages of PP used in mixtures were 0, 0.1, 0.2, 0.3, 0.4, and 0.5. It was noticed that the flowability of foamed concrete reduced as the proportion of PP fibers increased; nevertheless, the dry density, compressive strength, and splitting tensile strength increased as the percentage of PP fibers increased.

Allouzi et al., 2020 prepared two different foamed concrete group specimens with or without sand, with two different water-to-cement ratios and three different PP levels of 2, 3, and 4% by weight of cement. It was noticed that using PP fibers had a significant impact on the workability of mixtures containing sand and a minor impact on mixtures containing no sand. Besides, the compressive strength of foamed concrete mixtures without sand increased as the PP fiber content increased. Mixtures containing sand, however, have a decrease in compressive strength with increasing PP fiber concentration, with the exception of mixtures with higher foam agent content and mixtures with high-range water-reducing admixtures. Furthermore, using PP fibers affects the density of mixtures with sand due to reducing the flowability of these mixtures, whereas minimal effects were seen using PP fibers on the density of mixtures without sand.

This paper reports a study of the mechanical characteristics of cellular concrete specimens with varying SF or PP dosages, or both. The possible applications of the proposed mixtures for structural elements are investigated and addressed.

2. Materials and Methods

2.1. Materials

In this study, ordinary Portland cement and silica fume were used as a binder material. Table 1 shows the properties of cement. The SF utilized (Fumed Silica G-21) was synthetic, hydrophobic, and amorphous, with a high-quality white colloidal powder produced by flame hydrolysis and an average primary particles size of 12 nm. Coarse and fine silica-based sand was also used in the mixtures, Fig. 1 presents the sieve analysis of the coarse and fine sand. High-performance monofilament

polypropylene fibers (Master fiber 012) with the following specifications were also used in this study: 100 percent virgin PP with a specific gravity of 0.91 g/cm^3, tensile strength of 350 MPa, Youngs modulus of 3500 to 3900 MPa, and individual fiber length of 12 mm and thickness of 18 microns. It is also compatible with various admixtures and can be used with all types of cement. The preformed foam was prepared in the laboratory by combining foaming agent and water, also it required the use of compressed air equipment to create bubbles, in accordance with ACI 523.3R (ACI Committee 523, 2014). The foaming agent used was a synthetic pale-colored liquid-based foaming agent made of selected anionic surfactants with a specific gravity of 1.03 that is soluble in water and suitable for the design of foamed concrete with densities ranging from 300 to 1800 kg/m^3. The specifications of the foaming agent fully comply with the requirements of ASTM C 869, and it can also be used with all types of Portland cement, including sulphate-resistant cement and cement replacement materials. A Dark-brown liquid superplasticizer (Conplast SP500) with a PH of 6.6 and a specific gravity of 1.25 that can be used with all types of cement except high alumina cement was used. The superplasticizer complies with ASTM C494 type F and G admixture.

Table 1. Properties of cement

Compound	%
CaO	68.596
SiO_2	12.866
FeO or Fe_2O_3	4.967
Al_2O_3	4.098
MgO	3.126
SO_3	2.422
K_2O	2.396
TiO_2	0.780
Na_2O	0.37
P_2O_5	0.135
MnO	0.082
NiO	0.058
Cr_2O_3	0.048
Cl^-	0.042
ZnO	0.015

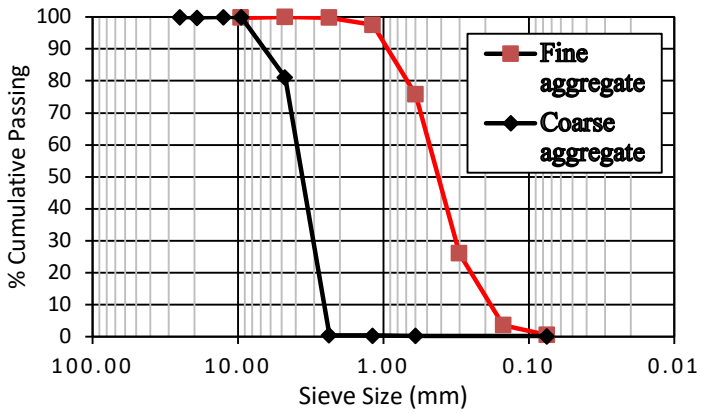

Fig. 1. Sieve analysis of coarse and fine aggregate

2.2. Methods and Mixing Preparation

Ordinary Portland cement, coarse sand, and fine sand were added in the mixer in the needed amounts for the desired mix. If the mixture contained either SF or PP, or both, they were also added. Then the materials were dry mixed for 60 seconds. The water was then added in the required amount, and the water used was fresh and drinkable according to ACI 523.3R (ACI Committee 523, 2014). After that, the mixture was stirred for around 120 seconds, or until it became homogeneous. If the needed mix included plasticizer, it was also added and the mixture was stirred for another 120 seconds; otherwise, no plasticizer was added. The foam mixture was then added to the mortar to form the cell structure (Panesar, 2013). Thereafter, the foam-containing mixture was then agitated for 120 seconds at a rotation rate of 60 r/min. Following that, the freshly foamed paste was prepared.

2.3. Sampels Preparation

Ten cellular concrete mixtures were designed in this study to achieve a mixture suitable for structural application. Silica fume and/or polypropylene fibers were incorporated as additive materials in these mixtures to evaluate their application in cellular concrete.

The fresh and dry density values for the mixtures were recorded also, three specimens of each mixture were prepared for the compressive strength test using 100x100x100 mm cubes. The cubes were kept at a room temperature of 20 ± 2 ºC for 24 hours, then they were exposed to 28-day standard water curing after demolding. Table 2 presents the mixture design of all specimens.

The specimens were identified using the following designation: C stands for specimens with no SF or PP fiber additives; S stands for specimens with the addition of SF; P stands for specimens with the addition of PP fibers; and PS stands for specimens with the addition of both SF and PP fibers.

Table 1. Mix proportion of cellular concrete specimens

Mixture	Designation	Cement (g)	Water (g)	w/c	Fine sand (g)	Coarse sand (g)	Super Plasticizer (g)	SF %	PP %	Foam %
C	C1 C2 C3	1900	650	0.34	2500	-	-	-	-	3.16

S1	S1a S1b S1c	3800	1200	0.32	2500	2500	-	0.84	-	4.37
S2	S2a S2b S2c	3800	1200	0.32	2500	2500	-	1.05	-	3.16
S3	S3a S3b S3c	3800	1300	0.34	1000	4000	-	1.16	-	2.89
S4	S4a S4b S4c	10000	3400	0.34	5000	5000	80	2.10	-	2.00
S5	S5a S5b S5c	3800	1200	0.32	2500	2500	-	2.76	-	3.58
P1	P1a P1b P1c	5000	1700	0.34	2500	2500	40	-	0.20	2.00
P2	P2a P2b P2c	1900	650	0.34	2500	-	-	-	1.16	3.16
PS1	PS1a PS1b PS1c	10000	3400	0.34	5000	5000	80	0.65	0.65	2.00
PS2	PS2a PS2b PS2c	3800	1200	0.32	2500	2500	-	0.87	0.87	6.05

3. Results

There was no specific target density in the design of the mixtures in this study, however numerous mixtures were made with the goal of obtaining a reliable cellular concrete mix with an optimum between density and compressive strength. Thus, the mixes that accomplished this were reported in this study. Table 3 shows the density and compressive strength (CS) test results after 28 days. The results are also plotted in Fig. 2, and the details of each specimen, such as the foam content (FC) and water-to-cement ratio (w/c), are shown. The w/c for the specimens was designed to be in the range of 0.32-0.34.

Table 2. Results of specimens

Mixture	Designation	Fresh density (kg/m^3)	Dry density (kg/m^3)	Compressive strength (MPa)	Average Compressive strength (MPa)
C	C1 C2 C3	1565	1377	7.70 6.30 8.70	7.57
S1	S1a S1b S1c	1570	1415	5.40 4.50 5.00	4.97
S2	S2a S 2b S2c	1900	1675	27.20 28.20 28.10	27.83
S3	S3a S3b S3c	1652	1340	25.40 24.80 excluded	25.10
S4	S4a S4b S4c	2000	1890	36.00 35.00 34.30	35.10
S5	S5a S5b S5c	1900	1677	31.10 30.00 28.10	29.73
P1	P1a P1b P1c	1850	1775	22 24 excluded	23.00
P2	P2a P2b P2c	1950	1700	30.00 27.10 excluded	28.55
PS1	PS1a	2050	1912	27.90	28.97

	PS1b			29.00	
	PS1c			30.00	
PS2	PS2a	1855	1676	19.59	18.45
	PS2b			17.30	
	PS2c			excluded	

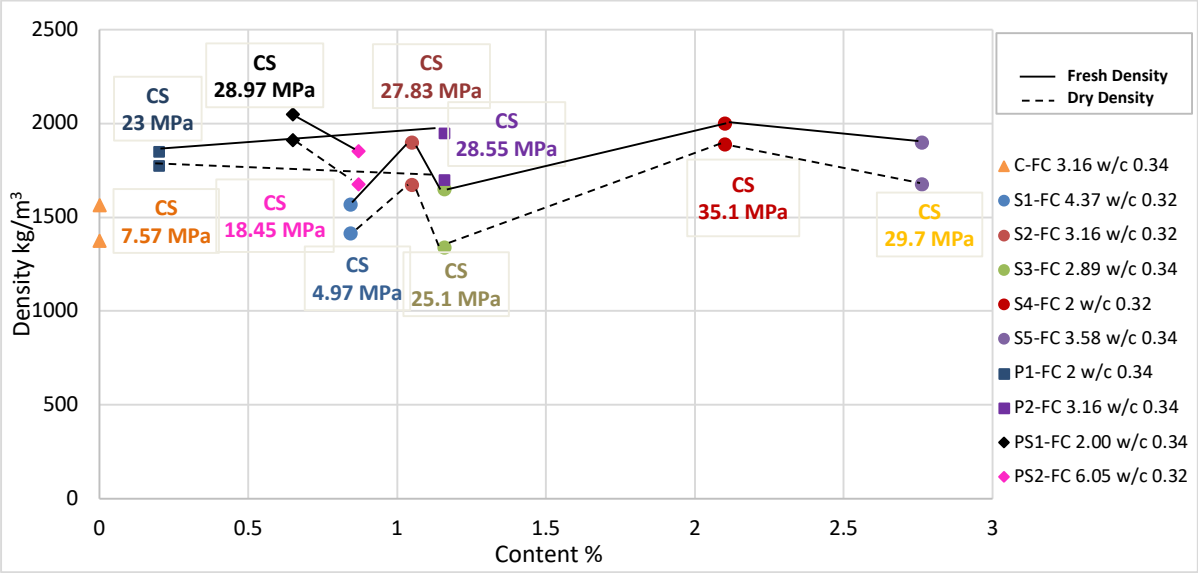

Fig. 2. The fresh and dry densities of cellular concrete specimens with the variation of additives content

4. Discussion

Fig. 2 shows that the incorporation of SF in S1, S2, S4 and S5 increased the dry and fresh densities in all specimens with respect to the control specimen. The dry density values were 1415, 1675, 1890 and 1677 kg/m^3 respectively. This is because the fineness of the supporting cementitious materials has a considerable influence on density, as fine silica particles form a coating over the air bubbles and inhibit flocculation, resulting in a homogeneous void structure. It has also been reported through literature that the addition of pozzolans like SF enhances the density of cellular concrete (Cong and Bing, 2015). However, a decrease in dry density was observed in the S3 specimen, which had a value of 1340 kg/m^3. Since this specimen had a higher coarse sand content of 105.3% compared to the other specimens, which had 50% for one specimen and 65.8% for all other specimens. Furthermore, the fine sand content in this specimen was 26.32%, which was less than the coarse sand content, but other specimens had the same coarse and fine sand content.

Additionally, the compressive strength values for S2, S3, S4, and S5 specimens were enhanced to 27.83, 25.10, 35.10, and 29.73 MPa respectively. However, a drop in compressive strength was observed in the S1 specimen, which had the highest foam content (4.37%) among the other specimens. This increased the voids and hence reduced the strength. Besides, when compared to other specimens, specimen S4 had the highest density and compressive strength values; this specimen was created with the lowest foam content and was the only specimen to have superplasticizer among SF-based specimens.

It can be also noted that the addition of PP increased the fresh and dry densities of the specimens. The dry density of the reference mix (C) was 1377 kg/m^3, while the dry density of mixes including 0.2% and 1.16% PP fibers was 1775 and 1700 kg/m^3 for P1 and P2 respectively. On the other hand, the compressive strength values were 23 and 28.55 MPa for P1 and P2, respectively. Various investigations have demonstrated that the compressive strength of foamed concrete containing PP fibers increases, as the PP fibers fill the air voids and reinforce the concrete. It should also be noted that the P2 specimen with the higher PP content produced higher strength than the P1 specimen, despite having a higher foam percentage. Furthermore, both specimens nearly provided the same dry density with P1 having the higher density. This is due to the fact that the P1 specimen had coarse sand, but the P2 specimen was prepared without coarse sand.

PS1 and PS2 specimens with both SF and PP fibers had dry densities of 1912 and 1676 kg/m^3 respectively; the dry density of PS1 specimen was the highest reported among all other specimens of different groups. PS1 and PS2 compressive strength values were 28.97 and 18.45 MPa, respectively, in comparison to the reference specimen (7.57 MPa). Furthermore, specimen PS2 had the highest foam content of 6.05% of all specimens in all groups. However, due to the addition of both SF and PP fibers, it still provided good density and compressive strength values.

5. Conclusions

This study investigated the use of silica fume and polypropylene fibers in cellular concrete mixtures for structural purposes. From the results obtained, the conclusions can be drawn as follows:

- The use of SF as an additional material increased the density, and thus the strength, of cellular

concrete. This is owing to the pozzolanic effect of the SF as well as its ability to introduce homogeneity into the pore structure of cellular concrete. However, increasing the foam content decreased the density, therefore in addition to the additives, the foam content in mixes must be controlled.

- The incorporation of PP fibers as additional materials improved both the density and compressive strength of specimens by filling the air space and reinforcing the cellular concrete. Furthermore, despite having a larger foam content and no coarse sand, the specimen with a higher PP content produced higher strength than the other specimen with PP fibers.
- The inclusion of SF and PP fibers increased the density and compressive strength values. Due to the addition of both SF and PP fibers, the specimen with the highest foam content among the other groups provided good density and compressive strength results.

Author Contributions

Raed Abendeh contributes to experimental preparation and testing, design of specimens, conceptualization, methodology, investigation, supervision, project administration, and manuscript editing. Mousa Bani Baker contributes to experimental preparation and testing, design of specimens, conceptualization, methodology, investigation, supervision, and funding acquisition. Donia Salman contributes to visualization, methodology, conceptualization, and writing origional draft. All authors have read and agreed with the manuscript before its submission and publication.

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Institutional Review Board Statement

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Raed Mohammad Abendeh is Associate Professor in the department of civil and infrastructure engineering at Al-Zaytoonah University of Jordan, Amman, Jordan. He received his BS and MS from Jordan University of Science and Technology, Irbid, Jordan, in 1998 and 2001, and his Ph.D. from Technical University of Hamburg, Hamburg, Germany. His research interests include construction and building materials and finite element analysis.

Mousa Bani Baker is Associate Professor in the department of civil and infrastructure engineering at Al-Zaytoonah University of Jordan, Amman, Jordan. He received his BS from Jordan University of Science and Technology, Irbid, Jordan, in 2000, and his MS and Ph.D. from Concordia University, Montreal, Quebec, Canada, in 2003 and 2010. His research interests include construction and building materials, geotechnical and foundation engineering.

Donia Ghnayem Salman is a Ph.D. Student in the department of civil Engineering at the University of Mississippi, Oxford, MS. She received her BS from Hashemite University, Zarqa, Jordan, in 2014 and her MS from the University of Jordan, Amman, Jordan, in 2018. Her research interests include construction and building materials, materials modeling, and finite element analysis.

Paper no. 99

Brief Clarity and Project Performance: Comparing Two Prediction Methods

Ali Vahabi[1], Farnad Nasirzadeh[2] and Anthony Mills[3]
[1]Ph.D. Candidate, School of Architecture and Built Environment, Deakin University, Waterfront Campus Geelong, VIC 3220, Australia, Email: avahabi@deakin.edu.au
[2]Senior Lecturer, School of Architecture and Built Environment, Deakin University, Waterfront Campus Geelong, VIC 3220, Australia
[3]Professor, School of Architecture and Built Environment, Deakin University, Waterfront Campus Geelong, VIC 3220, Australia

Abstract: Prediction of the influence of brief clarity on project outcomes at an early stage is a sustainable approach to mitigate latent changes and reworks throughout a project delivery. This leads to unavoidable extra cost and time and wastage of materials. However, the prediction process is complex since there are multiple interrelationships between processes and activities during the project delivery that are impacted by the briefing process. Moreover, a lack of project data at the early stage of the project delivery increases uncertainties in predicting accurately. This article reviews two developed simulation methods that address the highlighted issues and predict the influence of brief clarity on project performance. For this purpose, the influence of briefing on project outcomes was modelled by the system dynamics (SD) approach. Then, the initial brief clarity, as the model input, was measured using two different techniques to apply in the simulation model: 1) measured a range of values utilizing a fuzzy inference system at the early stage of the project when there is a lack of project data 2) measured a fix value, which is more accurate, using the project definition rating index (PDRI) tool when the first draft of the initial brief is prepared and more project data is available. The obtained value of the initial brief clarity from each approach was then applied separately into the adopted SD model to predict the project outcomes. In the end, two simulation methods were implemented in a refurbishment project to evaluate their outcome's reliabilities. The simulation results confirm that the two proposed methods can be effective in assessing the influence of brief clarity on project performance if each method is applied on the right stage of the project delivery.

Keywords: fuzzy inference system, initial brief clarity, , project performance, project definition rating index, system dynamics.

1. Introduction

Construction of new buildings and refurbishments allocate 58% of total Australian construction market (Master builders Australia, 2017). Although the data indicates the crucial role of buildings in the country's economy, this construction sector faces extra cost and delay, particularly in the conventional delivery system of design-bid-build (DBB). One of the key routes of cost and time overruns in the DBB projects is the lack of the brief clarity at the early stage (Yang et al., 2020). Briefing is a process that defines project requirements and client expectations and transfers them to design teams and other associated stakeholders (Molwus et al., 2017). Thus, if the brief is not clarified to the project team, there is a possibility that the completed design or construction works do not meet the project requirements, which will lead to changes and reworks throughout the project delivery. This means that any effort in clearly defining the brief increases the chance of project success within the budget and time schedule. Previous studies on methods to improve the brief clarity led to proposing guidelines, from a high-level review to a detailed instruction of activities which is needed to be provided for a brief (Tang, 2011; Collins et al., 2017). These methods' usages are limited to the process of briefing though. So, if the brief includes ambiguities after defining, these methods are not applicable to predict, assess, and control the consequences of the unclear brief. The prediction and assessment of the lack of brief clarity is beneficial for clients at the early stage before the beginning of the project delivery stage. However, this prediction is very challenging since DBB projects are complex due to several processes and activities, which are executed sequentially or concurrently. This creates multiple interrelationships between the activities that change over time. Although past research evaluated the briefing impact on the project

performance, their results did not reproduce a real DBB project delivery system since the complexities of many interrelationships between the processes and activities, were not considered over time (Xia et al., 2015). System dynamics (SD) modelling is an effective approach to capture and simulate the complex and dynamic influence of brief clarity on project performance. Chritamara et al. 2001 modelled the impact of the initial brief establishment on a project, while its outcome looks inaccurate. This is because the research assumed the completed design percentage as the indication of the brief completeness level, which cannot be right. A clear project brief can be prepared for a project, while the design is not completed yet, which means that the brief clarity level is not directly correlated to the completed level of the design (Xia et al., 2015). Thus, proposing a method that can measure the clarity level of the initial brief to apply in dynamic models for assessing the influence of the brief clarity is a gap in the past studies.

This paper reviews the proposed PDRI-SD approach that addresses the identified gap. In this approach, the project definition index rating (PDRI) tool is combined with the SD model to simulate the impact of the initial brief clarity on project cost and time. The SD was used to develop a dynamic model of the briefing, while the initial brief clarity, as the model input, was measured by PDRI. Then, the reliability of the proposed approach was evaluated in a real refurbishment project. The results indicated this approach is effective to assess the brief clarity impact on project cost and time, especially when the initial brief draft is prepared, and early data of the investigated project is available.

Although the PDRI-SD approach can simulate the influence of brief clarity, the accuracy of the simulation depends on the available data of the investigated project. This means the accuracy is improved when the project data reaches a certain level, which usually occurs after preparing the first draft of the initial project brief. So, utilising PDRI-SD before preparing the initial brief increases the uncertainties in the simulation outcomes, which limits the application of this approach. Also, the PDRI tool measures a single value for the clarity of the initial brief, which can be unreliable to implement in the SD model at the early stage of the project due to the existing uncertainties.

Fuzzy inference system can be considered as a solution for the highlighted issue, since it can predict a range of value for the initial brief clarity. Moreover, fuzzy inference system has been integrated with SD in the past studies to simulate other project management issues, which indicates the applicability of this approach (Nojedehi and Nasirzadeh, 2016; Nasirzadeh et al., 2019; Siraj and Fayek, 2020).

Therefore, this paper reviews the second developed method using a fuzzy-SD technique that predict the impact of initial brief clarity on project duration and cost when there is not sufficient project data. This method was created by proposing a dynamic model utilising the SD approach. Then, the model input which is the clarity level of the initial brief was predicted in a fuzzy number format using the fuzzy inference system. Predicting the impact of briefing in a fuzzy number format can aid in capturing the associated uncertainties of prediction at the early stage of the project. Finally, the fuzzy-SD performance was evaluated by applying in a refurbishment project.

The two proposed different methods of PDRI-SD and fuzzy-SD contributed to the existing academic knowledge to simulate the influence of brief clarity on DBB project cost and time. While PDRI-SD measures the influence of brief clarity in a fixed/single value with more accuracy, fuzzy-SD can predict this impact at the early stage when sufficient project data is not available. So, utilising these methods on the right stage of the project can help the clients to assess the influence of brief clarity on the project outcomes prior to beginning of the delivery stage and give them a chance to manage the possible consequences.

2. Research Methods

This paper reviews the two developed methods of PDRI-SD (Vahabi et al., 2022a) and fuzzy-SD (Vahabi et al., 2022b) that can simulate the complex and dynamic interdependencies between affecting factors in the briefing process. The PDRI-SD method is based on compiling the PDRI tool and the SD approach, while fuzzy-SD is integrating the fuzzy inference system with SD. Depends on the project delivery stage, each method is effective in predicting and simulating the influence of brief clarity on project time and cost.

2.1. SD Approach

SD was introduced by Forrester (1961) to model complicated systems in which several interdependencies between system's elements exist. Thus, SD was utilised in both methods to create a dynamic model to assess the impact of brief clarity on project duration and cost throughout the project delivery. This approach was selected because SD can capture complexity, dynamism, and nonlinearity in modelling.

Modelling with the SD approach is based on developing diagrams including a conceptual framework, a stock and flow diagram, and a causal feedback loop that portrays structure and behaviour of a system. The conceptual framework is the overview of the modelling and creates an idea how the whole concept of the system works (Vahabi et al. 2022b). The causal feedback loops are shown by variables where arrows link them together, which are called causal links. Placing plus or minus symbol on each arrows refer how independent variables can influence the dependent variables (Vahabi et al., 2020). Finally, the stock and flow diagram by which the workflow of the system is determined, as shown in Fig. 1. The stock and flow diagram is drawn by defining stocks showing the state of the system, then the flow is design between the stocks by which changes in the stocks are controlled. Convertor variables are then placed in the diagram which have auxiliary roles to simplify the readability of the diagram. In the end, connectors that link and transmit information between different model components, are drawn (Vahabi et al., 2022a).

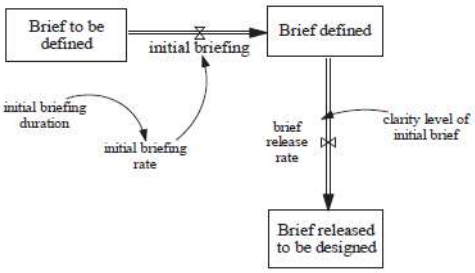

Fig. 1. Initial briefing stage shown by stock and flow diagram (Vahabi et al., 2022a)

2.2. PDRI Tool

PDRI was adjusted to quantify the initial brief clarity as the model input in the PDRI-SD method. Construction Industry institute developed PDRI from 1994 to 2008 as a comprehensive tool to quantify the completeness level of the project brief in three main sectors of infrastructure, building, and industrial projects (Gibson and Whittington, 2010). This tool utilizes a checklist including the crucial items that need to be defined in a project brief. Each item has its own weight and by scoring each of them based on how clearly has been defined, the total score of brief completeness is calculated. The scoring is done by the client or the responsible for preparing the brief. The total score is between zero to 1000. The higher score indicates the brief has not been completely defined (Bingham and Gibson, 2016).

2.3. Fuzzy Inference System

In the proposed second method, the fuzzy-SD technique, a fuzzy inference system was applied to predict the initial brief clarity, as the model input. Various factors, such as client's experience in briefing, time pressure, and number of similar projects that a client delivered in the past, affect the clarity level of the initial brief. Utilizing the value of these affecting factors, fuzzy inference system predicted the initial brief clarity level (Vahabi et al., 2022). The fuzzy inference is a control system under the fuzzy logic concept that utilizes fuzzy if-then rules for decision making (Nasirzadeh et al., 2008). Sugeno and Mamdani are two major techniques for utilizing fuzzy if-then rules. The difference between these two techniques is in how the fuzzy inputs generate the crisp output. Mamdani is mainly utilized in decision making applications due to the interpretable and intuitive nature of the rule base, particularly (Kaur and Kaur, 2012). Thus, the proposed fuzzy-SD method used the Mamdani technique for fuzzy inference system.

In this method, fuzzy inference system predicted based on the key affecting factors on the initial brief clarity. The three selected factors for prediction were: client experience in briefing, number of similar projects that clients have delivered so far, and time pressure on briefing (Vahabi et al., 2022b). The value of these three factors were predicted in the fuzzy number format according to the expert judgements who was involved in the delivery of the refurbishment projects. This research assumed the initial brief clarity directly impacts the volume of submitted RFIs. This assumption meant the value of RFI percentage can be predicted based on the three selected key factors using fuzzy inference system. Thus, the value of RFI percentage were predicted in the triangular fuzzy number to apply in the SD model (Vahabi et al., 2022b).

2.4. Model structure

The main steps that utilized to develop the two methods to simulate the influence of the brief clarity. Based on the method, these steps are as below;

PDRI-SD method (Vahabi et al., 2022a):

- Developed the SD model using feedback loops and stock and flow diagrams,
- Quantified the initial brief clarity level utilising the adopted PDRI tool.
- Compiled the PDRI outcome into the SD model.
- Simulated and validated the dynamic model.
- Implemented the PDRI-SD model in a refurbishment project to evaluate the model performance.

Fuzzy-SD method (Vahabi et al., 2022b):

- Developed the SD model using feedback loops and stock and flow diagrams,
- Predicted the initial brief clarity level in a fuzzy number set using the fuzzy inference system.
- Integrated the obtained fuzzy if-then rule outcomes into the adopted SD model.
- Simulated and validated the dynamic model.
- Applied the fuzzy-SD model in the refurbishment project to evaluate the model performance and compare it the simulation results of the other method.

3. Review of SD Model Development

Referring to Vahabi et al. (2022a), SD model was developed based on identifying key factors and variables, determining the model boundary, and defining cause-effect relationships between factors. This model was created based on three major subsystems which are the brief clarity influence on the briefing, the detailed design, and the construction process. The cause-effect relationships between variables were formulated using mathematical equations or extrapolation of historical data where determining a mathematical function was not possible.

As can be seen in Fig. 2, the first subsystem in the developed SD model was the briefing process comprising two main stages of the initial briefing and the latent briefing (Vahabi et al. 2022a). The initial briefing stage refers to the early stage when clients define their expectations and projects requirements prior to heavily involved in the project design. If the initial brief documents include any lack of clarity on the scope, the latent briefing stage begin to rectify the possible issues on the unclear scopes by undertaking whether extra brief clarification or brief changes. The key factor to detect these issues in the latent briefing was assumed the submitted request for information (RFI) by designers or builders. Undertaking the latent brief stage can aid in improving the clarity level of the initial brief. However, for undertaking the latent briefing process, extra resources and time are required, which increase the briefing cost and duration.

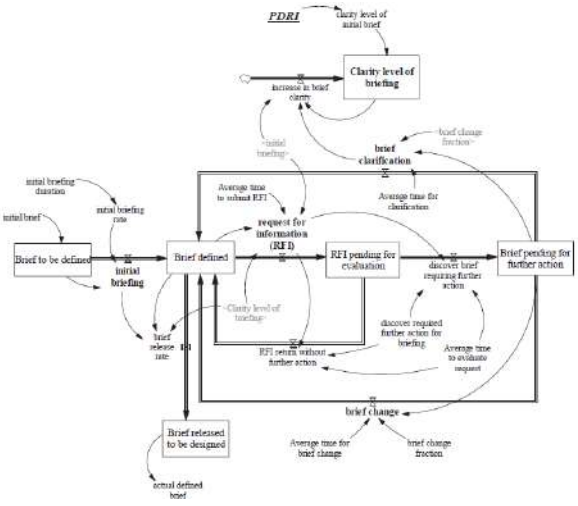

Fig. 2. Subsystem of the briefing process (Vahabi et al., 2022a)

The next subsystem in the developed SD model simulated the influence of brief clarity on the design process (Vahabi et al., 2022a). The brief clarity directly influence on the design quality and poor design quality is the key factor for design changes throughout the project delivery, which ultimately influences project duration and cost. The last subsystem in the proposed SD model simulates the impact of design changes led by unclear brief, on the construction process (Vahabi et al., 2022a).

4. Dynamic model simulation and validation

Once the initial brief clarity was measured by two different ways of the PDRI tool and the fuzzy inference system, the obtained values were applied into the adopted SD model separately to simulate the expected project performance based on two methods of PDRI-SD and fuzzy-SD. Then, the models were validated using a set of validation tests (Sterman, 2000), which assessed the model construct and behaviour of the model outcomes (Vahabi et al., 2022a, Vahabi et al., 2022b).

5. Results

The two methods of PDRI-SD and fuzzy-SD were applied into a specific refurbishment project to compare their simulation results and evaluate their applicability. The data required for both model simulation was collected from the same project, a 1,226m2 refurbishment of an educational building (Vahabi et al., 2022a, Vahabi et al., 2022b).

Simulation results of fuzzy-SD method

The values of the three influencing factors of client experience, number of past similar projects, and time pressure were collected through interviewing the project client to predict the initial brief clarity as the input in the fuzzy-SD method. The value of submitted RFI percentage, as the indicator of the level of the initial brief clarity, was predicted in a triangular fuzzy number of 1.86%, 8.36%, and 9.96% utilising the developed fuzzy inference system. These obtained values, as the inputs, were then applied into the adopted SD model to simulate the project duration and cost. Table 1 shows the simulated project cost and time against budget and planned time schedule. The simulation results were presented in the triangular fuzzy format of minimum value, most likely value, and maximum value to capture the associated uncertainty with the predication. For example, based on the fuzzy prediction, the investigated project will face minimum 1.01%, most likely 4.53%, and maximum 5.45% cost overrun.

Table 1. PDRI-SD and Fuzzy-SD prediction versus planned budget and scheduled duration

Description	Project cost ($)	Project cost overrun (%)	Project time (Week)	Project time overrun (%)
Planned budget & schedule time	673,100	--	50	--
PDRI-SD Prediction	695,300	3.30	62	24
Fuzzy-SD prediction (minimum value)	679,900	1.01	55	10
Fuzzy-SD prediction (most likely value)	703,600	4.53	68	36
Fuzzy-SD prediction (maximum value)	709,800	5.45	70	40

Table 1 includes the predicted duration of the main project stages and compare them with the associated scheduled time. For instance, the prediction indicates the refurbishment project can encounter minimum 10%, most likely 36%, and maximum 40% time overrun.

Simulation results of PDRI-SD method

For applying PDRI-SD method in the refurbishment project, the initial brief clarity was firstly measured by customised PDRI. The project client was interviewed to score the elements in the PDRI checklist. Given the PDRI tool was utilised after preparing the first draft of the initial brief when more project data is available, the initial brief clarity was measured with more accuracy in a single value. The obtained normalised PDRI score was 343 out of 1,000 in the investigated project, which was applied into the adopted SD model to simulate the project cost and duration. Table 1 shows the estimated project cost and time versus the planned project budget and time schedule.

Comparing the simulated project cost and time with the planned budget and duration indicates 3.3% and 24% cost and time overruns, respectively. This enlightens the crucial influence of the initial brief clarity on the project performance, particularly project delivery time.

6. Discussion

The purpose of this paper was to review the two developed methods of PDRI-SD (Vahabi et al., 2022a) and fuzzy-SD (Vahabi et al. 2022b), which were applied to simulate the impact of the brief clarity on project cost and time performance. Also, this paper compared the two method performances and determine their optimum applicability throughout the project delivery.

The fuzzy-SD method integrated fuzzy inference system into the SD modelling to predict the influence of clarity of the initial brief on project cost and time at the early stage when there is not sufficient project data. In this method, the initial brief clarity, which is the model input, was predicted based on its influencing factors of clients' experience in briefing, number of similar projects that clients have delivered, and time pressure on briefing. The obtained simulation outcomes from the fuzzy-SD method enlightened the crucial role of these three influencing factors in clearly defining the brief, which ultimately improve project performance. The result aligned with the past studies highlighting the criticality of these three factors in briefing. Given fuzzy-SD method utilised the influencing factors to predict the clarity of the initial brief, the need of project data for the simulation was mitigated, which is helpful for the clients at the early stage of the project. Also, this method measured the initial brief clarity in a fuzzy number format, which captured the associated uncertainties of the predication at the early stage. Thus, these two major strengths of the fuzzy-SD approach highlighted its effective

application at the early stage of the project delivery when there is a lack project data.

When the first draft of the initial brief was prepared and the project has proceeded, there is a possibility to enhance the accuracy of the simulation by accessing more available project data. So, the PDRI-SD method was proposed to simulate the impact of brief clarity where the customised PDRI tool measured the initial brief clarity (Vahabi et al., 2022a). Quantifying the clarity was undertaken by interviewing the project client to score the defined critical elements in the initial brief. Then, the obtained single value for the initial brief clarity was applied into the adopted SD model to simulate the project duration and cost. Compiling the PDRI tool with the SD approach in PDRI-SD method contributed to the existing knowledge by addressing the gap in the previous studies in modelling the influence of the brief clarity. Previous study attempted to model the impact of the initial brief on project performance by assuming the percentage of completed design as the index of the completed level of the brief (Chritamara et al., 2001). But this assumption does not appear flawless because a project with incomplete design might obtain a clear brief (Xia et al., 2015).

Comparing the simulation outcomes of the two proposed methods of fuzzy-SD and PDRI-SD indicates the results in each method aligns with the other. While the fuzzy-SD predicted a range of values for the project cost overrun (1.1%, 4.53%, 5.45%) and time overrun (10%, 36%, 40%), the PDRI-SD simulated a single value of 3.3% cost overrun and 24% time overrun. The obtained results show that the single value of the simulated project cost and time by PDRI-SD are within the range of fuzzy-SD prediction, which confirms the simulation of one method aligns with the other and reliability of both.

This paper theoretically contributed to the existing knowledge by reviewing two developed approaches, by which the influence of brief clarity on project duration and cost can be predicted. This will provide a platform for further academic research about project briefing and mitigating consequences of an unclear brief in the DBB project delivery. This paper also provided practical recommendations regarding the most effective stage for utilising PDRI-SD and fuzzy-SD methods to achieve the most precise simulation outcomes. While the fuzzy-SD approach provides client teams with a practical tool to predict the influence of brief clarity at the early stage when there is not enough project data, the PDRI-SD method can precisely measure the brief clarity impact after preparing the first draft of the project brief. The simulation outcomes of the models also enlighten whether the prepared brief aligns with the project goals or extra clarification is required in the brief before commencing the delivery of the project.

7. Conclusion

Clearly defining a brief is one of the crucial processes that can mitigate project cost and time overruns. So, it is helpful to assess the influence of brief clarity on project performance prior the delivery of the projects. This evaluation is challenging though because of the complexity and dynamism of the DBB project delivery system where several processes and activities are undertaken in parallel or in series over time. Thus, this paper reviewed the two proposed methods of fuzzy-SD and PDRI-SD that can simulate the impact of brief clarity on DBB project cost and time.

The simulation results of the two methods were comparable where both applied into the same refurbishment project. The simulated project cost and time by the PDRI-SD method take place within the range of values predicted by fuzzy-SD. This means the simulation outcome of each method aligns with the other if they are utilised on the right stage of the project. For example, fuzzy-SD is effective to apply at the early stage of the project when the initial brief is not prepared yet and there is a lack of information about the project. On the other hand, PDRI-SD can simulate accurately when the first draft of the initial is prepared, and more project data is available. Although these two methods can be utilised at different stage of the project separately, implementing both sequentially throughout the project delivery is deemed to be more efficient.

The two developed models were deemed as efficient tools for decision makers to simulate the influence of brief clarity based on the results obtained from their applications in a refurbishment project. However, utilising these models in more complex projects requires further investigation to ensure the model performance is reliable. Moreover, conducting further research on utilising these two models in other types of infrastructure or industrial projects, is beneficial.

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Ali Vahabi is a PhD Candidate in Construction Management at Deakin University. As a Senior Cost Manager with more than 10 years of experience in the construction industry, Ali's skillset cover Cost Management and Project Management services in transport infrastructure. His recent research area is in the simulation of project briefing and project performance using dynamic modelling approaches such as system dynamics (SD).

Dr. Farnad Nasirzadeh is a Senior Lecturer in Construction Management at Deakin University. Prior to joining Deakin, he was a Lecturer/Visiting Fellow at UNSW and an Associate Professor at PNU. Farnad has more than 17 years' experience in construction industry as a Senior Quantity Surveyor and Project Management Consultant.

Farnad's main research interest is modelling and simulation of complex systems with a specific focus on workers/human performance. He has used different simulation tools including System Dynamics (SD), Discrete Event Simulation (DES), and Agent Based Modelling (ABM) in his previous research to model workers' performance and safety in a virtual environment. Farnad's research has recently focused on data driven models which combine simulation and sensing to model workers performance more accurately. Farnad has published several papers in highly ranked journals in the areas of simulation and sensing and has attracted several internal and external research grants.

Anthony Mills is a Professor in Construction Management at Deakin University. He was formally Head of School of Architecture and Built Environment from 2013 to 2021. He is also a fellow of the Australian Institute of Quantity Surveyors (FAIQS), a fellow of the Australian Institute of Building (FAIB). He was the past President of the Australian Institute of Quantity Surveyors, and Secretary of the Pacific Association of Quantity Surveyors. Also, Inaugural member of the Australian Construction Industry Council, Construction Forecasting Council, and Secretary of the Pacific Association of Quantity Surveyors. His research interest is Construction management, procurement, construction forecasting, cost planning.

Paper no. 100

Developing Day Trading Techniques for the Thailand SET100 Index Using Artificial Neural Networks and Technical Indicators

Pannaphorn Nackarajarn[1], Rujira Chaysiri[2], Nattakrit Pitayasiri[3] and Pakawat Amatayakul[4]

[1]Undergraduate Student, School of Management Technology, Sirindhorn International Institute of Technology, Thammasat University, Pathum Thani, Thailand, E-mail: 6122790155@g.siit.tu.ac.th

[2]Assistant Professor, School of Management Technology, Sirindhorn International Institute of Technology, Thammasat University, Pathum Thani, Thailand, E-mail: rchaysiri@siit.tu.ac.th (corresponding author).

[3]Undergraduate Student, School of Management Technology, Sirindhorn International Institute of Technology, Thammasat University, Pathum Thani, Thailand, E-mail: 6122800574@g.siit.tu.ac.th

[4]Undergraduate Student, School of Management Technology, Sirindhorn International Institute of Technology, Thammasat University, Pathum Thani, Thailand, E-mail: 6122800822@g.siit.tu.ac.th

Abstract: Technical analysis is used by day traders to make money or prevent losing money when they trade often. The goal of this research is to develop day trading techniques for the Thailand SET100 index using a combination of technical analysis and artificial neural network (ANN). The resource group was chosen because it has the highest volatility and volume when compared to other groups of 37 stocks that have been listed on the Thailand SET100 index consistently for ten years. BANPU, BCP, EGCO, GUNKUL, IRPC, PTT, PTTEP, and TOP make up the resource group. ANN models were used to forecast stock prices, which were combined with technical indicators for day traders' strategic development. To compare trading strategies, Tukey's test was utilized. The most effective day trading strategies were those that excluded technical indicators, according to the findings. The results showed that day trading techniques without technical indicators were the most profitable, with an 11.09 percent profit. After accounting for transaction costs, the best trading strategies provide a profit of 10.03 percent.

Keywords: Artificial neural network, Stock Exchange of Thailand, Stock price prediction, Technical analysis, Tukey's test.

1. Introduction

Stock price prediction is the focus of this research, and stock trading has long been a popular activity. Most stock prices may fluctuate due to legitimate circumstances, according to the previous study (Mate et al., 2019). Generating precise stock price predictions, on the other hand, is an intriguing possibility for making a fortune. The purpose of this research is to forecast stock prices so that investors can better understand their prospects of making safe investments, earning acceptable returns, increasing their decision-making confidence, and minimizing investment risks.

The previous study and relevant literature were examined first (Yan, 2017; Huang, 2019; Nti, 2020; Fridson, 2022). In an ideal market theory, the stock prices would reflect fundamental information about a company's stock, such as the income statement, balance sheet, and cash flow (Fridson and Alvarez, 2022). Financial ratios such as the P/E ratio, which is relatively stable and may be coupled with a number of different ways to anticipate stock price, are also used in the fundamental analysis (Khatwani et al., 2019). However, technical analysis methodologies rely only on a stock's price time series (Picasso et al., 2019). The technical analyst attempts to forecast the stock market by studying charts that depict historical market prices and technical indications (Nti et al., 2020). The technical analysis predicts future stock prices by analyzing historical prices. This approach is appropriate for making short-term forecasts (Selvin et al., 2017). Bollinger Bands (BB), Relative Strength Index (RSI), and Commodity Channel Index (CCI) are examples of technical indicators. They are well-known indicators that have been frequently employed in past studies (Bhargavi, 2017; Vaghela, 2021).

Another method for stock price prediction that has been mentioned in the literature is time series forecasting, which is defined as a method of estimating the future by analyzing the past. Time series analysis may be used to

make decisions about future plans and forecasts. A time series with only one variable's data is referred to as a univariate time series, whereas one with more than one variable's observations is referred to as a multivariate time series (Idrees et al., 2019).

Machine learning techniques were also employed to predict the direction of the stock price. Artificial Neural Networks (ANN), for example, aid in the creation of a model for successfully forecasting stock values. Two widely used machine learning techniques for predicting stock price and stock market index values are artificial neural networks (ANN) and support vector regression (SVR) (Patel et al., 2015). The approach outperforms the Kalman Filter technique with a test error of 0.0027. Bernal et al. (2012) generalized and validated the algorithm on 50 different stocks, indicating that their results outperformed state-of-the-art techniques (Shah et al., 2019). Machine learning is a type of pattern recognition that focuses on recognizing patterns and trends in data (Young and Fu, 1986). There were multiple examples of neural networks predicting stock prices in the previous study. Backpropagation and algorithms were used to train the network, and the dataset was divided into only training and testing sets, with no validation set, as Yang et al. (2017) indicated, which is critical for unbiased neural network training. The model achieves an accuracy of 74.15 percent on the high and low of the Shanghai composite index and 73.95 percent and 72.34 percent on the Shenzhen Stock Exchange component index, respectively. Other machine learning techniques used in stock price prediction include support vector machine (SVM) (Ray, 2019), long short-term memory (LSTM) (Ding and Qin, 2019), and convolutional neural network (CNN) (Mehtab and Sen, 2020).

The goal of this research is to use the combination ANN and technical indicators to forecast stock prices in the SET100 index and to use the forecast price to develop trading strategies for day traders. The best trading strategy is then determined by comparing all trading strategies. The following is the layout of the paper. The technique is covered in Section 2, and the findings and comments are covered in Section 3. Our study concludes in Section 4.

2. Methodology

2.1. Data and Preparation

The Stock Exchange of Thailand's (SET100) list of stocks for the years 2012 to 2021 was retrieved from set.or.th/th/market/constituents. We would like to identify the list of stocks that have been consistently listed for 10 years because the SET100 stock list is updated annually. We verify the lists for each year for matches using Excel's Visual Basic for Applications (VBA). 37 stocks on the SET100 were continually listed from 2012 to 2021, according to the results. The stocks included ADVANC, AMATA, AOT, AP, BANPU, BBL, BCP, BH, BTS, CENTEL, CK, CPALL, CPF, CPN, DTAC, EGCO, GUNKUL, HMPRO, IRPC, IVL, KBANK, KTB, LH, MAJOR, MINT, PTT, PTTEP, PTTGC, QH, SCB, SCC, SPALI, STEC, TCAP, TISCO, TOP, and TRUE.

The 37 stocks are divided into seven groups: Technology, Property & Construction, Services, Agro & Food Industry, Resources, Industrials, and Financials. The volatility and volume of each group are then determined. The resources group has the highest volume and volatility, indicating that it is the riskiest (with the largest potential return) and has the most shares of stocks traded. Therefore, we would like to concentrate our study on the resource group. The resource group consists of BANPU, BCP, IRPC, ECGO, GUNKUL, PTT, PTTEP, and TOP.

Starting June 1st, 2020, and ending February 2nd, 2022, data for stocks in the resources group will be collected from finance.yahoo.com. The stock price would fluctuate more than usual in 2019 because to the COVID-19 pandemic. The situation will improve in June 2020. Because stock prices are particularly volatile due to the conflict between Russia and Ukraine in February 2022, we have stopped collecting data from that moment. A total of 404 data points were gathered and separated into training and test sets. The training set contains 70% of the entire data (269 points), allowing the neural network to learn and memorize the data before making a prediction, whereas the testing set contains the real data to be used. It contains 30% of the information (115 points). To avoid data overlap, the 20 points of data are omitted. The date, open price, open price of the previous day (Open-1), highest price of the previous day (High-1), lowest price of the previous day (Low-1), and adjusted close price up to five days ago (Adj. Close-1 to-5) were used as input data for each stock in the resources group, as well as the technical indicators BB, RSI, and CCI. The adjusted close price of the current day is used as the label to predict in this study.

2.2. Artificial Neural Network

To forecast adjusted close prices, a neural network (ANN) was applied. The ANN concept was inspired by a simulation of the human brain. To allow ANN to think and process in the same way as humans do. ANNs can learn and remember (are information-based) and can be defined as a collection of processing units represented by artificial neurons, interconnected by a high number of interconnections (artificial synapses), and implemented by vectors and matrices of synaptic weights (Da Silva et al., 2017). Figure 1 depicts an example of artificial neural network architecture.

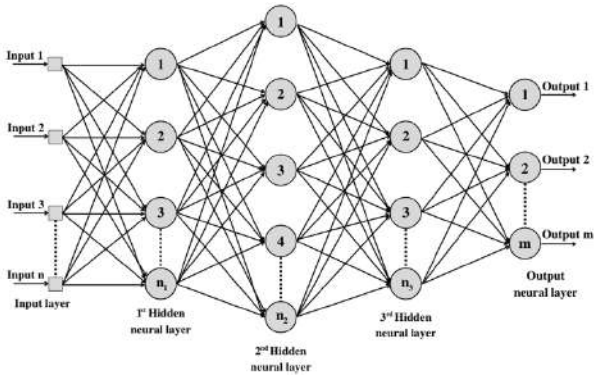

Fig. 1. An example of Artificial Neural Network Architecture.

RapidMiner is used to construct ANN models, and the data is analyzed using the neural net operator. The data is learned by the neural net operator using the training set as input. The artificial neural network (ANN) model is then used to apply the testing set. Day trading, week trading, and month trading input data were prepared. After utilizing the ANN model to input the data, it was discovered that the

week-trading and month-trading for the resources group were not accurate, as the average MAPE of week-trading and month-trading surpassed 5%. As a result, day trading was the sole alternative considered in this study. Fig. 2 shows the RapidMiner's artificial neural network.

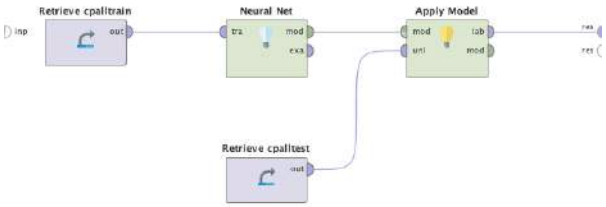

Fig. 2. RapidMiner's ANN Model.

2.3. Mean Absolute Percentage Error

A prediction's accuracy is measured by the mean absolute percentage error (MAPE). It uses a predict value minus an actual value divided by actual value to calculate the absolute percent of prediction. Eq. (1) is used to calculate MAPE. To build a trading strategy, the best model with the lowest MAPE for each stock was chosen.

$$MAPE = \frac{100\%}{n}\sum_{i=1}^{n}\frac{|A_i - F_i|}{A_i} \quad (1)$$

where A_i refers to the actual price, F_i refers to the forecast price or predict price, and n refers to sample size.

2.4. Bollinger Bands

Technical trader John Bollinger developed the Bollinger Bands (BB) indicator. The BB indicator uses standard deviation as a crucial factor in trading decisions. Stardard deviation is multiplied to construct lower and upper bands around a default 20-day moving average (Bollinger, 2002). The gap between the two bands widens with increasing volatility, whereas it shirks with decreasing volatility (Prasetijo et al., 2017). When determining if the stock price is relatively high or low, the Bollinger bands indicator is useful. Prices are regarded as being high when they exceeds the upper band and as being low when they fall below the lower band (Windasari et al., 2018). Traders can make trading decisions based on the price position in relation to the 20-day moving average, lower band, and upper band. Eq. (2) and Eq. (3) are used to calculate BB.

$$Upper\ BB = SMA + (SD \times 2) \quad (2)$$

$$Lower\ BB = SMA + (SD \times 2) \quad (3)$$

where *SMA* refers to the simple moving average, and *SD* refers to the standard deviation.

2.5. Relative Strength Index

When trading, the Relative Strength Index (RSI) is one of the indicators used to monitor price movements and time positions. It assists the investor in selecting the appropriate securities for their portfolio (Bhargavi et al., 2017). RSI is an indicator that analyzes the speed and fluctuations of prices. It is widely used by investors all over the world. If the value of overbought is 70 or higher, the asset has become overbought or expensive and is destin ed for a pullback or corrective price retreat. A reading of 30 or less on the RSI indicates that the market is oversold or undervalued (Bhargavi et al., 2017). Eq. (4) and Eq. (5) are used to calculate the RSI.

$$Relative\ Strength = \frac{Average\ Gain}{Average\ Loss} \quad (4)$$

$$RSI = 100 - \frac{100}{1+Relative\ Strength} \quad (5)$$

2.6. Commodity Chanel Index

Stocks and other commodities are traded using the Commodity Chanel Index (CCI). CCI calculates the difference between the historical average price and the present price. If the CCI is greater than +100, it is a buy signal; if it is less than -100, it is a sell or short-term trade signal (Vaghela et al., 2021). CCI is unique in that it measures volatility using mean deviation depending on the time series' actual conditions (Maitah et al., 2016). Eqs. (6) and (7) are used to calculate CCI.

$$Typical\ Price = \frac{High+Low+Close}{3} \quad (6)$$

$$CCI = \frac{Typical\ Price - SMA}{0.015 - Mean\ Deviation} \quad (7)$$

where *SMA* refers to the simple moving average.

2.7. Trading Strategies

By evaluating the difference between the day's open price and the predicted price of the approach with the lowest MAPE, trading strategies were created to discover buy, sell, or hold signals. Because of the high MAPE value, BB-involved methods are eliminated. Then trading strategies are used to determine the daily profit or loss. There are a total of twenty trading strategies, each having RSI and CCI indicators. The twenty strategies were organized alphabetically. The twenty trading strategies are shown in table 1.

Table 1. The twenty trading strategies.

Strategy	Buy	Sell
A	> 2%	< -2%
B	> 3%	< -3%
C	> 4%	< -4%
D	> 2%	< -3%
E	> 3%	< -2%
F	> 2% + RSI	< -2% + RSI
G	> 3% + RSI	< -3% + RSI
H	> 4% + RSI	< -4% + RSI
I	> 2% + RSI	< -3% +RSI
J	> 3% + RSI	< -2% + RSI
K	> 2% + CCI	< -2% + CCI
L	> 3% + CCI	< -3% + CCI
M	> 4% + CCI	< -4% + CCI
N	> 2% + CCI	< -3% + CCI
O	> 3% + CCI	< -2% + CCI
P	> 2%+RSI+CCI	<-2%+RSI+CCI
Q	> 3%+RSI+CCI	<-3%+RSI+CCI
R	> 4%+RSI+CCI	<-4%+RSI+CCI
S	> 2%+RSI+CCI	<-3%+RSI+CCI

T	> 3%+RSI+CCI	<-2%+RSI+CCI

where *diff* refers to the difference percentage between the open price and predicted price. When the RSI is less than 30, buy, and when it is larger than 70, sell. When the CCI is less than or equal to -100, buy, and when the CCI is larger than or equal to 100, sell. The difference starts at 2% because the lowest error from the ANN models was approximately 2%.

2.8. Transaction Costs and Slippage

When trading the stock, the transaction cost will comprise the GMO-Z com Securities (Thailand) Public Company Limited (ZCOM) commission fee, which is the lowest in Thailand, as well as slippage, which is the difference between the expected and actual price of a trade. The difference between the expected price and the actual trading price is known as slippage. It can display trading losses. This could aid with a more realistic trading evaluation. However, slippage may not be appropriate for short trades with small profits where the entry and exit prices are near. When slippage is factored in, significant profit may be lost when compared to doing the procedure without it (Martinez et al., 2009).

Trading costs should be taken into account in a more realistic trading environment (Wang et al., 2021). To account for price slippages that may occur due to variations between estimated and real stock prices, Lee et al. (2007) used a random perturbation of actual stock prices of 0%, 0.50 %, and 1% as the proportion of price slippage. The transaction cost will be deducted from each strategy's profit or loss.

2.9. Tukey's test

The significance of discrepancies between sample means is determined using Tukey's test. Tukey's test examines all pairwise differences while taking into account the chance of making one or more Type I errors. In this study, Tukey's test is used using RStudio to find the strategies with the maximum profit for the resource group. Eq. (8) is used to calculate Tukey's test.

$$S_q = \frac{Y_A - Y_B}{SE} \quad (8)$$

where Y_A is the larger of the two compared means, Y_B is the smaller of the two compared means, and *SE* is the standard error of the sum of the means (Choy and Chong, 2018).

3. Result and Discussion

The MAPE was utilized to analyze the ANN models in order to determine the difference between the real and forecasted prices. Each stock's seven training and testing sets were entered into the ANN model separately. The ANN model with the smallest MAPE was chosen:

1) MAPE of BANPU, CCI is 1.69%.

2) MAPE of BCP, RSI is 2.50%.

3) MAPE of EGCO, BB is 1.10%.

4) MAPE of GUNKUL, adjusted close is 4.92%.

5) MAPE of IRPC, BB is 2.06%

6) MAPE of PTT, adjusted close is 1.01%.

7) MAPE of PTTEP, CCI is 0.99%.

8) MAPE of TOP, BB-RSI is 1.17%.

For any company in the resource group, the BB-CCI and RSI-CCI did not provide the lowest MAPE. It was also discovered that the resource group's total day-trading is around 2.4% MAPE, while week-trading and month-trading are about 8.5% MAPE.

Table 2. MAPE of the trading period.

Trading Period	Average MAPE (%)
Day	2.418
Week	8.441
Month	8.528

The sole trading time chosen in this experiment is day trading to avoid the possibility of investment loss in the week and month trading periods, which have a high MAPE. Twenty trading strategies based on RSI and CCI signals were developed.

Tukey's test is used to compare all twenty techniques to see which one generates the highest profit. The results of Tukey's test suggest that the following three trading strategies outperformed other trading strategies:

1) Profit is generated by Strategy A at 11.09%.

2) Profit is generated by Strategy E at 9.21%.

3) Profit is generated by Strategy B at 8.75%.

Table 3. Tukey's test result.

Rank	Strategy
1	A, E, B
2	C, D
3	P, Q, R, S, T
4	M, L, H, K, G, O, I, N, F, J

The average profit of each trading strategy by order from the highest to lowest profit was displayed in Table 4.

Table 4. Average profit/loss of each trading strategy.

Strategy	Average Profit/loss (%)	Strategy	Average Profit/loss (%)
A	11.095	M	-6.309
E	9.214	L	-6.495
B	8.756	H	-6.649
C	7.517	K	-6.734
D	4.908	G	-6.881
P	0.000	O	-7.058
Q	0.000	I	-7.923
R	0.000	N	-8.131
S	0.000	F	-8.299
T	0.000	J	-9.168

A more realistic evaluation of trading strategies would include profit/loss calculations with transaction costs. The transaction cost is calculated by adding the commission fee of 0.065% and the slippage of 0.1%, 0.5%, and 1.0 %, as shown in Fig. 3.

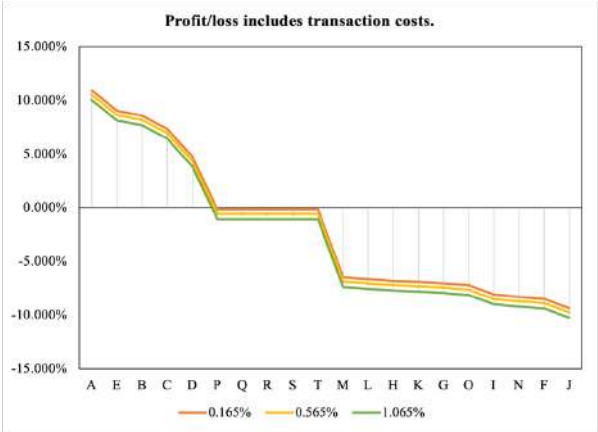

Fig. 3. Profit/loss includes transaction costs.

Fig. 3. shows that transaction costs have little effect on profit. Even once transaction costs are included in, the three most profitable trading strategies provide a satisfactory profit.

Despite providing valuable information, this study has certain limitations. First off, we solely utilize Thai stock data. This approach might not be appropriate for other stock markets. Second, employing hyperparameter optimization techniques could improve ANN performance because the hyperparameters in this work were manually adjusted based on trial and error. Thirdly, we didn't compare our results in comparison to those of other machine learning methods, such long short-term memory (LSTM) and convolutional neural network (CNN).

4. Conclusion

Because prices change due to a multitude of unpredictable causes, stock price prediction is both fascinating and difficult. Historical stock prices are included in the dataset, including open, high, low, close, and adjusted close prices. The ANN is used to forecast adjusted close prices which are used to construct the trading strategies. To enhance the performance of the trading strategies, BB, RSI, and CCI are incorporated into our study. The profit or loss is then calculated, and Tukey's test is used to determine which trading strategies for day-trading would profit the most in the resource group stocks. The results show that the strategy with no technical indicators makes the most profit, with a profit of 10.03 % after transaction costs. More advanced machine learning approaches, such as long short-term memory (LSTM) and convolutional neural network (CNN), will be used in future research. Furthermore, we intend to investigate alternative machine learning approaches in conjunction with various time frame datasets in order to develop new trading strategies.

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Pannaphorn Nackarajarn graduated from the School of Management Technology at Sirindhorn International Institute of Technology (SIIT), Thammasat University. She is currently work as a supply chain IT analyst at ExxonMobil Limited (Thailand). Her research interests include supply chain management, machine learning, and robotic process automation (RPA).

Rujira Chaysiri earned a Bachelor of Arts in Mathematics from the University of Virginia, a Master of Science in Operations Research from Columbia University, and a Doctor of Philosophy in Systems Engineering from the University of Virginia in the United States. He is currently an assistant professor at the School of Management Technology, Sirindhorn International Institute of Technology, Thammasat University, Thailand. His research focuses on financial economics and the application of analytical models to obtain exact or near-optimal solutions to operational problems in the business.

Nattakrit Pitaysiri earned a bachelor's degree in Management Technology from SIIT. During his internship program at DENSO DIAT in 2021, he was a member of the data analysis team. In 2022, he was also a part of the IRPC Public CO., LTD internship program's marine shipping, inventory management, and logistic management. His ambition is to apply RPA to his future career.

Pakawat Amatayakul earned a Bachelor of Science degree from SIIT's School of Management Technology. He has years of experience as a stock and cryptocurrency investor. His interests include financial markets and artificial intelligence technology.

Paper no. 101

Hand-Arm Vibration Exposure: An Occupation Hazard for Construction Workers

Mariam Akinlolu[1] and Theo C. Haupt[2]
[1]Department of Construction Management, Nelson Mandela University, Port Elizabeth, South Africa, Email: akinlolumariam@gmail.com
[2]Faculty of Engineering, Mangosuthu University of Technology, Durban, South Africa, Email: pinnacle.haupt@gmail.com

Abstract: Hand Arm Vibration has adverse effects on the physical abilities of construction workers who perform activities that require the use of vibration tools. This study analyses hand-arm vibration (HAV) trigger times and tool emission values (cumulatively representing vibration exposure) as part of efforts to mitigate the risks of construction workers developing hand-arm vibration syndrome (HAVS). Quantitative data on hand-held tool trigger times (seconds) was obtained from a non-probability convenience sample collated via field studies. The results reveal that from 20 workers observed, all but 13 were under the exposure action value (EAV) and only one worker exceeded the exposure limit value (ELV).

Keywords: Construction workers. Hand Arm Vibration. Musculoskeletal disorder. Vibrating tools. White fingers

1. Introduction

Notably, musculoskeletal disorders have a high prevalence in industries such as construction. Musculoskeletal disorders such as Hand-arm vibration syndrome (HAVS) are common in construction workers with at least 63% of the workforce possibly being affected (Donati et al., 2008). In the context of the construction industry, Hand-arm Vibration (HAV) is the term used to describe vibration that is transmitted into workers' hands and arms from mechanical hand-held power tools while conducting construction work activities (Palmer et al., 2001; Cederlund et al., 2001; Heaver et al., 2002 ; Lawrence et al., 2012; Shen and House, 2017 ; Lai et al., 2019). The vibrations are transmitted by various vibrating tools into the hands of workers. Such tools include, for example, jackhammers, power chain saws, pneumatic drills, concrete vibrators and concrete levelers, angle grinders and compactors (Shen and House, 2017).

HAV is a recognisable problem globally and studies in several countries have confirmed its prevalence such as Malaysia (Madhushanka et al., 2011), Sri Lanka (Harada et al., 1999), Canada (Shen and House, 2017), United Kingdom (Edwards and Holt, 2007), Norway (Su et al., 2011), and the United States (Heaver et al., 2002). To date very little research has been conducted on HAVS on construction sites in South Africa. Over-exposure to hand-arm vibration (HAV) emissions from power tools combined with excessive exposure (trigger times) cumulatively increase the risk of operators developing the permanently debilitating HAVS.

Hand-arm vibration syndrome causes irreparable and debilitating muscular skeletal, neurological, and vascular damage and in the case of this study of construction workers using tools that have high levels of vibration Kingdom (Edwards and Holt, 2007). The prevalence among exposed workers has been estimated at 50% and varies by intensity, duration of vibration exposure and climate conditions. Due to the presence of white fingers which is a common feature of HAVS and provoked by low ambient temperature, the condition is easily recognised in temperature zones (Harada et al.,1999; Chen et al., 1994) . The prevalence of HAV is not well documented in warm countries because VWF is typically provoked by cold weather conditions, and literature in warm countries is minimal (Yamamoto et al., 2002).

An overview of epidemiological studies show that features of HAVS are vascular, neurologic, and musculoskeletal (Shen et al., 2017). Its vascular feature, also known as vibration-induced white finger (VWF), is a type of secondary Raynaud phenomenon because of attacks of well-demarcated finger blanching (Olsen,2002).

During an attack the a person my experience numbness of the fingers and 'pins-and-needles' sensation. A worse state of VWF can be triggered by high temperature and if left uncared for through continued HAV exposure and/or no medical intervention the condition will ultimately result in increased numbness, tingling, and a significant decrease in manual dexterity of the hands (HSC,2002). In severe cases, blood circulation is damaged and may become permanent (HSE,2005) causing fingers to turn 'blue-black'. In the most exceptional of cases, it may lead to gangrene (HSE,2003).

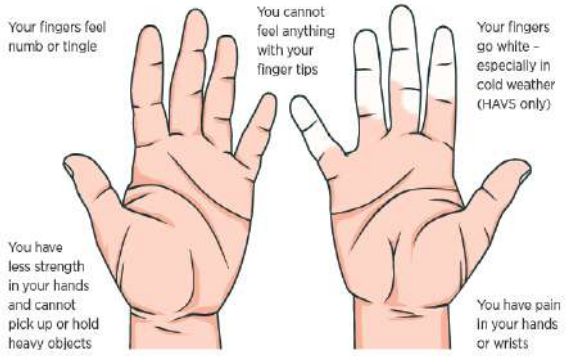

Fig. 1. Symptoms of HAVS

Fig. 2. White Fingers

Overall, the lack of adequate and timely diagnosis of HAVS are major causes for delays in treatment (Cederlund et al., 2001). Further, the lack of awareness by workers and their employers and fear of repercussions by their employers are also barriers (Shen and House, 2017). Little is known about how exposure to handheld vibration tools can impact on the ability to perform daily activities (Lawrence et al., 2012). The key to effectively managing this risk is to employ optimised working practices and risk mitigation and control measures that limit exposure to vibration energy. Against this contextual backdrop, a sparse number of reputable contractors have attempted to implement risk control measures but often fail to understand the basic problem they face - namely, identifying a hierarchy of which working practices pose severe vis-a-vis modest exposure to hand-arm vibration using field observations.

Given the prevalence of HAV in construction, the paper seeks to respond to the following research question: What is the level of exposure of construction site workers to Hand Arm Vibration in South Africa, where HAV is misunderstood and ignored despite the negative health impacts? To achieve this study analysed hand-arm vibration trigger times and tool emission values (cumulatively representing vibration exposure) among construction workers.

2. Legal Requirements And Calculations

In South Africa, the onus is on the employer to deliver a safe and acceptable working environment for all employees. Before an employee begins working with vibrating tools, it is the employer's responsibility to bring to their attention the health effects and the sources of hand-arm vibration, whether or not they will be at risk, how to identify symptoms and how to minimize the risk (Tidy, 2015). Employers must ensure that there are principles regarding the maintenance and replacement of materials to guarantee it works at optimum level thereby decreasing stress on the operator. Efficient work schedules need to be drawn up to limit the time each employee spends operating the equipment thus limiting their exposure to vibrations (HSE, 2012).

The Occupational Health and Safety Act 85 of 1993 (OHSA) communicates that the general duties of an employer include "taking such steps as may be reasonably practicable to eliminate or mitigate any hazard or potential hazard to the safety or health of employees, before resorting to personal protective equipment." Therefore, according to clause 8 of OHSA an employer is compelled to take corrective action when the daily exposure action value and/or the daily exposure limit value is exceeded (Statistics South Africa,1993). The daily Exposure Action Value (EAV) is the amount of vibration exposure that an employee can safely encounter for one day, usually within an eight-hour period. The limit is 2.5m/s2 A(8), above which it is crucial for employers to implement corrective action and control measures to eliminate the risk and/or reduce the amount of vibration (Bodley et al.,2002). A(8) units of meter per second indicates that vibration is a type of acceleration (Eqaution 1). The daily Exposure Limit Value (ELV) indicates the highest level of vibration that an employee can absorb in one day. This limit is 5m/s2 A(8), above which employees should under no circumstances be exposed (Edwards and Holt, 2007). A(8) increases with vibration magnitude and/or exposure time such that:

$$A(8) = a_{hv}\sqrt{\frac{T}{T_0}} \qquad \text{Eq.1}$$

where ahv is the magnitude of vibration source expressed in m/s2; T is the exposure time to the vibration magnitude ahv; T0 is the eight hour duration expressed in seconds (28800 seconds); and ahv, is a function of:

$$a_{hv} = \sqrt{a_{hwx}^2 + a_{hwy}^2 + a_{hwz}^2} \qquad \text{Eq. 2}$$

where ahwx, ahwy and ahwz are the root-mean-square acceleration magnitudes (m/s2), measured in three orthogonal directions, x, y and z, at the vibrating surface in contact with the hand, and frequency weighted as Wh. ISO 5349-1 provides the definition for Wh (ISO, 2001, 2015). If the daily exposure of an operator is made up of more than one tool, with different vibration magnitudes, then:

$$A(8) = \sqrt{\frac{1}{T_0}\sum_{i=1}^{n} a_{hvi}^2 T_i} \qquad \text{Eq.3}$$

where n is the number of tools; ahvi represents the vibration magnitude for a corresponding tool i; and Ti is the amount of time exposure to tool i. By simple transposition of Equation 1, maximum exposure time (T) may be calculated given A(8) and a known vibration magnitude (ahv).

The EAV (2.5 m/s2 A(8)) is equal to 100 points; and the ELV (5 m/s2 A(8)) is equal to 400 points (HSE, 2019)1. HSE points can be calculated as:

$$HSE\ Points = \left(\frac{(a_{hvi} \times a_{hvi}) \times 2}{3{,}600\ (secs)}\right) \times T(secs) \qquad \text{Eq.4}$$

where ahvi is the vibration magnitude for tool i; and T is the duration of exposure to tool i in seconds.

3. Methodology

Field studies of two construction sites in South Africa were conducted during the period March and April 2021 and 31 construction workers were sampled. The aim being to determine the prevalence of HAV and also learn how successful risk controls are being implemented. Concomitant objectives being to and use a culmination of evidence and analysis presented to further augment health, safety and well-being policies and procedures adopted on construction sites.

The study ensured that appropriate ethical processes were followed. Consent through an informed consent form distributed to all respondents with all the necessary information regarding the research was distributed. Implications of their participation in the study were clearly stated. Gatekeeper's permission was obtained from the employers before collecting data from the site workers.

4. Results

A total of 31 separate utility workers were initially recorded but 11 observations (35.48%) could not be used due to either missing data, erroneous data or no data entered. This left 20 useable observations for the sampled workforce. In terms of tools used: 17 workers used one tool only (75%) during the course of an eight hour working day, 2 workers used two or more tools (10%), 2 workers used three or more tools (10%) and only 1 worker recorded four tools used (5%). Table 1 presents summary statistical analysis for trigger times recorded (in seconds) and HSE points accumulated.

The data for trigger times recorded illustrates extreme positive skewness and therefore the median value is taken as a measure of central tendency (i.e. average 10 minutes (600 seconds) tool trigger time). In terms of variability around the measure of central tendency, a minimum of 40 seconds trigger time was recorded and the maximum was 180 minutes (10,800 seconds or 3 hours). For HSE points, again the data was positively skewed and therefore the median value was used to report upon the measure of central tendency (8.2 points accrued during the course of an 8 hour working day). The minimum recorded was 0.27 points and the maximum 62.5 points which exceeded the 'threshold limit' of 400 points (or 5m/s2). 13 workers (or 65%) exceeded the 'action value' of 100 points (2.5 m/s2) and ten observation exceeded the 'threshold limit' of 400 points (76.9%).

Table. 1.Trigger Times Recorded

	Trigger Times (Seconds)		HSE Points
Mean	1222.966	Mean	25.85047455
Standard Error	95.23813	Standard Error	1.483412324
Median	600	Median	8.247
Mode	600	Mode	1.763333333
Standard Deviation	1463.076	Standard Deviation	53.50705061
Sample Variance	2140591	Sample Variance	2863.004465
Kurtosis	14.8158	Kurtosis	71.80280331
Skewness	3.28119	Skewness	7.225037686
Range	10760	Range	624.7226667
Minimum	40	Minimum	0.277333333
Maximum	10800	Maximum	625
Sum	288620	Sum	6100.711994
Count	20	Count	20

Of these 13 observations, one observation involved using four tools; one observation involved using three tools; one observation involved using two tools and 11 observations involved using one tool only. The one observation that exceeded the limit value used a battery drill with a vibration magnitude of 12.5m/s2 for over two hours trigger time. Table 2 provides a more detailed breakdown of tools used and trigger times for these 13 workers who exceeded the action value (one of which exceeded the limit value).

A total of 17 tools were used by these 13 operators, these included: seven trench compactors; four drills; one impact wrench; two petrol breakers; one cut-off saw; one grit saw; and one floor saw. Interestingly, apart from the cut-ff saw, all other tools used had comparatively higher vibration emissions above 5m/s2 meaning that such tools could not be operated for more than eight hours per working day without exceeding the action value. Summary statistical analysis of trigger times used is presented in Table 3.

Table 2. Operators who exceeded the action and limit values

Operator	Tools used (No.1)	Trigger time (Seconds)	HSE points	Tools used (No. 2)	Trigger time (Seconds)	HSE Points	Tools used (No. 3)	Trigger time (Seconds)	HSE Points	Tools used (No. 4)	Trigger time (Seconds)	HSE Points	Total HSE Points
1	Trench Compactor	3,000	101.40	-	-	-	-	-	-	-	-	-	101.40
2	Trench Compactor	3,629	122.66	-	-	-	-	-	-	-	-	-	122.66
3	Trench Compactor	3,480	117.62	-	-	-	-	-	-	-	-	-	117.62
4	Trench Compactor	3,600	121.68	-	-	-	-	-	-	-	-	-	121.68
5	Drill	1,800	156.25	-	-	-	-	-	-	-	-	-	156.25
6	Impact Wrench	1,200	54.00	Cut-off saw	600	1.76	Petrol breaker	1,200	38.50	Grit saw	1,200	24	118.27
7	Drill	7,200	625.00	-	-	-	-	-	-	-	-	-	625
8	Drill	1,200	104.16	-	-	-	-	-	-	-	-	-	104.16
9	Floor saw	10020	133.65	-	-	-	-	-	-	-	-	-	133.65
10	Trench Compactor	3000	101.40	-	-	-	-	-	-	-	-	-	101.40
11	Plate Compactor	900	10.10	Drill	1,200	104.16	-	-	-	-	-	-	114.29
12	Petrol Breaker	10800	346.56	-	-	-	-	-	-	-	-	-	346.56
13	Trench Compactor	3000	101.40	-	-	-	-	-	-	-	-	-	101.40

NB: vibration values per tool were: cut-off saw = 2.3m/s2; drill = 12.5m/s2; floor saw = 4.9m/s2; grit saw = 6m/s2; impact wrench = 9m/s2; petrol breaker = 7.6m/s2; plate compactor = 4.5m/s2; trench compactor = 7.8m/s2;

NB: value round to 2 d.p.

Again the data illustrates positive skewness a higher median value of 3,000 (i.e. 50 minutes) which demonstrates that relatively high vibration emission tools are being used for longer trigger times to increase HSE points accrued. Possible job rotation (as a viable risk control measure) could well eliminate this issue.

Table 3. Trigger times for 17 tools above the EAV

Trigger Times in Seconds	
Mean	3354.647
Standard Error	753.4681
Median	3000
Mode	1200
Standard Deviation	3106.629
Sample Variance	9651142
Kurtosis	1.693843
Skewness	1.597374
Range	10200
Minimum	600
Maximum	10800
Sum	57029
Count	17

5. Discussions

Previous studies have explored HAV related risks and suggested that there is a high prevalence of HAV in construction work (Su et al., 2011; Lawrence et al., 2012; Lai et al., 2019; Marie et al., 2010). However, there is limited investigations in construction workers in South Africa. The analysis revealed that of the 20 useable observations for the sampled workforce analysed, only one instance of exceeding the ELV was recorded.

The none awareness of construction workers of HAV indicates that there is still a gap which needs to be bridged. A culmination of summary statistical analysis of trigger time data for power tools gather via field studies illustrates that the risks posed to workers being over-exposed to HAV risk is maximal. Since the study findings revealed that the HAV risks posed to workers is high, it is apparent that HAV appears to be a severe problem in South Africa. Construction employers should endeavour to eliminate HAV risks through a number of risk control mechanisms, including: training operators; providing supporting HAV information; procurement of low vibration tools; good service and maintenance of tools etc.

Informal discussions with senior managers revealed desired changes to be made to safeguard the health and safety of construction workers handling vibration tools. A few of the respondents believed that modifications to the equipment, increased number of breaks and division of labour could be possible solutions to the issues faced due to the equipment used. Specially designed anti-vibration gloves could be introduced and worn by construction workers to protect against vibration emitted by the equipment.

Further research is required with a larger sample of subcontractors to ensure that they are reminded of their duties to control HAV risks for their workers – such would include ensuring that makes and models of tools (together with their emission values) are known by their workers.

Construction workers should be expected to use the vibrating equipment for a specific amount of time each day. Consequently, several individuals should be trained and qualified to operate the equipment thereby ensuring successful division of labour. Workers should also be allowed to use the equipment in intervals as opposed to continuous exposure. A few construction workers from the sample population had suggested the features of the equipment be modified to make the equipment more user friendly and less hazardous.

The data collected could be used to develop a more robust field study but also using such data as a basis for further continuous improvement – as part of a viable HAV knowledge management system.

6. Conclusion

The results reveal that from 20 workers observed, 13 were under the exposure action value (EAV) and only one worker exceeded the exposure limit value (ELV).Therefore, the risk was deemed to be medium-high, but the need to reinforce job sharing (and other control measures such as low vibrating tools) was also apparent. Common tools used by these 13 operators include trench compactors and drills – both of which have relatively high vibration emission values. Procuring lower vibration tools and/or alternative ways of working would eliminate these incidents altogether. The research also revealed that a high number of tools utilised were not listed on recommended tools. Overall, further work is therefore recommended to improve data collection (and the quality of information within) and a renewed effort to communicate with sub-contractors to the need for them to better manage HAV for their own employees health and well-being.

Since this study sampled a limited group of construction workers, a further extension of the study should consider a larger sample to better examine the extent of HAV in high-risk occupations such as construction and mining.

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Mariam Akinlolu is a Researcher in the Department of Construction Management and Quantity Surveying, Mangosuthu University of Technology, Durban, South Africa. She holds a PhD in Construction Management from the University of KwaZulu-Natal, South Africa. Her research interests are engineering education, gender issues in construction, sustainability and construction health and safety.

Prof Theo C. Haupt is South African National Research Foundation-rated Research Associate in the Department of Construction Management, Nelson Mandela University, Port Elizabeth, South Africa. He has been involved in health and safety practice and research for several years with a PhD from the United States focusing on alternative approaches to managing health and safety in construction. He is an advocate for incorporating health and safety in every aspect of construction and across all phases of construction projects. He has authored and edited several books and published over 200 research articles. He is involved in the International Council for Research and Innovation in Building and Construction (CIB) Working Commissions W99 (Safety, Health and Welfare in Construction) and W123 (People in Construction). He has served on the Advisory Council for Occupational Health and Safety of the South African Minister of Labour. He has worked on several research reports on the state of the construction industry in South Africa including Construction Health & Safety in South Africa Status & Recommendations. His construction industry experience spans more than two decades.

Paper no. 102

Applications of Drone Technologies for Small or Medium Contractors

Mark C. Tatum[1] and Junshan Liu[2]
[1]Associate Professor, McWhorter School of Building Science, Auburn University, 118 Miller Gorrie Center, Auburn, AL, USA, E-mail: mtatum@auburn.edu
[2]McWhorter School of Building Science, Auburn University, 118 Miller Gorrie Center, Auburn, AL, USA

Abstract: Non-contact spatial data collection (remote sensing) techniques, such as LiDAR and photogrammetry on unmanned aerial vehicles (UAV's), have been used in Architecture, Engineering and Construction for many years with various applications. The main objective of this study was to determine what systems are being commonly used today, what benefits are obtained, and the relative cost of implementing a program for use on jobsites. Many medium and small contractors with limited budgets have been asking these questions in order to determine whether to capitalize on this technology for their jobsites. This study used questionaires and interviews with contractors who are currently using drones. A qualitative analysis was done to gain insights and understand people's perceptions. The analysis grouped ideas into themes to show what people consider to be the most important benefits. Additional investigation was done to gather information on features and related costs of current equipment commonly being used. A case study involving drones to verify earthwork is presented as an example of one typical use of drones. As with any new technology, not all contractors will immediately adopt these ideas until actual implementation and use can demonstrate benefits. Unmanned aircraft systems are a tool that can be used throughout the life of a construction project. This study shows a wide range of benefits contractors are seeing with a range of applications and costs.

Keywords: application, contractor, construction, drone, uas

1. Introduction

Unmanned aircraft systems (UAS's), commonly referred to as drones, can help make advances in the construction industry. While many larger contractors have been using UAS's for some time, many smaller contractors have not taken advantage of the technology. Some of the reasons for this include a lack of knowledge concerning what benefits may be had, how much capital must be applied, what equipment should be used, what software is available, and what type of training and licensing is required.

In order to help contractors decide if this technology would be right for them, 4 questions were asked:

1. What are some of the requirements and challenges when using drones in the United States?
2. How are contractors currently using drones on the jobsite?
3. What are the costs associated with using drones?
4. What do people see as the main benefits gained from using this technology?

This study starts with a broad search for common practices that have been developed through the review of current literature. Subsequently, the literature was used to develop appropriate questions to ask professionals in the construction industry who are currently using UAS's to answer some of these questions and define common practices being used. Using pertinent data, recommendations discovered through interviews, and a review of the governmental regulations regarding UAS use, information is compiled to help small to medium contractors determine if the technology would benefit their operations.

2. Method

2.1. Literature Review

2.1.1. regulations

An unmanned aircraft is a flying system that is flown by a pilot on the ground using a control system or an onboard computer; many necessary communication links are required to allow for the unmanned aircraft systems to operate adequately and safely. The unmanned aircraft

system encompasses all of the associated support equipment, control station, data links, telemetry, communications and navigation equipment, etc., necessary to operate the unmanned aircraft. In the United States, the Federal Aviation Administration (FAA) recognizes the entire system as parts of the defined UAS, not just the flying portion of the system (Federal Aviation Administration, 2015a).

Part 107 of the Federal Aviation Regulations (FAR's) regulate the use of UAS's in the United States.

2.1.2. unmanned aircraft system challenges

Challenges with unmanned aircraft systems not only include the liability concerns but also have some fundamental challenges. Liability and safety considerations are a significant reason that the FAA took over a year to write and adopt the regulations for Unmanned Aircraft Systems. Factors include but are not limited to; bodily injury to civilians on the ground, property damage, personal privacy invasion, invasion of business confidentiality, and cyber liability (Potts and Ziss, 2015). Flight path interference is also a primary safety concern of the FAA. Other challenges include but are not limited to; natural causes such as wind speed, to challenges with camera weight limitation, flight time limitation depending on the model, as well as software limitations. These are just a few of the many challenges with UAS, but the benefits outweigh any challenges.

2.1.3. unmanned aircraft system benefits

Unmanned aircraft systems increase overall efficiency while taking human risk out of the equation and increasing operational value for a company. UAS's allow construction industry professionals to explore extreme heights, confined spaces and areas with dangerous material, without direct human involvement, which reduces risks for construction workers (Abaffy, 2015). Unmanned aircraft systems also have operational versatility, are cost efficient, green technology, and independent of airport facilities (Potts and Ziss, 2015). The use of unmanned aircraft systems can become an easy cost effective way to stay ahead of the workload, and innovate while using fewer resources (Smith, 2015). Unmanned aircraft systems can also be used for scheduling benefits. Using unmanned systems to prevent accidents (Nicas and Pasztor, 2015) is another significant benefit to implementing unmanned aircraft systems in the construction industry.

2.1.4. case study using a UAS to verify earthwork

A second case study is an example of the way a general contractor might use a UAS to verify earthwork. Whether capturing aerial photos or video, or generating detailed 3D models of entire sites through the use of photogrammetry, UAS enables the team to gather information rapidly during all phases of construction in a safe, economical, and practical way (DroneDeploy, 2020). This contractor used a DJI Inspire series UAS operated by their Virtual Design and Construction (VDC) group.

During the construction of a hospital, the VDC team used a UAS to determine if the initial earthwork that a subcontractor had just finished was completed to match what had been designed. The VDC team was tasked with finding the difference between the current overall site grade and the proposed final grade. Since the site was over 50-acres, it became a great site to use UAS mapping to measure the elevations of the earthwork, since traditional practices are expensive and time-consuming (DroneDeploy, 2020).

The VDC group contracted with a local UAS services provider, to fly the site and provide the required licensed pilot. The UAS services provider used the DroneDeploy mobile app to plan and automate the flight. Due to the size of the site, multiple flights were needed. Total flight set-up and execution took about an hour. Since the map would be used for comparative analysis, it was important that the map overlayed properly with the design drawings. To ensure a high degree of accuracy, the general contractor incorporated ground control points (GCPs) (DroneDeploy, 2020).

After flying the site, the general contractor uploaded the captured imagery to DroneDeploy. Later that day, DroneDeploy's cloud platform finished processing the imagery into an orthomosaic map shown in Figure 1 (DroneDeploy, 2020), an elevation map, and 3D model. The next step was to get the elevation data from the UAS flight into a format where it could be compared to the existing site plans. That meant the model had to be projected in the same local coordinate system that the design file used, and had to achieve a high degree of accuracy. Entering the ground-based measurements of the ground control points made sure that the map was aligned. Then the 3D model was exported as a point cloud and uploaded to third- party software. From there, the team re-projected the model into the same local coordinate system used in the design file. Once the two models were properly aligned, the team could then compare the model of the existing site with the design file, as shown in Figure 2 (DroneDeploy, 2020).

Fig. 1. Orthomosaic Map

Fig. 2. Elevations Relative to 3D Point Cloud

The final output was a heat map showing the external contractor's earthwork progress according to plan. The green indicated areas where actual elevations matched the design plans. Areas in blue were too low, while areas in red/pink were too high relative to plans. This is shown in Figure 3 (DroneDeploy, 2020). Using the UAS to fly the site and using software to analyze data collected, the general contractor was able to show the earthwork subcontractor where they needed to go back and fix their work.

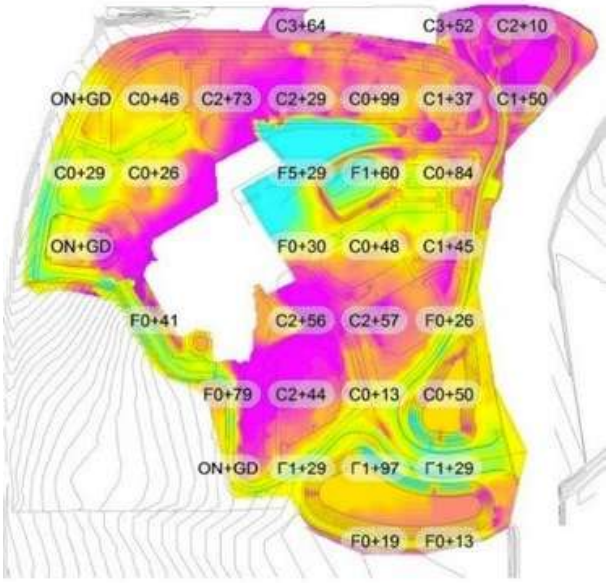

Fig. 3. Elevation Comparison Heat Map

Using a UAS to map the area allowed the VDC team to assess earthwork on the site more quickly than they could have done using traditional methods, while also providing a higher degree of detail. Traditional methods would have necessitated over 1,000 survey shots. Even though 1,000 shots sounds like a lot, the drone easily captures many more data points that result in a more detailed model of the site's elevation. Overall, the project demonstrated the extensive time and cost savings that UAS mapping can bring to the general contractor and construction industry at large (DroneDeploy, 2020). This is an alternative way to traditional methods that promotes innovation in the construction industry while also providing time and cost savings to construction companies.

2.1.5. main findings

Unmanned aircraft systems are a tool that can be used throughout the life of a construction project. Understanding the governmental regulations regarding UAS use commercially will be necessary to use unmanned aircraft systems effectively. According to a report from Goldman Sachs released in early 2020, construction will be the biggest commercial sector for drone use in the near future (DroneDeploy, 2020). This literature review, as well as additional information gathered, will be used in working towards the development of a best practices plan for construction companies to legally use commercial unmanned aircraft systems.

2.2. Research Metodology

2.2.1. research approach

This research will be heavily qualitative; it will serve as the groundwork for small to medium contractors to follow when using UAS's. Semi-structured interviews with industry professionals were conducted to work towards validating the information found in the literature review and provide information to assist in creating a best practices plan. For this study twelve, homogenous interviews were used to promote credible research (Guest et al. 2006). After examination of the regulations, literature, and interviews, a best practices plan was created.

2.2.2. research strategy

This qualitative research method allows for personal perceptions and situational knowledge to be revealed and explored. The subject at hand has multiple interrelated variables and therefore requires more flexibility. Data saturation for interviews usually occurs at twelve interviews (Francis et al. 2010). Consequently, a total of twelve candidates were interviewed. The observations recorded during the interviews were transcribed and analyzed for similarities.

The construction industry professionals considered for interview have been using UAS data on projects and are familiar with the FAA regulations. The target personnel interviewed were project managers, superintendents, and UAS flight school personnel.

2.2.3. interview design

The interview itself has two main factors, the subject matter to be covered, and the framework of design. The subject matter covered describes what areas are of specific interest in this research. The literature review was used as a basis for subject matters most important to explore. The framework of design designates how long the interview should be, and when to ask certain types of questions. A sample of the refined interview questions can be seen in Appendix A.

The main areas of investigation are past, present, and future UAS use in the construction industry.

2.2.4. interview framework

The interview questions were arranged into four main segments in the following order: opening, personal

experiences, tasking, and review. The entire interview was intended to last between thirty to forty-five minutes, depending on the level of participation. Arranging the questions allowed the interviewee to prepare mentally for the detailed questions before asked to share. It also gave ample opportunity and freedom for the interviewee to mention and discuss somewhat unrelated subject matter within the opening and personal experiences questions.

Interview segments were:

1. Opening segment
2. Personal experience segment
3. Tasking segment
4. Review segment

The opening segment consisted of background information to inform the interviewee about the study and how it will benefit the construction industry.

The personal experience segment started with the first interview question asking which sector of the industry the interviewee works in. That allowed the interviewee to describe what types of projects they work on and was beneficial for the best practices plan. The second question asked about their job details, which allowed the interviewee to describe his or her role while mentally shifting from focusing on his or her job to this interview. In a majority of participants, that question brought up many of the themes specifically asked for later in the interview. It, therefore, gave the interviewer a point to revisit and clarify when asking the most detailed questions.

The tasking segment consisted of questions three through five. The questions focused on personal experiences of the participants and were rather subjective. The responses were largely based on personal preference, trial, and error, or a combination of the two. This type of question was utilized for the following subject matter: factors of UAS usage, projects UAS are used on, software preference, and safety. A more subjective framework was used for these subject matters because there is no definitive, objective answer uniformly recognized in any of the listed areas. This seemed most practical for eliciting past information and allowing the interviewee to remain relaxed and confident for the remainder of the interview. After a participant had the chance to offer most personal preferences and experiences, it was expected to be this point at which he or she would be the most likely to deliver accurate and detailed information regarding complex situations.

Lastly, the review segment of the interview was utilized to conclude the interview and let the interviewee add final remarks. In essence, the interview was laid out to invite, comfort, task, and finally, relieve the participant.

2.2.5. data analysis

The interviews were recorded to preserve the interviewees original word and to allow the interviewer to go back and listen to themes they may have missed. This will allow for qualitative analysis of the information collected. The information gathered will be grouped and put into the UAS best practices plan.

The qualitative analysis aimed to gain insights and understand people's perceptions (Farrell 2011). Analysis of this data consists of the following four step process: reading over the interviews to become familiar with the data, re-reading the responses, highlighting and tracking key points, looking over the key points tracked and group them into themes. This process is explained fully in the following paragraphs.

Step one consisted of simply reading the responses by question. This allowed the interviewer to develop a general idea of repeated themes. It was important to read the response without associating the data with the participant's information or background, allowing for a more objective analysis. After the responses were read, the researcher assessed the data. Every time an important word or idea was found within a response, it was highlighted.

According to the information found in the literature review, the inductive inference was used to group similar ideas together. Pointing out critical information should allow for future research to be more easily organized. Finally, to provide a completeness of information found, key participant statements were also discussed in detail. The data was then inserted into a best practices plan based on themes and reoccurrence of information.

3. Research Results

3.1. Participant Typology

There were twelve participants in the final round of. Table 1 below displays backgrounds for the participants.

Table 1. Participant background 1 (minimal) – 5 (expert)

Number of Interviewees	Career in the Industry	Construction Experience	UAS Experience
4	Yes	5	5
3	Yes	4	4
3	Yes	3	2
2	No	1	5

3.2. Qualitative Content Analysis

The results obtained from the interviews were somewhat consistent with what was to be expected. For the most part, it has been agreed that UAS will help to improve and add innovation to the construction industry. Each company interviewed has their factors of UAS usage, reasoning behind why UAS should or would be used on a construction site. Reasons included, but were not limited to the strive for innovation, advancement in technology, progress documentation/reports, cost savings, time savings, safety impacts, and quality improvement. Through performing the qualitative content analysis, four main themes were found, all relating to one overarching main theme. Each theme describes an important aspect of the Impact of Unmanned Aircraft Systems in the construction industry and was developed by grouping similar participant responses found in the data. The main theme of quality is seen as most important. The four additional themes: safety, timesaving, cost and progress data all have individual importance, however, once examined closely they all promote quality.

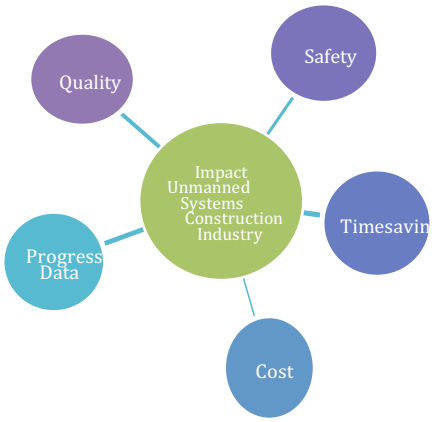

Fig. 4. Thematic Mapping Qualitative Analysis

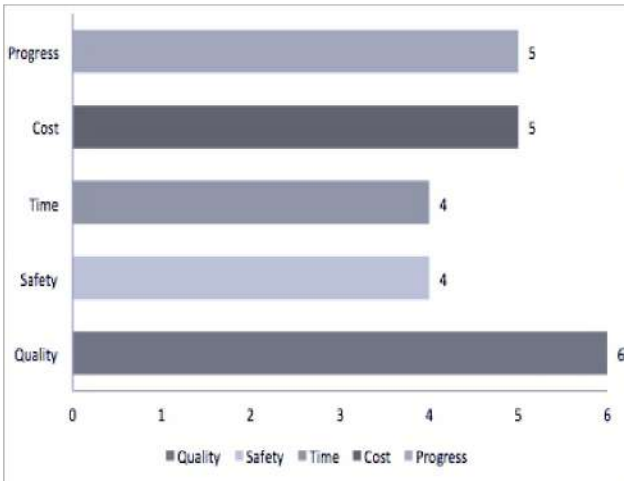

Fig. 5. Qualitative Theme Response

3.2.1. safety

The main theme of safety covers the area pertaining to a safer work environment, which can be produced when using an unmanned aircraft system. Using a UAS to create a safer work environment is a key to helping innovate an already dangerous industry. UAS can be used to inspect high areas, not putting individuals at risk. In traditional practice, a worker in a lift will be raised up to inspect areas such as curtain walls, exterior roofs, high walls, and many other areas. Now this can all be done with a UAS instead of putting someone's life at risk.

3.2.2. timesaving

The central theme of timesaving covers the work hours saved when using a UAS on a construction site. Using a UAS is faster than using a total station and surveying. While there are still plenty of tasks on a site that will not be able to eliminate the use of surveying, for small things and a quick turn around time a UAS will be able to be used. Data is also retrieved abundantly with relatively little effort. For example, it could take a team to survey a site up to two weeks, while with the drone it can be done in less than two days. This brings up the idea of accuracy; however, the data retrieved is pretty accurate within under an inch, while that is not as accurate as the total station, which is accurate within seconds, the UAS is still developing and will only continue to gain accuracy. In an industry that is pressed for time, a UAS will become a popular tool to use to gain quick and accurate answers in a short amount of time.

3.2.3. cost

Uncovered through the interviews, was the fact that UAS's have a significant cost efficiency, approximately 50% - 75% more economical than traditional methods. They are more cost efficient in a variety of ways discussed in interviews but not limited to, using a UAS gains more images than hiring a traditional aerial photographer. Using a UAS to survey a site is more economical than sending two people out to survey the site. The use of using unmanned aircraft systems raised the question of whether contractors will contract out the UAS work or self-perform the UAS work in-house. In the construction industry long run, it will be more cost efficient to self perform work with UAS. Out of the participants interviewed, 50% of them self-perform unmanned aircraft system use, while 33% prefer to contract the use of unmanned aircraft systems out, and 17% were not assessed. The main benefit for self-performing was the cost efficiency over time, once you are properly vetted the ability not to have to wait for a third party to fly and ability to fly as many sites as you want at little to no additional cost. While the main benefit to contracting a third party to fly is the fact that you have little upfront costs to be able to use the UAS and data collected with it, you don't need to be concerned as much with the FAA regulation because the third party company will have taken care of that need. There are positives and negatives to self-performed vs. contracted out UAS use on a site, however, the cost savings outweigh the traditional approach, making using the UAS a valuable tool. With the use of UAS, this is the first time in construction the industry is moving the necessity of having construction management on the job site, to allowing them to work from the main office. An UAS allows one or two people to gather data about how the project is progressing with the data then reported electronically back to the main office. A UAS is one of the many technological advances that will allow for a smaller staff on a job site, while allowing the project to be run from the main office. Not having to staff, as many people on a job site and allowing a majority of the project management to occur in the main office will create cost savings for companies. In an industry with high costs, costs savings in any way is a significant benefit to any job.

3.2.4. progress

The interviews uncovered the fact that using a UAS is incredibly efficient for tracking the progression of a job. Instead of traditional aerial images, where you only gain a handful of images from a set angle, using the UAS you can get hundreds of images from a variety of angles and at a height that is more beneficial for tracking progress than the traditional aerial image. The images collected from the UAS will then become increasingly beneficial to the job as a whole. These images can be used for, but not limited to, record keeping, progress, and evidence should claims arise. The construction industry is always looking for innovative ways to track progress and keep records, using a UAS is just another tool in the toolbox to add value to a project.

3.2.5. quality

The theme of quality when it relates to construction means meeting and exceeding the client's expectations. This theme is one of the crucial aspects of a construction job as the client is very important. Quality is built upon

safety, timesaving, cost, and progress, all aspects that have an increase in value when using a UAS. UAS's increase the amount of pictures being captured; the variety of pictures and the resolution of the pictures exceed traditional approach. The UAS additionally provides data that is more current than data collected through aerial photography, since using a UAS is more economic, flying the job can be done more frequently than if aerial photography via a plane is used.

UAS's allow for innovation in project planning and delivery. The UAS can be used to map the job site prior to construction, to allow for adjacent boundaries to be clearly seen, traffic patterns to be realized and site space allocations to be made. Overall the importance of achieving the best quality is very important, and now this new tool can be used to help achieve excellent quality.

3.3. Limitations with UAS's

Through interviewing industry professionals, it was discovered that while there are many benefits to this innovative tool, like with anything, there are limitations. One of the main issues is the battery life on UAS. Each battery when full will allow for approximately 20 minutes of flight time since you are required to land with 10% battery life. If you are trying to get complex data from the UAS, then it is recommended that you have all the batteries fully charged and have a place set up in close proximity to charge batteries as you fly. Another downside to UAS is the software run through the Apple iPad/tablet is very process intensive and can cause the equipment to overheat. If the iPad/tablet overheats while flying the operation must be stopped to all the device to cool down before flying again. Additionally, most software needs access to WIFI to be able to set up your flight and access Google Earth®. The height and placement of trees can become a limitation when they are in the path of the UAS when flying. It is important to examine the area and either fly in front of the trees if the view is still attained from that location or fly at a height that is above the obstacles while still keeping the UAS under 400 feet and in visual line of sight (VLOS). Another limitation would be equipment malfunctions, but with anything, there are always chances for equipment to malfunction. However, the safety benefits of being able to use a UAS outside to inspect the building are a greater benefit than the risks. Limitations happen with any type of equipment, however, the benefits of UAS's use on a construction site are far greater than the limitations UAS use poses.

4. Discussion – Best Practices Plan

4.1. What Can the UAS Do For Projects

An unmanned aircraft system is a valuable tool that, when used on a construction site, can improve quality, safety, time and save money for an entire project. An unmanned aircraft system can be used to innovate processes in the industry that is notoriously known for lagging behind on advancements. The following is a list compiled through doing interviews with industry professionals that can provide ideas for what a UAS can be used for on a construction project:

1. Powerful marketing tool
2. Progress documents; for record keeping, and great imagery
3. Topographic maps
4. Surveying
5. Site layout and mapping
6. Site analysis
7. Site and exterior building inspections
8. A way to catch errors
9. Utility location tool
10. Better safety planning
11. Building and traffic logistics

4.2. Popular Systems

Three major unmanned aircraft companies are Dajiang Innovation Technology (DJI). SenseFly and Skydio. While there are other UAS companies out there, for the purpose of construction these have proven most useful.

The DJI unmanned aircraft systems range in price from around $600 for the DJI Mini 2, to over $11,000 for enterprise units that can carry custom payloads. These are typical 'quad copters' with 4 motors/blades and can be operated in small areas. Flight time is typically 15-25 minutes depending on wind and operator.

Fig. 6. DJI Inspire in flight

SenseFly makes the eBee which is a fixed wing drone which can cover large areas with up to 50 minutes of flight time. Pricing is in the $25,000 range.

Fig. 7. SensFly eBee

Skydio makes a 'quad copter' similar to the DJI units but is made in the US and approved for use by the military. They use cameras for collision avoidance and positioning eliminating the need for a good GPS signal as do the other units. This makes them work well indoors. They have two models from around $2500 - $9000.

Accessories may be added to any system, such as additional controllers, extra batteries, or cases that would add to the overall cost.

4.3. Programs to Plan Flights and Collect Data

Each UAS comes with software that can be pulled up on an Apple or Android mobile device. An ipad or phone screen can be used to 'see' what the drone camera sees and to

provide flight data for manual flying. Additional programs allow pre-program flights using Google Earth as a map to set waypoints and plan a flight path that can be flown automatically by the drone collecting photographs, movies or data along the way.

Fig. 8. Ipad® with controller

The latest generation of drones and cloud-based image processing put professional-quality aerial imagery into the hands of builders and project managers in a way that is faster, and more cost-effective

Due to the length restriction of this paper it is not possible to discuss each of the programs for data collection and post processing in detail. These will be presented at the conference proceedings and the author(s) may be contacted for additional information. A list of commonly used programs are below:

1. DroneDeploy – provides autonomous flight programming and collection of data. Their cloud based service can process uploaded photogrammetry and provide post processing for topographic maps, 3d point clouds, etc. It offers complex data simplified through orthomosaics, terrain models, NDVI analysis, and 3D models. It additionally allows cropping of maps, measurements to be taken, exact distance and volume, as well as annotations (DroneDeploy, n.d.). DroneDeploy runs pre-flight and in-flight checks to ensure that the UAS is safe to fly before take off and can take corrective action if needed. UAS and mobile device battery levels are checked, so the operator never runs out of power. The builtin geo-fencing helps the operator stay compliant with local regulations, automatically. The free DroneDeploy app provides easily automated flight and data capture, live streaming first person view, auto-flight disable and resume control, multiflight mission support, enabling high-quality interactive maps for analysis, 3D modeling and more. This offers a wide variety of aerial image and mapping applications, including crop scouting, mapping and surveying, construction and mining stockpile measurement, roof and insurance inspection all helpful for the construction industry

2. FPV Camera – a very inexpensive app that allows setting up autonomous flights using waypoints and targets to collect photos and video.

3. Maps Made Easy - Map Pilot helps you create and fly the optimal flight path to create maps using the Maps Made Easy map processing service. Collecting abundant data to create highresolution aerial maps.

4. Litchi –a popular autonomous flight app. With a few simple clicks and taps, users can set up flight plans that go way beyond a simple waypoint mission engine. Litchi includes standard Panorama, Orbit and a Follow me feature, but operators can also use select focus mode, where Litchi assists you by taking control of both the gimbal and the drone's yaw axis, freeing the operator allowing them to concentrate on horizontal movement. Litchi also comes with a tracking mode, keeping the object or person you select in the frame while you fly or during an autonomous mission. Finally, Litchi creates readable flight logs for each and every flight, before automatically uploading them to HealthyDrones account. Having a linked cloud base to store data on is a great feature for pilots looking for instant post-flight analysis. (Murison, 2016)

5. Pix4D – Analyze and monitor construction sites as they evolve, using geo-referenced orthomosaics and elevation data. View the as-built situation of your site for up-to-date measurements and continued analysis, as well as volumetric measurements for more efficient earthwork management. Pix4Dcapture allows the operator to turn the UAS into a mapping and measuring tool by defining autonomous mapping flights, allows the operator to select an area for mapping, start a fully autonomous mission, images are taken automatically and are geo-tagged ("Pix4D - Drone Mapping Software," 2021). Additionally, the operator can interrupt the mission at any time in case of danger, transfer images to your computer. The images can be converted into maps and 2D models as well as 3D models (BIM and CAD) using the Pix4Dmapper desktop software or on a cloud. This is able to run with sensFly and DJI unmanned aircraft systems.

6. 3Dscan – Skydio's program which can produce highly accurate point clouds from photometric data.

These are just a few of the many programs available to get the most out of the equipment. Prices and accuracy can suit most any need.

5. Conclusions and Further Research

5.1. Conclusions

The entire research was originally formatted as a sixty page article. Reducing the length to fit the limitations for this conference proceedings required leaving out considerable detail. If you would like more information you may contact the authors. While the detailed conclusions are represented in previous sections, this section will summarize some of the basic benefits of implementing a UAS program on the job site.

The use of unmanned aircraft systems in the construction industry will continue to increase as more companies push for innovation and look toward safer, faster, cheaper construction methods. UAS data can be gathered by one to two people on site with the data reported electronically back to the main office. A UAS is one of the many technological advances that will allow many aspects of management, quality control, and verification of accurate job progress to be done remotely. This could result in smaller staff on the job site while allowing actual jobsite

conditions to be distributed to peoply who normally would need to make a jobsite visit thus reducing project costs.

UAS's enable innovation in project planning and delivery. The UAS can be used to map the job site prior to and continually during construction, to allow for adjacent boundaries to be clearly seen, traffic patterns to be realized and site space allocations to be made. The construction industry is always looking for innovative ways to track progress and keep records. A UAS is just another tool in the toolbox to add value to a project.

Using a UAS to create a safer work environment is a key to helping innovate an already dangerous industry. UAS's can be used to inspect high areas, not putting individuals at risk. Finally, using a UAS allows project teams to assess various aspects on the site much more quickly and in greater detail than they can do using traditional methods.

5.2. Further Research

The use of Unmanned Aircraft Sytems in construction is a very rapidly evolving field. There are new drones that map their own flight paths, including indoor flights. The post processing of photographic data is increasing in accuracy to produce 3D point clouds with near laser scan accuracy. Recently a drone was introduced using quick response LiDAR. While the accuracy is not yet as accurate as a fixed mount laser scan, the speed opens up this technology to new applications.

The main elements of this research:

1. Investigation of what industry is currently doing, how they are using the technology
2. What benefits are being seen in what areas, safety, accuracy, management, etc.
3. What equipment is available and what are the capability vs cost comparisons
4. What post processing software is available and what are the capabilities

With the rapid changes in technology, these same investigations can be done again as the industry evolves and continue to give useful information to those who may want to start using UAS's as well as those who may want to upgrade their equipment and best practices.

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Appendix A – Interview Research Questionnaire

General Questions:

1. In which sector of the construction industry do you work in? If you do not work in the construction industry then what industry do you work in and what work are you using UAS's in?
2. What does your job entail?

Unmanned Aircraft Systems Questions:

1. How do you think the use of unmanned aircraft systems can impact the area of construction you are involved in?
2. If you are currently collecting or prior to the regulation change were collecting information using UAS's, how are you integrating it into the construction process?
3. How do you think the use of UAS's will impact project safety?
4. How do you think the use of UAS's will affect project cost?
5. Does your company self perform or contract out when using unmanned aircraft systems?
   - (IF contracted out) How do you tell the company in which you contract the work to, what you want flown with the UAS?
   - Is there a tolerance for UAS data?

Paper no. 106

Circular Economy for Successful Implementation of Sustainable Development in the Construction Industry

Maria Ghufran[1], Khurram Iqbal Ahmad Khan[1*], Abdur Rehman Nasir[1], Muhammad Usman Hassan[1] and Ahsen Maqsoom[2]

[1]Construction Engineering and Management Department, National University of Sciences and Technology (NUST), Islamabad, Pakistan; E-mail: mghufran.cem17nit@student.nust.edu.pk (M.G.); abdur.nasir@nit.nust.edu.pk (A.R.N.); usman.hassan@nice.nust.edu.pk (M.U.H)

[2]Department of Civil Engineering, COMSATS University Islamabad Wah Campus, Wah Cantt 47000, Pakistan (A.M), E-mail: ahsen.ait@gmail.com

*Correspondence: khurramiqbal@nit.nust.edu.pk (K.I.A.K)

Abstract: The construction sector must make the switch from a linear to a circular economy to reduce global impacts and preserve natural resources. Products and materials in a circular economy continue to circulate through the supply chain in a high-value state of usage for as long as possible. As an essential step towards attaining sustainable development, the circular economy concept is gaining prominence among governments, academia, organizations, and individuals. The latest research has urged for transformation in favour of a circular economy built on sustainability. Consequently, the purpose of this article is to ascertain the key drivers of the circular economy promoting sustainable development in the construction industry. This research found 31 drivers from the literature via content analysis. A field survey was further conducted to shortlist the crucial drivers. The collected score from the literature and field survey was used to decide the decisive ranking of drivers. A total of 10 circular economy drivers in terms of importance were selected for further consideration. The findings of this research can assist construction industry personnel in implementing the circular economy., which will foster innovation, sustained growth, and enhance competition.

Keywords: circular economy, content analysis, construction, drivers, sustainability.

1. Introduction

The construction industry (CI) is one of the world's substantial users of energy and raw material (Heisel and Rau-Oberhuber, 2020). With the growing world's population, there is more usage of material resources, resulting in an increased demand for raw materials and a decrease in supplies (Adams et al., 2017, Agrawal et al., 2021). The linear economy (LE) works on the principle of "Take-Make-Dispose", whereas the circular economy (CE) is a closed-loop system that focuses on the "Make-Use-Recycle" approach, designing for long-term use, remanufacturing, and reprocessing to retain products, components, and materials circulating in the economy (Geissdoerfer et al., 2017). With CE one can minimize virgin resource use, avoid waste, turn waste into a resource, cut costs, and create jobs (Aranda-Usón et al., 2020). Moving towards a CE allows the reduction of the consumption of primary materials, conserving natural resources, and lowering carbon footprint, providing economic benefits, such as increased economic output, net material savings, employment growth, and reduced risk of material price volatility (Saidani et al., 2019). Instead of considering a holistic perspective of all three dimensions of sustainability, CE concentrates on increasing environmental performance (Ghisellini et al., 2016). CE seems to be almost completely silent on the social issue (Clube and Tennant, 2020). Sustainability, on the other extreme, seeks to benefit the environment, the economy, and society (Corona et al., 2019). For successful CE implementation, it is crucial to understand the social, environmental, and economic aspects of sustainability. A true CE must also be a sustainable economy (Geissdoerfer et al., 2017). Though CE is gaining traction among researchers, the actual application of its concepts is still in its infancy (Dantas et al., 2020). The majority of the research concentrate on the discussion of concepts around CE (Kirchherr et al., 2017, Klein et al., 2020) whereas the research concentrating on the variables that drive sustainable development is limited and mainly focused on single indicators. In some cases, the perspective varies as Lozano et al. (2015) discussed the drivers for corporate social responsibility, Pietzsch et al. (2017) described drivers of waste management, Geng and Doberstein (2008) discussed societal factors related to CE and Bilal et al. (2020) discussed barriers in the implementation of CE. No specific research related to drivers of CE for sustainable

development has been conducted (Dantas et al., 2020). The CI has an urgent need for this paradigm shift towards a sustainability-based CE (Abadi et al., 2021). This leads to the research question that how can CE be successfully implemented for sustainable development? To achieve this, a study having a holistic view of drivers of CE for the successful implementation of sustainable development is needed (Hysa et al., 2020, Patwa et al., 2021). As this research is nascent, therefore, the objective of this research is: to find the crucial drivers of CE for sustainable development in the CI. To achieve this objective, this study will use content analysis and a field survey. Content analysis is a method for quantifying qualitative data (Stemler, 2015). The results of this study can assist CI practitioners in terms of implementation of CE resulting in cost reduction, increasing productivity, environmental protection, driving innovation, boosting economic growth, and improving competitiveness.

The article is organized in the following manner: the literature regarding CE for sustainable development is discussed in the subsequent part. The research methodology is described in the third part. The findings are discussed together with the shortlisted drivers in the fourth part. The study's findings are reported in the final section.

2. Literature Review

Structured on a take-make-consume-throwaway pattern, the CE is a paradigm of manufacturing and utilization that encourages the reuse, repair, recycling, and sharing of pre-existing goods and materials. (Wang et al., 2016, Guerra and Leite, 2021). CE termed the recycled-based economy is based on the closed flow of materials, that can keep harmony between the environment and humanity (Clube and Tennant, 2020). It is a new paradigm for achieving sustainable development (Morseletto, 2020). Its implementation necessitates the involvement of key stakeholders as well and above all, it benefits public health, as environmental degradation and health dangers associated with poor e-waste treatment have become major concerns in many nations (Heacock et al., 2016). The problems of implementing CE in industries are ubiquitous (Joensuu et al., 2020), associated with faster economic growth, significant net material cost reductions, alienation of growth from raw materials and price volatility, as well as job creation, and increased productivity (Suárez-Eiroa et al., 2019).

Given its huge prominence among politicians, corporate executives, and scholars, the CE idea and its underlying concepts are not without its critics and obstacles (Carroll and Brown, 2018). Attempting to achieve 100% recyclability in the situation can be detrimental (Marshall and Farahbakhsh, 2013). Furthermore, abuses of power, biased labour, and a disdain for human rights may continue to jeopardize people's basic needs on a worldwide scale (Avraamidou et al., 2020). Regardless of these challenges, the principles of the CE hold a lot of promise as it allows for the reconciliation of environmental stewardship and business concerns, asserting that value creation is still possible within strict ecological limits (Rincón-Moreno et al., 2021).

To ensure that products, components, and resources circulate through the economy, professionals must take durability, reuse, remanufacturing, and recycling into account. Sustainability and CE are closely related concepts that have been espoused for many years. CE is considered a subset of sustainability (Benachio et al., 2020). CE can lead to sustainable development that satisfies existing requirements without jeopardizing the capability of future generations (Toman, 2010). A more circular world benefits from sustainability efforts, however not all sustainability efforts benefit from circularity (Blomsma and Brennan, 2017, Clube and Tennant, 2020). Though sustainability is more widely related to people, the environment, and the economy, circularity is mainly concentrated on resource cycles (de Abreu and Ceglia, 2018). The CE seamlessly integrates into the larger context of sustainable development (Guerra and Leite, 2021). It is a part of the overall strategy that also incorporates elements of the sustainable economy, resource efficiency, eco-design, or the economic growth of functionality (Janik and Ryszko, 2019).

3. Methodology

The schematic diagram for this research is presented in Fig.1.

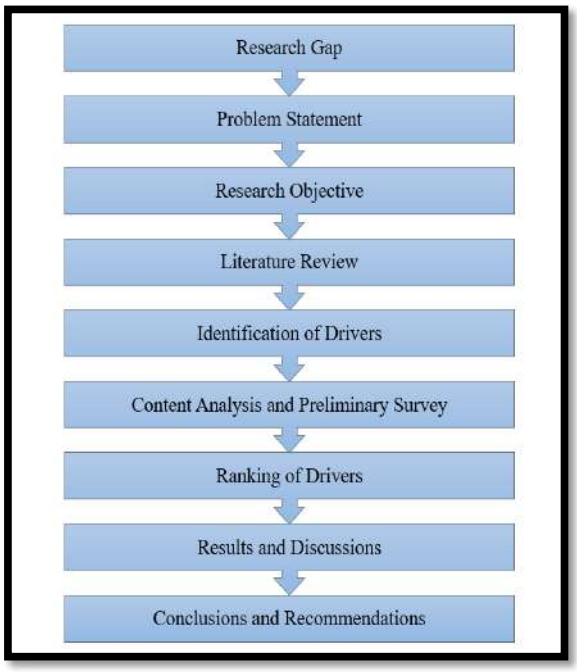

Fig.1. Methodology Chart

The problem statement and study objective were established after a thorough literature review which assisted to identify the research gap. A detailed literature review of 35 research articles was further conducted for the identification of the CE drivers using content analysis. The selected 35 articles were published between 2016 to 2021 concentrating more on the recent developments of CE. Keywords used for scrutiny of these articles include the “construction industry”, “drivers of circular economy”, and “sustainable development”. Initially, 31 drivers were identified from the body of knowledge. They were ranked based on a normalized score obtained by a research method called content analysis. Through thorough literature research and content analysis, the influence of each driver (high, medium, low) was assessed (Ghufran et al., 2021, Amin et al., 2022, Jahan et al., 2022) in content analysis. Each impact was assigned a numerical value (5 for high, 3 for medium, and 1 for low) and the maximum occurrence influence was selected for each driver. Equation 1 shows the literature score (LS) computation via the Relative Importance Index (RII), where A represents the maximum score, N is the complete number of articles deemed to identify the drivers, whereas W shows the highest frequency impact (Rasul et al., 2019).

$$RII = \frac{\Sigma W}{A * N} \quad (1)$$

$$NLS = \frac{LS}{\Sigma LS} \quad (2)$$

As shown in Equation 2, the LS was normalized by dividing the individual LS (RII) for each driver by the cumulative LS. Table 1 displays the normalized literature score (NLS) and references of the 35 identified drivers from the literature along with the assigned codes.

Table 1. Driver's identification from literature

Sr. No	Code	Driver	NLS	Reference
1	D1	Financial support of government	0.1213	(Rizos et al., 2016, Govindan and Hasanagic, 2018, Brown et al., 2019, Tayebi-Khorami et al., 2019, Barreiro-Gen and Lozano, 2020, Kanters, 2020, Patwa et al., 2021, zu Castell-Rüdenhausen et al., 2021)
2	D2	Stringent regulations	0.1070	(Brown et al., 2019, Tura et al., 2019, zu Castell-Rüdenhausen et al., 2021)
3	D3	Product life cycle extension	0.1070	(De Jesus and Mendonça, 2018, Ranta et al., 2018, Tayebi-Khorami et al., 2019, Barreiro-Gen and Lozano, 2020, Kanters, 2020, Torres-Guevara et al., 2021, Velenturf and Purnell, 2021)
4	D4	Incentive schemes offered by organization	0.0999	(Adams et al., 2017, Govindan and Hasanagic, 2018, Ormazabal et al., 2018, Ranta et al., 2018, Tura et al., 2019, Dantas et al., 2020, zu Castell-Rüdenhausen et al., 2021)
5	D5	Smart and innovative technologies	0.0856	(Adams et al., 2017, Govindan and Hasanagic, 2018, Ranta et al., 2018, Barreiro-Gen and Lozano, 2020, Charef and Lu, 2021, zu Castell-Rüdenhausen et al., 2021)
6	D6	Awareness provided through workshops and education programs	0.0713	(Adams et al., 2017, Alhosni and Amoudi, 2019, Guerra and Leite, 2021, Smol et al., 2021)
7	D7	Regulative support	0.0642	(Xia et al., 2018, Hart et al., 2019, Guerra and Leite, 2021)
8	D8	Durability of resource	0.0342	(Rizos et al., 2016, Antikainen et al., 2018, Ranta et al., 2018, Tura et al., 2019, Zhou et al., 2020, Dantas et al., 2020, Patwa et al., 2021)
9	D9	Collaboration among different parties	0.0342	(Kalmykova et al., 2015, Ormazabal et al., 2018, Alhosni and Amoudi, 2019, Brown et al., 2019, Tura et al., 2019, Barreiro-Gen and Lozano, 2020, Dantas et al., 2020, Velenturf and Purnell, 2021)
10	D10	Priority of political parties	0.0285	(Ilić and Nikolić, 2016, Hart et al., 2019, Kanters, 2020, Smol et al., 2021)
11	D11	Circularity of materials	0.0285	(Ilić and Nikolić, 2016, Smol et al., 2021)
12	D12	Management support	0.0257	(Ranta et al., 2018, Brown et al., 2019, Dantas et al., 2020, Torres-Guevara et al., 2021)
13	D13	Social Recognition	0.0214	(Ranta et al., 2018, Brown et al., 2019, Torres-Guevara et al., 2021)
14	D14	Supportive infrastructure	0.0214	(Alhosni and Amoudi, 2019, Torres-Guevara et al., 2021, Velenturf and Purnell, 2021)
15	D15	Accessibility to transparent data	0.0171	(Ilić and Nikolić, 2016, Ormazabal et al., 2018, Guerra and Leite, 2021, Torres-Guevara et al., 2021)

16	D16	Transparency of supply chain	0.0171	(Ranta et al., 2018, Tura et al., 2019, Ratner et al., 2021)
17	D17	Flexible decision making	0.0171	(Tura et al., 2019, Charef and Lu, 2021, Velenturf and Purnell, 2021, zu Castell-Rüdenhausen et al., 2021)
18	D18	Consumer Demand	0.0128	(Epstein et al., 2018, Patwa et al., 2021, zu Castell-Rüdenhausen et al., 2021)
19	D19	Big data	0.0128	(Patwa et al., 2021)
20	D20	Organization culture	0.0086	(Ilić and Nikolić, 2016, Ranta et al., 2018, Charef and Lu, 2021)
21	D21	Reduction of risk	0.0086	(Charef and Lu, 2021)
22	D22	Teamwork spirit	0.0086	(De Mattos and De Albuquerque, 2018, Dantas et al., 2021)
23	D23	Education and Training	0.0086	(Pomponi and Moncaster, 2017, Charef and Lu, 2021)
24	D24	Regulations and standards	0.0086	(Adams et al., 2017, Hart et al., 2019)
25	D25	Digitalization (Virtualization)	0.0057	(Pomponi and Moncaster, 2017, Ormazabal et al., 2018, Charef and Lu, 2021)
26	D26	Consumer Behavior	0.0043	(De Mattos and De Albuquerque, 2018, Ormazabal et al., 2018, Patwa et al., 2021)
27	D27	Leadership	0.0043	(Ilić and Nikolić, 2016, Ormazabal et al., 2018, Hart et al., 2019)
28	D28	Supportive vision	0.0043	(Alhosni and Amoudi, 2019, Velenturf and Purnell, 2021)
29	D29	Skills development	0.0043	(Avdiushchenko and Zając, 2019, Dantas et al., 2020, Smol et al., 2021)
30	D30	Legislation	0.0043	(Ormazabal et al., 2018, Dantas et al., 2021)
31	D31	Stakeholder's early involvement	0.0029	(Antikainen et al., 2018, Smol et al., 2021)

Since a response rate of 30 is widely accepted, a primary survey was conducted with a response rate of 30 for field score (Chan et al., 2018). This survey consisted of II parts. Respondents were questioned about their demographic profile in the first section while in the second part, on a scale of 1 to 5, they were asked to rate the significance of each driver with 1 being the least important and 5 being the most important (Jahan et al., 2022). The survey was sent to almost 1000 respondents via LinkedIn, Gmail, and Facebook. Based on the combined score (survey and literature), the final ranking of drivers was done with a weightage of 60R/40L (60 % of the respondent's normalized score and 40% of the literature's normalized score) (Ghufran et al., 2021). Using SPSS ®, simple statistical tests were used to determine the reliability and normality of the data. Cronbach's Alpha value turned out to be 0.82 which shows that the data is reliable and consistent (Longo, 2018). After arranging factors in descending order concerning their merged score, factors having cumulative percentage normalized scores up to 50 percent were shortlisted for further analysis (Rasul et al., 2019). In total 10 drivers of CE for sustainable development were shortlisted as shown in Table 3.

3.1. Respondent's Profile

Table 2 represents the demographic details of the respondents. According to Table 2; discussing the role of the respondents in the CI, the survey encompassed 7 Construction Managers (23%), 5 Assistant Managers (17%), 6 Project Managers (20 %), 4 Project Directors (13 %), 3 Academicians (10%), 3 Project Designers (10%), and 2 Planning Engineers (6%). Concerning the working experience of respondents; Table 2 shows that 23% of respondents had working experience of more than 20%, 7% had 16-20 years, 10% had 11-15 years, 43% had 6-10 years, 10% had 2-5 years and 7% had of 0-1 years. Respondents belonged to both government and private sectors. 40% of the respondents were from the government sector, 47% were from the private sector, whereas 13% were from the semi-government sector. Discussing the qualification of respondents 17% of respondents were Ph.D. holders, 50 % of respondents were MS holders, 26% had done graduation

and 7% were diploma holders. Regarding the understanding of the topic, 50% of respondents had a high understanding, 40% had a moderate and 10% were having a slight understanding of the topic.

Table 2. Respondents' Profile

Profile	Frequency	Percentage
Total responses = 30		
Designation		
Executive Engineer	7	23%
Assistant Engineer	5	17%
Architect / Designer	3	10%
Planning Engineer	2	7%
Project Manager	6	20%
Project Director	4	13%
Academician	3	10%
Professional Experience (Years)		
0-1	2	7%
2-5	3	10%
6-10	13	43%
11-15	3	10%
16-20	2	7%
> 20	7	23%
Education		
Diploma Holder	2	7%
Graduation	8	26%
Post-Graduation	15	50%
PhD	5	17%
Organization type		
Government	12	40%
Semi-Government	4	13%
Private	14	47%
Understanding of circular economy		
Slight	3	10%
Moderate	12	40%
High	15	50%

The questionnaire was sent to developing economies that were selected following (Amin et al., 2022, Jahan et al., 2022). Most respondents belonged to Pakistan, South Africa, Kenya, Nigeria, Turkey, and Saudi Arabia. Discussing the level of understanding, 50% of respondents have high understanding,40% were having moderate and 10% were having slight understanding. Country-wise awareness levels and implementation of CE were reported as Pakistan (25%), South Africa (22%), Kenya (20%), Nigeria (18%), Turkey (15%), and Saudi Arabia (3%). The respondents' geographical distribution is presented in Fig.2.

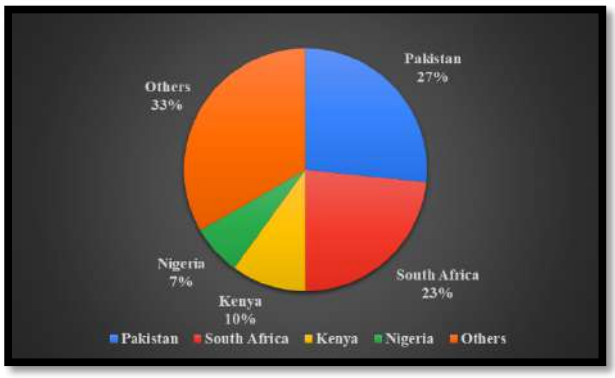

Fig.2. Geographical Distribution of Respondents

4. Results

Table 3 shows the ten CE drivers for sustainable development that were selected. For the government financial support, the 60 R/40L value came out to be 0.074 depicting this as the strongest driver of CE for sustainable development followed by extension of product life cycle as 0.068 and organizational incentive schemes as 0.060. The description of the shortlisted drivers is given below

Table 3. Selected Drivers

Sr. No	Code	Drivers	60R/40L	Cumulative Score
1	D1	Financial support of government	0.074	0.074
2	D3	Product life cycle extension	0.068	0.141
3	D4	Incentive schemes offered by the organization	0.060	0.201
4	D5	Smart and innovative technologies	0.059	0.260
5	D2	Stringent regulations	0.053	0.313
6	D7	Regulatory support	0.051	0.364
7	D6	Awareness provided through workshops	0.044	0.407
8	D8	Durability of resource	0.034	0.441
9	D10	Priority of political parties	0.031	0.473
10	D11	Circularity of materials	0.031	0.504

The governments' role can indeed be crucial in fostering a long-lasting perception of the CE (Almulhim and Abubakar, 2021). Government can motivate the private sector towards CE through coherent guidelines. Instead of just finishing buildings with low-quality materials, the government can persuade designers to follow guidelines that increase their lifespan (Rissman et al., 2020). Similarly, designing construction elements to survive longer and retain their value has been identified as a key driver for sustainable growth. According to Cooper (2020), the extension of product life cycles is the second most

important driver for sustainable development in the UK. Organizational incentive schemes are arrangements in which employees are rewarded based on their best performance (Koskey and Sakataka, 2015). A fair portion of the increased output can dramatically enhance the performance and productivity of employees having a clear substantial impact. This was confirmed by a survey conducted by Horbach et al. (2015), who found that when an incentive program was implemented, average production improved. Utilizing smart technologies that enable transparency and information exchange about reusable components is a key enabler in the transition to circularity. Benachio et al. (2020) concluded that the successful CE implementation can stem from the utilization of innovative and smart technology. The government's stringent regulations on CE implementation serve as a significant driver for the shift to sustainable development (Gholami et al., 2021). Despite the lack of attention paid to this driver in the literature, Alhosni and Amoudi (2019) demonstrated that implementing strict waste management, energy efficiency, and construction policy regulations will make it easier to implement CE regulations because disposal will be costly and difficult. Policy support is a powerful driver for sustainable development. To expedite the transition to a CE in CI, policies have been highlighted as a significant driver; nevertheless, additional understanding of how enterprises might be assisted in practice is required (Klein et al., 2020). Awareness through workshops and education programs must be provided as MacArthur (2013) suggested that it is an initial step towards CE implementation. The sustainable use of world's limited resources while minimizing adverse effects on the environment is referred to as resource durability. It is a critical strategy for separating economic expansion from environmental damage while simultaneously boosting human well-being (Klein et al., 2020). Political priority refers to the level of attention given to a certain concern by political parties. This contains the most essential plans that will be used by the government or the relevant organization and help in implementing CE (Friend and Jessop, 2013**).** After being used, the materials lose their value and functionality, and they become waste. The CE concept tries to achieve circularity by covering the linear paradigm of take-make-dispose by closing loops (Mboli et al., 2020).

4. Discussions

The provision of guidance through the government assists in the CE implementation and is vital. In addition, the shift to sustainable development is significantly assisted by the government's rigorous restrictions (Sachs et al., 2019). Support from policy acts as a potent catalyst for sustainable development. Increasing awareness through workshops and educational programs is the very first step in implementing CE (Caiado et al., 2018). Political priority is an important determinant since it affects the crucial strategy the government will use to implement CE. It has been highlighted that having these programs available has led to greater performance. Organizational incentive schemes are additional compensations to the employees following their best performance (Triplett, 2018). A fundamental driver in the switch to CE is the usage of innovative technologies. Smart technology utilization, in particular, permits transparency and information sharing about recyclable materials, making it a crucial enabler in the transition to circularity (Giourka et al., 2020). The extended product life cycle plays a significant role as well (Srinivasan and Jayaraman, 2021).

5. Conclusions

The study aimed to identify the most important CE drivers for sustainable development in the CI. Using content analysis, this research found 31 drivers in the literature from a total of 35 research articles. A field study was further conducted to shortlist the most important drivers. The final ranking of drivers was established using the data gathered from the literature and the field survey using a 60R/40L ratio in which 60 % was the survey normalized score and 40 % represents the literature normalized score. A total of ten CE drivers for sustainable development were shortlisted having a 50% impact as shown in table 3.

According to the results, the governmental perspective has by far the most favorable effect on CE implementation. Laws, procedures, risk minimization (via tax levies), and strict management can all assist the CE. The conclusions of this research are meant to be a valuable resource for policymakers in both emerging and developed countries looking to ensure the sustainability of the CI. Adapting CE approaches and educating/increasing awareness of CE strategies may assist people in accepting new, long-term policies and practices. The conclusions of this study can assist practitioners in the construction sector drive innovation, increasing economic growth, and improving competitiveness.

5.1. Theoretical Contribution

The study findings can assist practitioners in the construction sector to drive innovation, increase economic growth, and improve competitiveness. This research has added to the repository of knowledge by bridging the gap identified by Hysa et al. (2020) and Patwa et al. (2021) who specified that research having a holistic view of drivers of CE for the effective implementation of sustainable development is needed.

5.2. Practical Contribution

Organizations can benefit from new prospects by implementing the CE concept into practice. CE can assist in employment and economic growth expansion. Financial incentives may be used to encourage CE-based innovations and persuade the CI to take a chance on investments related to closed-loop project value chain management.

5.3. Limitations

The study's limitations include only including participants from developing economies. In addition, this study only considered a small number of literature-based factors. It is recommended that future research include participants from developed economies. The identification of the connections between the drivers may be one of the future directions.

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Biographies

Maria Ghufran holds a bachelor's degree in Building and Architectural Engineering. She has completed her Master's in Construction Engineering and Management from National University of Sciences and Technology, Islamabad, Pakistan. Currently, she is enrolled in Ph.D. in Construction Engineering and Management at National University of Sciences and Technology, Islamabad, Pakistan. Her research interest lies in subjects including Complex Systems and Dynamics, Supply Chain Management, and Sustainability.

Dr. Khurram Iqbal Ahmad Khan holds a bachelor's degree in Civil engineering. He holds a master's degree in Construction Management and a doctorate in Construction Engineering and Management from the University of Reading in the United Kingdom. He has more than 8 years of experience in the field. He is currently employed as an Assistant Professor at Pakistan's National University of Sciences and Technology. He teaches subjects which include Complex Systems and Dynamics, Supply Chain Management, Sustainable Construction, and Construction Project Administration to the postgraduate students. His research interest and expertise lies in subjects including Complex Systems and Dynamics, Supply Chain Management, Sustainability and Circular Economy.

Dr.-Ing. Abdur Rehman Nasir is currently the Head of Construction Engineering and Management Department at School of Civil and Environmental Engineering (SCEE) at National University of Sciences and Technology (NUST) - Pakistan. Dr. Nasir holds a PhD degree in Civil Engineering with specialization in Construction Engineering and Management from Bauhaus Universität Weimar, Germany. Dr. Nasir focused on Building Information Modeling (BIM) in his doctoral thesis and developed a task instructional model for low-skilled construction workforce. Currently, Dr. Nasir is undertaking various teaching and research supervision assignments at NUST in the areas of Building Information Modeling (BIM), Contract management, Construction Law, Occupational Health and Safety in construction among other fields of construction project management.

Muhammad Usman Hassan has completed his Ph.D. in Civil Engineering from METU, Turkey. He has a professional experience in multinational companies and my research is focused on automation in construction. His research areas include Construction Safety Automation, BIM, IoT for construction safety, Behavior-based safety, Machine learning, Artificial Intelligence, prevention through design.

Ahsen Maqsoom is a Ph.D. and M.Eng. graduate of the Asian Institute of Technology in Bangkok, Thailand. He is currently employed as an Assistant Professor at Pakistan's COMSATS University Wah Campus. He has written three book chapters and published over 100 research articles in peer-reviewed international journals and conferences. Project management, international business, remote sensing, machine learning, risk management, and civil engineering are among his research interests.

Paper no. 107

Social Media as a Phenomenon in Projects and the Project Management: A Comprehensive Literature Review

Razieh Karimi[1,2], Robert C. Moehler[1,3] and Yihai Fang[1,4]
[1]Building 4.0 CRC, Caulfield East, Victoria, Australia
[2]Ph.D. Student, Department of Civil Engineering, Monash University, E-mail: razieh.karimi@monash.edu (corresponding author).
[3]Lecturer, Department of Civil Engineering, Monash University, Clayton, 3800, Victoria, Australia, E-mail: robert.moehler@monash.edu
[4]Senior Lecturer, Department of Civil Engineering, Monash University, Clayton, 3800, Victoria, Australia, E-mail: yihai.fang@monash.edu

Abstract: Considering the widespread use of social media throughout many business operations, social media use is a growing field of interest. Studies of professional networks highlight the use of social media for member support, profile and relationship building enabling new dimensions of reach and transparency.Typicial limitating highlights are the threat of leaked information and brand damage. The concept of social media is considered a new age phenomenon that opens up exciting possibilities for collaborative communication. The social media platforms, such as Twitter, WhatsApp, Facebook, LinkedIn, and WeChat emerge as new-generation collaboration platforms. To date, only a few studies have looked at the context of projects and project management. The purpose of this article is to establish the extent social media as a phenomenon in projects and project management has been captured. The research method followed a Systematic Literature Review strategy but was extended to include a snowball method, including references and citations of the identified articles too. Despite social media's widespread use, the literature review findings reveal that the use of social media for project management is still an understudied field that receives little attention from researchers. However, the parallel literature reveal insights into potential new dynamics that need to be explored in projects. The definitions of social media are still evolving and may refer even in similar contexts to different applications, uses, and expectations. Using social media in projects can be attributed to communication, profile building and knowledge sharing, perceived social presence/ intimacy, real-time/immediacy, and linked cultural context to relationships are emphasized as potential avenues for improved collaboration. Associated benefits are professional profile- and relationship building, greater social presence, and interactions with other team members/ member support, accessibility to information, increased interactions with others, and immediately available, shared, and personalized information. Issues include surveillance, lack of trustworthiness, confidentiality/privacy, information overload and technology used as distraction. To date, the phenomena of social media in projects have only been mentioned in relation to governance with a limited set of applied theories, stakeholder management theory, social exchange theory, and knowledge-based theory. Future research on social media in project management needs to investigate practices around social media in projects empirically to shed light on the implications for project management. The knowledge contribution establishes premises to contextually realize value-adding practices for practitioners and helps navigate this emerging topic in project studies.

Keywords: Social media, communication, social media use, project management, practice, culture, project performance.

1. Introduction

The notable feature of Social Media Constructs that promotes the success of social media adoption has been recognized as the capacity to communicate not only via laptop and desktop but also through portable smart devices like cell phone, tablets/ iPad and mobile computer stations/laptops, etc.. The continuous use of social media platforms is largely due to its accessibility from any location and at any time using any device (Kanagarajoo et al., 2019).

In the last 15 years, social media has become a significant part of regular communication and has been utilized as a virtual communication practice by numerous businesses (Bertolotti et al., 2015). Interest in using social media to achieve organizational goals needs additional features (Daemi et al., 2021). Social media platforms

named in the literature such as Twitter, WhatsApp, Facebook, YouTube, LinkedIn, and WeChat are not only transforming the way people communicate in everyday life but also opening up new chances for effective collaboration (Bertolotti et al., 2015; Kanagarajoo et al., 2019; Papa et al., 2018; Ma et al., 2021). Businesses have benefited greatly from the introduction of new social media platforms that are provided with a variety of functionalities such as marketing and sales, education, governance and IT (Kanagarajoo et al., 2019). In many industries, such as marketing, healthcare, banking, insurance, and IT, social media is already an essential communication practice due to its nature of real-time information exchange (Wang et al., 2016). Social media allows organizations to communicate with their diverse stakeholders both internally and externally, and provides a variety of options, consequently utilizing the increased reach (Cardon & Marshall, 2015; Walker & Garrett, 2016). For businesses, social media platforms are typically used to make corporate statements, share knowledge, and communicate with external stakeholders (Wang et al., 2016).

The usage of social media platforms can assist organizations in overcoming the geographical limitations with constant electronic communication virtually among team members. Furthermore, the introduction of Enterprise Social Media (ESM) has greatly improved team member communication and consequently enhanced work efficiency with coordination and increased interaction (Zhang et al., 2018). Project management is a field where the systematic identification and implementation of best practices is critical to success. Project management refers to techniques that aid in resource management, project completion within scope, time, quality, and cost constraints, and risk mitigation (Samset & Volden, 2016), and social media plays an important role. To keep control and perform effectively when using social media in project management, standardized frameworks and methodologies are required. Some of the biggest threats are compromised security and the leaking of key project data (Hysa & Spalek, 2019). Concerns about the accuracy of information used to integrate social media into project management have arisen as a result of the usage of social media in managing projects (Daemi et al., 2021). Changes in communication and management approaches have also resulted from the use of social media in project management.

Using social media as a key collaboration platform in project teams is more popular when team members are located across the country or when the team is made up of younger generations who use social media as their primary means of communication (Kanagarajoo et al., 2019). Furthermore, when comparing other professional fields, the usage of social media in project teams is very limited, as there is no strong academic or practical research on social media and its impact to project performance (Hysa & Spalek, 2019).

However, surveys have illustrated project managers concern that there are additional threats and challenges to address when putting the team on a quick information exchange platform, like information security, info overload, mixing the content of personal and professional information, and privacy concerns (Moorhead et al., 2013; Anders, 2016). Conversely, following the covid- 19 pandemic lockdown periods, project teams that are physically separated have paid closer attention to social media. As a result, it is important to understand the impact of social media on project team performance and what affects project managers should be managed with social media in the context of project management.

Using social media for project management creates a number of limitations, including (1) behavioural (a "write first, think later" tendency; a lack of focus and direction in discussions); (2) cognitive (impaired decision-making due to a lack of appropriate and complete information); and (3) environmental (management of access control and accountabilities; information leakage) limitations (Ram and Titarenko, 2022).

On a personal level, social media is becoming an increasingly important part of people's lives, and more organizations are adopting social media platforms like Twitter, WhatsApp, Facebook (or Workplace – Facebook for companies), and WeChat as a source of effective communication platforms (Kanagarajoo et al., 2019; Bertolotti et al., 2015; Papa et al., 2018). It remains to be seen whether the new working practice is suitable for project management context under different internal and external scenarios, especially when it comes to internal communication within project teams and communicating with external stakeholders, such as sponsors or clients.

This article has the objective to investigate the role of social media in projects and the project management. RQ1 What are social media practice in projects? RQ2 What are the associated benefit of social media? RQ3 What impact does social media have on project team performance? RQ4 What are the factors that to be considered in evaluating social media in projects? RQ5 What theoretical framework has been used?

The primary research strategy for this study is a comprehensive literature review. As a search strategy, searching relevant databases such as Scopus and Google Scholar is meant to capture the use of social media and project management literature. Appropriate keywords strings (social media" and "project studies" or "project management" or "management of projects") or respective combined searches for social media, knowledge sharing, project management, practice, communication and culture for searching were determined through multiple iterations of evaluation and refining the search results and comprehensively analyzed. The iterations identified a general gap in papers in this area after few preliminary searches to see what terms and combinations would work best. A parallel search for social media papers in project environments, business and cooperate literature for seminal papers was added.

This paper is structured as follows. The next section outlines the Literature review. It is followed by the discussion section that outlines the significance of the findings, in light of the existing literature including further research areas reviewed, and the final section, in conclusion, summarizes critical aspects of the study along with the limitations.

2. Literature Review

2.1. Social Media Definition

According to Kaplan and Haenlein (2010; p. 61), social media is "a collection of Internet-based applications that are built on the ideological and technological foundations of Web 2.0, and that allow users to create and exchange user generated content". Through multisensory communication,

social media allows users to create, share, receive, and comment on social material amongst multi-users (Kaplan & Haenlein, 2010; Moorhead et al., 2013). Even though the phrases "social media" and "social networking" are frequently employed interchangeably and have some overlapping, they are not equivalent. Social media operates as a communication platform that delivers a message, such as requesting something (Moorhead et al., 2013). Kaplan and Haenlein (2010) mentioned that communication through social networking is two-way and direct, and information is shared among a variety of parties. Several ways can be employed to categorize social media, including collaborative projects (e.g., Wikipedia), content communities (e.g., YouTube), social networking sites (e.g., Facebook), and virtual games and worlds (e.g., World of Warcraft, Second Life). The importance of social media in communication and knowledge sharing (Kanagarajoo et al., 2019), the created perception of social presence/ intimacy (Kaplan and Hanelein, 2010), real-time/ immediacy transparency and links posts to the cultural context to the relationship (Manzoor, 2016) are emphasized as a strong argument for organizations using it in projects. Nevertheless, to take full advantage of social media adoption in projects, its use of it must correspond to certain principles (Hysa & Spalek, 2019). A clear definition of the purpose and form of social media use, clarifying restricted and confidential project information, defining the responsibilities of project team members, and establishing guidelines for making a distinction between professional and private presence are some of the underlying principles that need to be examined (Kanagarajoo et al., 2019; Hysa & Spalek, 2019).

2.2. Social Media and Communication in Projects

In project management, social media allows for both formal (recognition of progress, project achievements, etc.) and informal (member support) communication, allowing for better flexibility and easier communication coordination. Formal project-related information, such as project progress, milestones, and meeting schedules, can be easily supported and established on social media platforms such as Twitter, WhatsApp, Facebook, YouTube, LinkedIn, and WeChat (Bertolotti et al., 2015; Kanagarajoo et al., 2019; Papa et al., 2018; Ma et al., 2021). In comparison to traditional means such as emails and physical meetings, the use of social media as the first choice communication platform has been recognized as the most preferred communication option for younger generation team members since it quickly integrates their daily interaction, making them comfortable in communicating and sharing thoughts (Kanagarajoo et al., 2019). In addition, social media has also made collaboration more efficient through more accurate communication without as much coordination work compared to meetings or emails, which is particularly useful for keeping relationships with external stakeholders, such as partners and sponsors (Silvius, 2016). Nevertheless, there is a point to be made that increased collaboration through the use of social media will result in lower individual autonomy, which will have a negative influence on the team performance in the sense that there will be an extreme level of collaboration and interdependency between team members (Puranam et al., 2006).

However, from the standpoint of project managers, the real-time information sharing inside the team would also provide more sensitive signals when collaboration exceeds expectations. Project managers can also stay in touch with team members more easily via instant messaging through social media since the platform is capable of both formal and informal communication. Consequently, they can better coordinate communication and understand the status of the project team (Rimkuniene & Zinkeviciute, 2014). When it comes to social media use for stakeholder engagement, there are case studies of government projects that use social media as a communications platform. Social media was used to publish progress updates, engage community members, announce project positions, and promote a national organizational logo (Ninan et al., 2019). The goal was to increase external stakeholder support. Comments on social media about the "south to north water transfer" project were evaluated to determine community interests and perspectives (Zhang et al., 2018). In another case, the government's decision to reply to critical comments on social media demonstrated a two-way proactive communication method for dealing with possible public relations issues (Jiang et al., 2016). In other contexts organizing stakeholder engagement proactively to create value for the project has been recognized as challenging, particularly through its dynamic nature (Lehtinen & Aaltonen, 2020). The Twitter analysis method can be a good practice in e-government projects where the failure probability is predicted to be high. This strategy is used to track citizens' reactions to project failure and respond to those reactions with a social media-based communication management plan (Anthopoulos et al., 2016; Williams et al., 2015). Silvius (2016) adds that the learning curve has just started and for the planned deployment there still may be barriers.

2.2.1. Social Media in Project Management Knowledge Sharing

The usage of social media for knowledge sharing to improve productivity is on the increase (Mukherjee & Natrajan, 2017). In organizations, social media allows for immediate knowledge sharing across set boundaries (Kanagarajoo et al., 2019). Project team members create knowledge repositories using social media to store cross-functional information (Sarka & Ipsen, 2017). Knowledge sharing is enhanced by building intimate relationships with others and being able to relate to understand the context (Hysa & Spalek, 2019). Social media is an effective way to do so. Enterprise Social Media (ESM) is being used by some organizations to overcome the knowledge-sharing complexities caused by their organizational structure (Oostervink et al., 2016). Project team members can contact team members from other departments, join inter-organizational groups, access messages or shared documents posted by other members, and modify or reflect on subjects posted by others by using ESM (Leonardi et al., 2013). Knowledge gained in projects is also documented through social media platforms (Kanagarajoo et al., 2019; Oostervink et al., 2016; Wiewiora & Murphy, 2015). Both retrospective and prospective learning techniques (Rosa et al., 2016) are facilitated by social media, which are typically discussed in learning lesson meetings.

Using social media as a platform for virtual teams enhances knowledge sharing within the project team. The Social Exchange Theory and the knowledge-based theory are two theories that can be used to measure knowledge sharing in virtual teams (Alsharo et al., 2017; Chen & Wei, 2020). Individual team members are seen as knowledge sources in the knowledge-based theory of the firm, and it is

the role of the project manager or the organization to extract, retain, and apply specific information from individuals. According to this theory, virtual teams built on social media can share information more effectively than traditional project teams. First, that's because knowledge may be quickly exchanged and shared via instant message transmission and a reduced internal feedback loop (Alsharo et al., 2017; Rosa et al., 2016). Second, a virtual setting based on social media allows project managers to choose team members from a bigger group of candidates without consideration of location. This means that project managers will be able to choose educated and qualified team members who are more suited to the needs, and the project team will get access to more relevant expertise from professionals. Individuals, according to social exchange theory, generally act to maximize return at the lowest effort/investment. The benefit of virtual teams using social media is improved collaboration because it allows for quick information sharing among individuals. But if the required effort increases, e.g. to make sense of uncertain or ambiguous information, the individual team members start losing their comparative benefit, which could lead to rejection of share information (Molm et al., 2000). As a result, the social exchange theory suggests that when virtual team members are afraid to disclose knowledge, virtual teams would be less effective than traditional teams due to the increased time spent on acquiring knowledge, and project delivery will be delayed (Johansson et al., 2013).

2.2.2. Social Media and Project Team Innovation

To achieve their innovation goals, organizations use team-based structures to conduct knowledge-intensive tasks (Lowik et al., 2016; Ali, Wang, et al., 2020). This puts pressure on teams to enhance their performance quickly and consistently. The implications of social media for team collaboration and knowledge sharing are fascinating (Ali, Bahadur, et al., 2020). In project teams, social media has a positive impact on the knowledge production process, which leads to improved team innovation performance (Cao & Ali, 2018). By promoting a higher level of collaboration and knowledge exchange between team members in a virtual setting, using social media as the main communication platform at work can improve knowledge management. When the project team is knowledge-oriented to encourage innovation in activities, social media would provide high available resources for team members to engage, communicate, and collaborate (Cao & Ali, 2018). The approach is particularly effective when tasks require creativity and the project team is knowledge-oriented. According to the findings, using social media as a communications platform can help teams recognize the importance of building social capital, ensuring communication cohesion between individuals through common language and values. Furthermore, from the perspective of knowledge management, social media may be considered an open-source knowledge transitory and knowledge store because it facilitates knowledge generation and exchange. A social media platform, such as a social networking website or a blog, has proven to be the most popular way to share, discuss, and create knowledge because of the explanatory and narrating nature what knowledge is and who has it (Cao & Ali, 2018).

Interestingly, the hypothesis by Ali et al. (2020) concluded that there is no significant association between social media as a communication platform and innovation, challenging the repeatability of results from Krancher et al. (2018) highlighting the very relationship mediated communication medium awareness. In the parallel literature (e.g. review from Krancher et al. 2019; Chen and Wei, 2020) social media can improve team absorptive capacity in knowledge generation, which is a key aspect of team creativity. As a result, by enhancing information sharing, the use of social media in project teams has the potential to improve team innovation performance and needs to be further researched in the project management literature (Krancher et al., 2018).

2.3. Using Social Media in Project Teams

Even though several studies have demonstrated the advantages of social media utilization, others imply that some businesses are still hesitant to implement social media technologies. The lack of specific social media facilitators and the existence of barriers could discourage project managers from adopting social media (Daemi et al., 2021). This section examines the literature to determine the barriers and enablers of social media utilization.

Social media adoption initiatives could be hindered by barriers to use. These barriers need to be considered in the strategic management of social media. The fear of losing control over information and security, according to empirical research (Hysa & Spalek, 2019; Kanagarajoo et al., 2019; Rimkuniene & Zinkeviciute, 2014), is the most significant barrier to social media adoption. Other limitations include the technology used, time limitations, a lack of clarity on organization needs, and social media integration training requirements (Janes et al., 2014). Changes are required for the adoption of new technology, and unwanted changes might stall the process. Kaplan & Haenlein (2010) pointed out that there may be a falsely perceived unified set of social media (instead of diversity and potential competing ideals embedded in the platforms), leading to a set landscape underestimating regional or language-related pluralism (Silvius, 2016). Insufficient technology infrastructure or social media regulations that aren't inclusive are other barriers to use. Governments employ social media prohibitions to restrict freedom of speech or control the flow of information for political or national security reasons (Hysa & Spalek, 2019). Furthermore, when strict delivery deadlines are imposed, the motivation to investigate and implement social media techniques is limited.

Governments employ social media prohibitions to restrict freedom of speech or control the flow of information for political or national security reasons (Hysa & Spalek, 2019). Adoption initiatives may come to a stop in organization domains where social media adoption is a complex task with an unclear definition (Janes et al., 2014). Further, social media threats were characterized as social, technical, and legal by Di Gangi et al. (2018). Social threats can affect an organization's effectiveness as well as customers' trust in an organization's brand. Technical threats, on the other hand, put organizational information technology resources at risk, such as introducing malicious code (malware) into the computing environment or harming digital devices, while legal threats can result in organizational loss as a result of mismanaging sensitive information from business partners (Di Gangi et al., 2018). When social media is utilized, projects can face similar threats. As a result, awareness is essential. Hysa and Spalek (2019) listed many social media threats in the communication area, including the revelation and acquisition of confidential project data, incidents of various

technological concerns, and hacked project employee accounts. They discovered time-wasting on personal and non-work-related matters in the areas of collaboration and work efficiency. Furthermore, in areas of engagement and work productivity, they cited the threat of occupational burnout caused by blurred boundaries between professional and personal time.

For governments, social media threats may be more severe when it comes to project management. At both the governmental and technological levels, it is important to avoid losing citizens' trust (Rosenberger et al., 2017). The inability to properly govern accident or failure news can generate unfavorable feelings in citizens (Ninan et al., 2019). Similar effects could be expected in teams with control intent towards social media blending personal, commercial, and public association. When governments employ third-party social media platforms, they are exposing themselves to data privacy, data security, integrity, and data accessibility threats (Rosenberger et al., 2017), thus caution must be maintained.

Strong leadership, a knowledge-sharing culture, and organizational demands may make social media adoption easier and smoother (Janes et al., 2014). Project management and project team members are forced to explore chances to use social media platforms when organization leadership is invested. A culture of sharing learned experiences must be present even with strong leadership support and especially when lacking a proper communications platform for any organization could accelerate social media adoption. In addition to promoting knowledge acquisition and social capital, both work-oriented and socialization-oriented social media use positively impacts overall project performance (Ma, Jiang and Wang, 2021).

According to Rimkunien and Zinkeviciute (2014), the business manager is responsible for matching relevant social media technologies to the organization's goals. Eventually, the competency of the implemented technology determines the quality of the communication (Treem et al., 2015). The notable feature of Social Media Constructs that promotes the success of social media adoption has been recognized as the capacity to communicate not only via laptop and desktop but also through portable smart devices like cell phone, tablets, and laptop. The continuous use of social media platforms is largely due totheir accessibility from any location and at immediacy using any device as a multiplatform accessibility (Kanagarajoo, 2018; Hysa and Spalek, 2019). Employee competency may reduce the number of induction and training activities necessary. When using social media platforms, expertise is recognized as a critical aspect (Orta-Castañon et al., 2018).

Because of the increased uncertainty and impersonality of the Social Media Platform, trust has been demonstrated to be a critical aspect that affects virtual team communication. Managing trust in virtual settings is considered a big issue. Trust affects communication and collaboration effectiveness, and virtual team trust is described as a shared psychological understanding that leads to supportive actions from virtual team members when faced with a situation that is unknown and risky (Cao & Ali, 2018). Unlike the other elements that may affect virtual team performance, the impact of trust on team cooperation has been thoroughly researched and recorded in earlier research. According to De Jong et al. (2016)'s research, trust may be viewed as a predictor of team performance that managers can utilize to coordinate and predict team performance. Trust in virtual teams is considerably more sensitive than trust in on-site teams, especially when project teams confront risks and uncertainties, and project managers must be constantly cautious to keep virtual teams communicative and secure (Choi & Cho, 2019).

It has also been shown that the relationship between trust and collaboration is more visible and dynamic in virtual teams based on social media since such teams lack physical interaction, such as face-to-face conversations with various emotional expressions, which enables engagement more accurately (Cheng et al., 2016). As a result, using social media as a virtual communications platform for project teams requires a significant investment in trust-building, which is an important problem for project managers to address. According to Choi and Cho (2019), trust may be built in virtual teams primarily by having a shared understanding and motivation for the same project goals. This means that the responsibilities assigned to team members should be as diverse as possible, allowing for more partnerships and a firm foundation for building trust among team members. Another issue mentioned in the study to handle the danger of trust is the requirement for a well-managed interaction between team members and the virtual platform. According to the findings, the design and functionality of virtual communication platforms play a crucial role in team trust-building (Choi & Cho, 2019). As a result, project managers need to consider using social media as a communications platform depending on the unique team circumstance, selecting the most appropriate platform that encourages trust-building and thus increases team collaboration. Kaplan and Haenlein (2010) predict that social media creates the effect of social presence and the influence of intimacy and immediacy with different media possessing different richness and thus are more or less effective in resolving intended ambiguity and uncertainty. Even though project managers have identified trust-building as the most difficult challenge for project teams to be collaborative, program managers can create proper project goal coordination, more cohesiveness between each individual's goals and tasks, and more concerns in selecting the appropriate social media to address this issue.

The management of relationships between tasks, technologies, and teams is another problem for social media as a communication platform in project teams. In this situation, the project context, communication platform and technology employed, and project team members are the three factors in project teams. These three dimensions are also influenced by social media, which has an impact on technology deployment and adaptation, team dynamics, and project outcomes (Zhang et al., 2018). To determine whether social media is appropriate for a certain project team, the dynamics of the team, as well as the project's specific fit, must be considered.

The study of social media usability can be tackled from two main directions: the platform's utility and comfort of use, as these two criteria have been shown to have a moderating influence on task-tool matching degree and team dynamics (Zhang et al., 2018). When a project needs a higher level of confidentiality or legality, the communication platform may switch away from social media or (internal “less”/controlled social media) and toward face-to-face meetings with more physical

interaction. The fact that social media may be accessible by phone anywhere at any time could be another benefit for it as a platform to communicate. This function is particularly popular among young generations who utilize social media as their primary means of communication, resulting in a higher rate of technology adoption in general (Krancher et al., 2018; Zhang et al., 2018). Nevertheless, while there is a significant age gap between team members, alternative perspectives of how to use social media may arise.

2.4. Effective Implementation of Social Media in Project Management

To effectively use social media within a project, specific management aspects are needed, which will ensure that the use of social media is handled properly. The latest literature review by Daemi et al. (2021) indicates that team cultures that are supportive of knowledge sharing are a powerful force for the usage of social media since they acknowledge knowledge sharing as a valuable activity within a project team and social media may be a suitable platform for this process. Managing the relationship between communication platforms and project goals should be a priority for program managers when selecting social media, according to Rimkunien and Zinkeviciute (2014). This was discussed in greater depth in the previous section, where the tool-task fit is a critical component of communication efficacy. When a new communication platform is implemented, a communication plan should be developed as well. Furthermore, when a new communication platform is adopted, a communication strategy should be developed. As part of a communication strategy for social media in project teams, the project leaders should focus on the main purpose of using the platform (Daemi et al., 2021). One of its purposes might be to promote knowledge sharing and innovation to build relationships between member teams.

Another component of approaching a successful adoption of social media is the effective management of social media reliance in a project team. In a recent study by Zheng and Davison (2022), the impact of social media reliance on the communication patterns of team members was investigated. According to the findings of the study, when work-related communication seems to be heavily reliant on social media, the communication style looks to be more formal and limited. Similarly, when work-related communication is less reliant on social media, the communication appears to be more informal and is frequently used to build relationships. As a consequence, in a project team where social media is the major communication platform and most information about the project is discussed via social media applications, team members will be less likely to share personal information. In another scenario, when reliance is low, social media will be mostly utilized for casual discussions, allowing team members more freedom to communicate (Zheng & Davison, 2022). As a result, managing social media reliance in a project team is critical for managers to monitor and manage communication on a team level. Ignorance of the reliance will result in a communication gap, which will negatively impact team synergy and performance.

3. Discussion

According to existing research, using social media for project management is still a relatively unexplored topic that has received little attention. In the parallel literature, it is apparent that social media brings benefits as well as data accessibility threats that need to be managed.

The definition of social media from the various studies is not clear-cut and different studies formulate different definitions depending on "…ideological and technological foundations of Web 2.0" (Kaplan & Haenlein, 2010; p. 61) that have evolved and matured (through e.g. governance concerns, media image profile narratives, etc.). Social media is a phenomenon that has impacted projects and project management. In the context of the project manager, team, and stakeholders this is already embraced but as a phenomenon is not researched yet. The concept of social media is regarded as a new age phenomenon that provides exciting opportunities for project management scholars for collaborative communication and subsequential outreach and visibility. As a powerful argument for organizations using social media in projects, the importance of communication and knowledge sharing, the perception of social presence/ intimacy, real-time/immediate transparency, and providing cultural context to the relationship are emphasized as potential avenues (Kanagarajoo et al., 2019; Kaplan & Haenlein, 2010; Manzoor, 2016). A collaborative environment is an advantage for a large team environment. Using social media in that context allows for accessibility to information, increased interactions with others, and immediately available, shared, and personalized information (Molm et al., 2000; Moorhead et al., 2013). A strong leadership towards a knowledge-sharing culture aligned with business requirements may make social media adoption easier (Janes et al., 2014).

Cybersecurity, lack of trustworthiness, confidentiality/ privacy, and technology use were among the most pressing issues noted. The most significant barrier to social media adoption is the fear of losing control over information and security (Moorhead et al., 2013). Other limitations include the technology used, time limits, a lack of understanding of the organization's needs, and the requirement for social media integration training (Hysa and Spalek, 2019; Kanagarajoo et al., 2019; Rimkuniene and Zinkeviciute, 2014; Janes et al., 2014). Other limitations to adoption include the lack of clarity of ownership of technical infrastructure (many people blend private devices, accounts on platforms, etc.) or inclusive social media rules. Compromised security and the leakage of sensitive key project data are among the biggest threats (Hysa & Spalek, 2019).

Social media can generate trust but also lose trust. In a professional context, personal relationship building is heavily reliant on the use of social media (Zheng & Davison, 2022). When virtual teams work together on the same goal with a shared vision (generating an implicit profile), trust can be built by shared understanding and motivations. In addition, trust through social media can empower project team members (member support) and it can be powerful in conveying messages to the whole team with the embraced leadership (Choi & Cho, 2019). On the other hand, social media as a knowledge-sharing perspective is great but from the exchange theory, it can also create redundancy so knowledge is not seen as utility value anymore and aesthetic entertainment value. As an implication of social exchange theory, virtual teams with fear of revealing knowledge will be less effective than traditional ones due to the increased time spent on acquiring

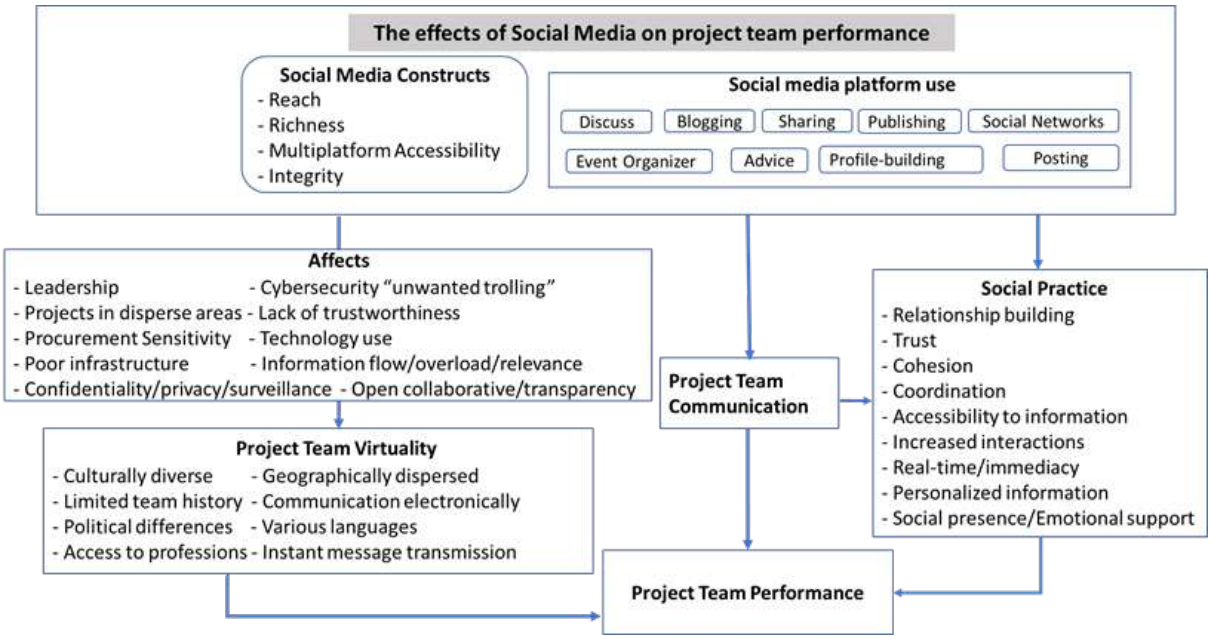

Fig. 1. The effects of Social Media on project team performance

knowledge and can not utilize this for performance gains (Johansson et al., 2013). Social media in its medium has designed shortcomings. With diverse media having different richness's, social media provides the effect of social presence and the influence of intimacy and immediacy, and differ in efficiency to resolve intended ambiguity and uncertainty (Kaplan & Haenlein, 2010). In project teams, if users are mature in tasks and technology/medium use, social media has a positive impact on the knowledge production process, which leads to improved team innovation performance (Cao & Ali, 2018; Krancher et al., 2018). Project teams from diverse cultures use social media very differently due to geographical, language, and political differences in platforms or even on alternative platforms. An interesting finding from the comprehensive literature review of project management-based literature and related areas that looked at the project context is the exclusive focus on three theories, including stakeholder management theory, social exchange theory, and knowledge-based theory, to look at social media in projects (Alsharo et al., 2017; Chen & Wei, 2020; Molm et al., 2000). In summarizing the section the figure 1 shows the effects of Social Media on project team performance.

4. Conclusion

Using social media for project management is currently a relatively unexplored area that receives limited attention from researchers, according to existing studies, however, there are some discoveries in the parallel literature that give insights into potential new dynamics that need to be explored in projects. The definitions of social media is still evolving and may refer in similar contexts to different applications, uses, and expectations. Using social media in projects can be attributed to communication, profile building, knowledge sharing, the perception of social presence/ intimacy, real-time/immediacy, and providing cultural context to the relationship, which are emphasized as potential avenues for improved collaboration. The associated benefits are 1) Professional profile and relationship building (e.g., trusted followers), 2) greater social presence and interactions with other team members, 3) accessibility to information, increased interactions with others, and 4) immediate available, shared, and personalized information. The limitations mentioned included 1) cybersecurity 2) lack of trustworthiness, 3) confidentiality (potential damage to profile and associated profiles)/ privacy, and 4) technology use. The use of social media in project teams can increase team performance by enhancing information sharing, and it needs further research in the project management literature. To date, there is little understanding of the implication of the impact of social media and the theories have focused largely on governance from the company point of view. Until now, the phenomena of social media in projects have only been studied with a limited application of theories, stakeholder management theory, social capital theory, social exchange theory, and knowledge-based theory. In order to enhance the discussion and understanding of the social media, there is a need for empirical study of the practice of social media use. Future research on social media in project management needs to investigate practices around social media in projects and how those impact on management of projects.

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Author Contributions

Razieh Karimi contributes to draft preparation as main author, conceptualization, methodology, analysis, investigation, data collection, manuscript editing and visualization. Robert Moehler contributes to conceptualization, methodology, validation, draft preparation, manuscript editing, supervision, project administration, and funding acquisition. Yihai Fang contributes to validation, draft preparation, manuscript editing, supervision and project administration. All authors have read and agreed with the manuscript before its submission and publication.

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Razieh Karimi is a Ph.D. candidate and recipeient of the Building 4.0 CRC Scholarship at Monash University's Department of Civil Engineering. Her research interests are in social media, team feedback, team performance, and project management. She has also been involved as a research assistant in Building 4.0 CRC.

Robert Christian Moehler is currently a Lecturer of Project Management in the Department of Civil Engineering at Monash University. He is the Deputy Course Director and core team member of the cross-faculty Master of Project Management and Master of Project Leadership degrees at Monash University. Robert is Business Model Theme Coordinator at the Building 4.0 CRC. Robert's research interests include Project Management, Project, Program and Portfolio Management, Business Model Innovation, Sustainability, Knowledge Sharing, Value co-creation, Collaboration, Stakeholder Management and Project Governance.

Yihai Fang is a Senior Lecturer in Construction Engineering and Management at the Department of Civil Engineering at Monash University. Yihai is Connected Construction Sites Theme Coordinator at the Building 4.0 CRC. Yihai's research interests include Construction Automation and Informatics, Construction Robotics, Digital Twin for Construction and Built Environments, and Construction Safety and Human Factors.

Paper no. 115

Skill Shortage within the UK Construction Industry, and the Impact on Quality Management

Rashid Maqbool[1], Luke Oldfield[2], Saleha Ashfaq[3] and Mohammed Rayan Saiba[4]
[1]Faculty of Engineering and Environment, Northumbria University, Newcastle upon Tyne, UK, E-mail: rashid.maqbool@northumbria.ac.uk (corresponding author)
[2]Faculty of Engineering and Environment, Northumbria University, Newcastle upon Tyne, UK, E-mail: luke.oldfield@northumbria.ac.uk
[3]School of Economics and Management, Fuzhou University, Fujian, China, E-mail: m170719004@fzu.edu.cn
[1]Faculty of Engineering and Environment, Northumbria University, Newcastle upon Tyne, UK, E-mail: mohammed.saiba@northumbria.ac.uk

Abstract: A skilled workforce is essential for producing high quality work, efficiently and effectively. This paper is formulated to improve the understanding and knowledge surrounding the skill shortage currently being faced within the UK, and the significant impact it is having on quality management. It is broken down into section surrounding each main area, and the impacts of recent years: Brexit, Covid-19 and ageing workforce. Both skill shortages and quality management techniques have been influenced by these impacting factors and a clear solution was highlighted from all. The review on Brexit investigated the impact of trade and labour agreement changes faced across the UK. The effects of Covid-19 were explored, such as being "locked down" and the issues surrounding social distancing. The ageing workforce uncovered the significance of high skilled trade members leaving the industry and there will be little to no one to fill their places. Mixed method approach was applied to collect data. A case study has been conducted on a large-scale construction project located in the Northeast of England where the outcome of these issues can be seen in all aspects of the work. Secondary data was collected through the questionnaire surveys. Relative importance index was used to analyse the quantitative data. Training and development are the fundamental issues highlighted during the literature review and then subsequently expressed by participants of the surveys. It was also found that the need for training has never been greater within the construction industry as the impact from Brexit, Covid-19 and an ageing workforce has never been higher. This research will allow the industry to understand the need for a skilled workforce and how it benefits the quality management elements of a construction project. Analysis has shown how the industry can develop in key areas and what is required to get there.

Keywords: Skill shortage, quality management, Covid-19, Brexit, ageing workforce, training and development.

1. Introduction

The United Kingdom (UK) is currently seeing a huge increase in unemployment across all businesses due to the effects of Covid-19. Although the job retention scheme put in place by the UK Government has allowed for many to protect their jobs, with the easing of restrictions there has been an influx of recruitment in all job sectors. As restrictions begin to ease, it encourages people to spend the money that they saved during the pandemic, leading to businesses requiring more staff/labour to meet the demand of the public (Wylie, 2021). As Covid-19 has impacted the UK, it has led to huge delays within construction projects across the country and caused further shortages in skilled workers who have had to take their skills elsewhere to receive a higher income.

To add to the effects from Covid-19, in recent years Brexit has played a huge part in the lack of skilled workers within the industry. A study conducted by Mohamed, Pärn, & Edwards (2017) determined that the effects of Brexit would lead to an unattractive career for "foreign skilled labour" and that skill shortages would only increase upon the implementation of Britain leaving the European Union.

Contractors are limited to the skills that their workforce have and therefore spend a greater amount of time and money investing in a handful of competent. Consequently, businesses resort to investing more money into the current workforce. Additional training and rewards are a good motivator however the long-term consequence of only investing in the current workforce will fall short in the

future when the cost of labour increases and the need to adapt becomes more significant (Matthias & Laszig, 2021).

Young people are less encouraged to get into the construction industry across the UK. In most cases when students are leaving secondary and higher education going into an apprenticeship is seen as a less favourable decision. It is not as well advertised in schools to go into "manual labour" or be trained into a "trade;" subsequently leading to a lower intake of students into the vital trades required on sites, which in turn will impact the quality of buildings long term. Recent legislation within the UK has made it compulsory for all UK schools to promote all forms of training to its students (Daniel, et al., 2020).

Quality management has numerous definitions and each project is often assessed differently as it is affected by distinct factors such as execution time and quality of the personnel (Keenan & Rostami, 2021). "In the construction and management of work, people are the main part." The quality management of a construction project can only be optimised with improvement in all aspects: from design to the optimisation of personnel and systems (Fu, 2019).

One of the main issues faced when trying to maintain quality management systems is the requirement to keep staff motivated to conduct quality control for the business. Additionally, each aspect of quality management is different from business to business (Howarth & Greenwood, 2017).

The aim of this research is to determine the effects that a skill shortage within the UK has on quality management systems. Specific objectives for this research are;

To review the history of current/retiring workforce.

To determine the cause for a lack of skilled workers within the industry.

To establish what Quality Management is.

To determine the short and long-term affects skill shortage has on quality management.

To determine a possible solution for getting an increase in skilled workers.

Research was conducted by completing anonymous surveys with members of the construction industry, my target group is anyone past and presently working or studying within the construction industry. The research has consisted of questionnaires that were snowball sampled throughout the industry. The main body of my research is quantitative, as the information acquired is based off a wide range of people and pinpointing a key knowledge demographic. Key questions were created which will help to get an understanding of the knowledge about UK skill shortage. Quantifiable information was gathered by taking a systematic approach to distributing my surveys to the correct population of participants.

A case study has been used for the research to pinpoint the direct affects that have been impacting the industry and to allow for further understanding of what is required by the industry to move forward (Queiros, et al., 2017).

2. Literature Review

2.1. The UK Construction Sector

The UK Construction Sector has expressed significant concerns in recent years regarding the shortage of skilled labour and the impact that this will have on the need for traditional and new skills on current projects. It has been observed that the practice of "poaching" high skilled labour amongst companies has become more commonplace. This has led to an increase in the cost for construction, which further leads to "extreme fluctuations in construction output" (MacKenzie, et al., 2000).

Following on from this; the damaging effects a skill shortage can cause within construction have made an impact on Quality Management Systems (QMS) which are in place. High quality tradespeople are becoming more difficult to acquire due to the increased cost for their skills. This is not only for their performance, but for the knowledge they have of the industry as whole, i.e., safety and environmental awareness. Construction managers spend more time focusing on trying to enable their current workforce to produce and therefore the QMS faulters (Harris, et al., 2021).

2.2 The Skill Shortage within the UK Construction Industry

Since 2015 the UK has seen a significant increase in recruitment across England, Scotland, and Northern Ireland with minor changes in Wales (Ball, 2019). Whether it be tradespeople or managers, it has been more difficult to hire out of education than ever before. In the 2017 skills survey the UK reported that a third of available job vacancies were considered "hard to fill" with a further 8% increase in skill shortage vacancies compared to 2015, with candidates simply lacking the requirements specified by employers (Winterbotham, et al., 2017). In the same report it was stipulated by the Department of Education that "vacancies were highest in construction" where 36% of vacancies were related to skill shortages.

It is necessary to investigate certain areas relating to the shortage of skills within the UK. In a report from the University of Cambridge, Dr Kwadwo Oti-Sarpong (2019) highlighted the well known issues within the construction industry, describing the main concern being a "labour crisis" stemming from the skill shortage, an ageing workforce, Brexit and apprenticeship attendance. These key areas have the potential to be explored further to determine a root cause.

2.2.1 The Impact of Brexit on the Skill Shortage

Post Brexit it has become apparent that the UK has been experiencing difficulties with labour across most business sectors, especially within construction and production. When the UK engaged in the European Union it meant that the skilled work that was required could be achieved at the same high quality but for a lower price in European countries. However, now that we can no longer acquire work offshore as easily, reshoring needs to take place and there is not enough skilled labour to cope (Moradlou, et al., 2021).

In a survey conducted by Mohamed, Pärn, & Edwards (2017) it was believed strongly by members of the construction industry that the UK not only benefited from access to a foreign work force, but was reliant on it. Additionally, the use of a foreign workforce is necessary across the industry as it corrects for the fluctuation of the skills shortage. The disruption caused by Brexit creates difficulties when procuring a foreign workforce for most employers (Rolfe & Hudson-Sharp, 2016).

2.2.2 The Impact of the Ageing Workforce on the Skill Shortage

The UK construction sector employs approximately 2.2 million people, from unskilled manual labourers to highly skilled architects. However, it is estimated that half of this workforce perform in skilled trades (McNair & Flynn, 2006). Further to the research by McNair and Flynn, in a report by the Department for Business Innovation & Skills (2013), the UK Government also believes that the ageing workforce is the way forward to plugging skill gaps and labour shortages. However, the Government also expect to lose the ageing workforce to retirement and young workers not being attracted to the industry to replace that loss.

Statistics show that the percentage of unemployment increases with age. It was recorded that 86% of people over 50 were employed as of 2016 with a gradual decline in employment to 31% of people over 65 being employed (Forster, 2018). Training and investment are the products of an ageing workforce as companies often take time to develop the skills they require from their workforce within the business. With the current industry moving so quickly it is hard for this investment in current employees to take place as there is higher usage of temporary contracts and low skilled work (Ayodele, et al., 2020).

2.2.3 The Impact of Covid-19 on the Skill Shortage

The Covid-19 (Coronavirus) pandemic impacted the entire world; every element of working life was paused for many sectors within the UK and a lot of people were told to remain at home and not go out unless it was essential. Construction was impacted by the governments using lockdowns to slow the spread of Covid-19 and because of this the labour demand in the future was predicted to be higher than it was before. Where other industries could work from home, the construction industry could not. It can be seen in the statistics that there is a negative correlation between "working from home" and the "decline in job postings" during this lockdown period (Lydon, 2020).

On April 20th, 2020, the UK Government launched the "Furlough Scheme", where employers could send their employees home to self-isolate. However, this meant that they could not conduct any work for the company, and their pay was limited to 80% of their annual turnover (The UK Government, 2021). Due to the furlough scheme, the construction industry saw negative annual growth by -1.1%, this statistic shows the dexterity of the furlough scheme as this could have been much greater (Lea, 2021). In a survey conducted by LSE-CEP on the UK Self-Employed, it is apparent that less than 20% of self-employed people from the construction sector could conduct less than 20% of their work from home (Blundell & Machin, 2020).

2.3 Quality Management in UK Construction Projects

Quality Management Systems are a standardised framework which allow for "quality assurance in design, development, installation and servicing." Most contractors adopt this framework to achieve customer satisfaction and quality requirements for the project client (Harris, et al., 2021). However, when quality management systems are introduced into businesses they are to be maintained by middle management within the company, because of this there can often be disruption between teams as "conflicts often arise upon integration" (Chountalas & Tepaskoualos, 2021). It is important that these systems are maintained to ensure quality work is produced.

Quality Management within the UK is a necessary process for projects as it improves the performance of the workforce as well as establishing a framework which each construction project within the business must follow to achieve the high standards required by clients and the construction sector. Maslow's Hierarchy of needs indicates that the basic psychological need of a person is fundamental for achieving their best possible performance; "This concept of benefits is the most important and key to the achievement of quality", therefore the impact of quality management can play an important role in UK construction projects (Hoyle, 2007).

Management System integration is something that businesses are adopting as it makes them more appealing to the clients offering work. These mainly consist of but are not limited to: Quality Management (ISO 9001), Health and Safety Management (OHSAS 18001) and Environmental Management (ISO 14001) (Ofori, et al., 2002). ISO 9001 is a quality management system that organisations often introduce to improve "internal and external effectiveness" where improvements can be seen in management, leading to an enhanced workforce (Demir, et al., 2021).

2.4 The Impact of the Skill Shortage on Quality Management in Construction

The impact on Quality Management can be related to the effects from the skill shortage within the UK. Covid-19, Brexit and an ageing workforce have all influenced the performance of construction projects and quality management, especially within the last few years due to the issues that the UK has faced. Quality has suffered because of impacts relating to cost and time burdens.

2.4.1 The Impact of Brexit on Quality Management

Brexit has impacted quality management within the UK construction industry in numerous ways, with the "resource limitations" having a significant impact on the desired quality of the project (Mohamed, et al., 2017). Further data gathered from a survey conducted by Mohamed, Pärn, & Edwards (2017) led to 51 responses, where 30 participants agreed that the quality of projects would be reduced due to the impact of Brexit.

A "no-deal Brexit" was a huge uncertainty which affected most trade passing between the UK and the rest of Europe. Trade is considered one of the most crucial elements of Brexit which needed to be agreed before Britain withdrew from the EU as international agreement needed to be established to ensure the UK was getting a fair deal (Brautzsch & Holtemöller, 2021). There were concerns for the increasing cost associated with the trade between the UK and the EU, as an independent nation with no land borders it was important to make sure that the UK could still get the goods and materials that it would require (Belke & Gros, 2017).

High transaction costs are a limiting factor which could impact the quality of materials that the UK suppliers are willing to pay for as the increased cost will in turn limit spending (Malik, et al., 2019). Furthermore, construction companies are paying extra for materials due to new import costs and cannot complete work to the highest standard. It is well known between tradespeople that using inexpensive materials impacts reputation, durability, aesthetics and variation in costs (Ozinga, 2021).

2.4.2 The Impact of Covid-19 on Quality Management

During the height of the Covid-19 Pandemic it was determined that tradespeople within the construction industry were not "essential/key workers" (McSweeney, 2020) and because of this it meant 25.8% of construction personnel were not in work between April and June in 2020 (Russ & Nigg, 2020). Covid-19 impacted the construction industry as a whole but the impact on quality is determined by the quality of tradespeople. Given that there was a limited number of tradespeople on sites, it is to be expected that overall quality would fall during the pandemic. However, research carried out by Ogunnusi et al., (2021) determined that the time off provided by the lockdowns across the world could lead to "Improved productivity" with the additional time allowing for critical decision making, leading to better quality and progress overall (Ogunnusi, et al., 2021).

Guidance offered by the Government was to avoid face to face contact which meant quality checks on site could not be completed in as much detail (Ministry of Housing, Communities & Local Government, 2020). The role of Building Control in the industry is essential to ensuring education around the materials used and improving the overall quality achieved from the tradespeople (Murtagh, et al., 2018).

2.4.3 The Impact of the Ageing Workforce on Quality Management

Quality workmanship comes from years of training and developing an understanding of a specific trade. For this reason, it is commonly seen within different industries that higher quality work is achieved across projects with a mature workforce. The benefits they offer are often overlooked, with the older generation naturally teaching the younger generation as well as having a strong work ethic and retention of business knowledge and networks (Finkelstein, et al., 2021) (Ciutiene & Railaite, 2014).

Despite all the advantages, an ageing workforce comes with issues as the impact of being older in an active and fast paced environment can often increase duration of work. Quality can be maintained but at the risk of increasing duration (Finkelstein, et al., 2021).

The importance of ageing workforce on quality is often overlooked but it can provide many benefits. However, the delays and issues relating to an ageing workforce can often have major effects on a project and it is a risky position for management to put themselves in to accept older generations onto projects if time is a limiting factor. Reduced motivation and a slower pace are fundamental downfalls for an ageing workforce on projects.

2.5 The Role of Training and Development in UK Construction Sector

To have a skilled workforce it is important that the level of teaching is high quality and consistent to allow for specific skills to be developed and maintained. Research conducted in India determined that the structure of their training was one of the factors leading to the downfall of most training as sites simply did not have the infrastructure to allow for on-site training (Johari & Neeraj Jha, 2019). Similarly, this can be seen within the UK: "Investment into training is low in comparison to other sectors" with only 7% of school leavers under the age of 25 being employed in the construction industry. Therefore, training infrastructure in the UK is not attracting school leavers as well as other sectors (Brooks & McIlwaine, 2021).

Women within the construction industry is an important topic of conversation and it could be another limiting factor as to why the shortage of skills within the industry is on the rise. Worrall, et al., (2010) explained that women are less common in senior positions within construction, this is thought to be because of the culture which the construction industry has been connected to in its earlier years. They go on to further develop the need for change in training and advertisement within the industry as the process for women to get involved in a male dominated industry is daunting and may be unappealing.

The appeal to be a part of the industry is an area which needs improvement. Parents and guardians have a significant impact on young school leavers and the focus is on getting students into university. This could be is due to a lack of understanding that the influencing parents and guardians have regarding the "earning power" of being part of a skilled workforce (Lawani, et al., 2021).

Statistics gathered from the UK Government highlight the fluctuation in apprenticeship start-ups from each available year. Between 2019 and 2020, research shows that the apprentice starters are down by 6.9%, showing a significant decline in the number of people starting apprenticeships (Office for National Statistics, 2021). This decreasing statistic could be due to Covid-19 as recruitment for apprenticeships was reduced by most employers to focus on their fulltime and fully qualified staff. Additionally, it was difficult to encourage a training labourer to work from home when work needs to take place in a practical environment (Doherty & Cullinane, 2020).

Building Information Modelling (BIM) is a collaborative network which allows consultants and professionals within the industry to share and work simultaneously on a model to reduce time, improve collaboration and achieve better quality results first time (Oraee, et al., 2019). The use of more detailed and intricate modelling and measuring techniques has increased over the last decade with their use becoming more prominent across the construction industry (Moreno, et al., 2019). However, the development of an innovative technology means changes within the industry, and with change comes challenge. "A significant amount of education we had to do with the FM (facilities managers) team, even to bring them up to a basic awareness of what could be done with BIM…" (Rae, et al., 2019).

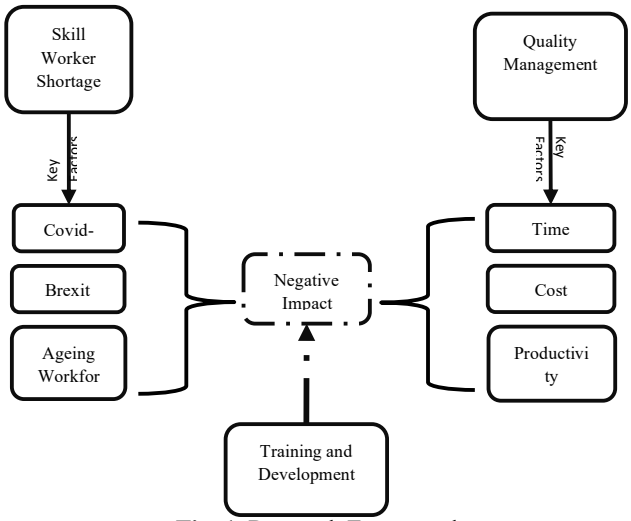

Fig. 1. Research Framework

Additional training is necessary for most "technical innovation" that comes into the industry. Whether it is a new type of material or tool, there will always be a requirement to ensure the knowledge is passed from developer to producer (Gann & Senker, 1998). Quality assurance techniques have been simplified using BIM as it allows for easier recognition of the issues and therefore allows for professionals to ensure these areas are addressed before the project is handed over (Burgess, et al., 2018). Without BIM the quality assurance process involves copious amounts of documentation and record keeping which can all be simplified by completing it electronically (Bassion, et al., 2004). Training in BIM is necessary for businesses as it means development can take place and it ensures the entire process is streamlined, saving on time, costs and an overall improvement in quality (Pollack, et al., 2018).

Table 1. Summary of the Past Studies

Key References	Highlighted Aspects	Quality	Skill Shortage	Methodology	Training Required
(Mohamed, et al., 2017) Brexit: measuring the impact upon skilled labour in the UK construction industry.	Skilled labour from Europe necessary. Impact of Brexit. Research determined participants agreed labour from Europe improved quality.	✓	✓	Qualitative	Quality could be improved further with training and recruitment within the industry.
(Wylie, 2021) The impact of Covid-19 and the lockdown on the UK economy.	Labour Shortages during the pandemic and lockdown. Industries affected by Covid-19.		✓	Quantitative	Training not mentioned in this reference however it can be used to express the further need to educate people.
(Keenan & Rostami, 2021) The impact of quality management systems on construction performance in the North West of England.	Skill shortage mentioned as a main factor affecting construction performance. Insufficient skill level within the industry. Impact on quality management as a whole. Training required to improve construction performance.	✓	✓		Lack of training mentioned and more will be required to improve construction performance. Inadequate training also a key element Quality management mentioned little in training courses.
(Winterbotham, et al., 2017) Employers skills survey 2017.	Training across each industry and the amount of spending in each. Difficulties meeting quality standards within the industry. Impacts of skill shortages within the UK.	✓	✓	Qualitative	Training mentioned throughout this report. Inadequate training in several areas. Development in training required.

Key References	Highlighted Aspects	Quality	Skill Shortage	Methodology	Training Required
(Hasan, et al., 2017) Factors affecting construction productivity: A 30 year Systematic Review.	Significant factors impacting productivity are skill shortages. Incompetent supervision leading to inadequate quality work and rework. Lack of skills impacting time, cost and quality.	✓	✓	Qualitative	Training in developing countries leading to fluctuation in performance. Quality can improve if companies invest in training. Taking the first step in training the workforce is the difficult part.
(Rolfe & Hudson-Sharp, 2016) The impact of free movement on the labour market: case study of hospitality, food processing and construction.	Migrant workforce has changed the skill profile within the UK. Shortage of people within the UK with technical skills means migrant workforce is necessary to increase productivity within the industry.		✓	Quantitative	Employing migrants was not seen as an alternative for training UK labour. For low skilled worker, training often took place on the job. Inadequate investment into training has been seen within most industries including construction.

2.6 Gaps in the Available Literature

Throughout the literature it is evident that there are areas in the research which need to be further understood and highlighted. There are gaps in the literature surrounding the impact that Brexit and Covid-19 have had on the training/development in education as well as slowing down the technical innovation provided by BIM. This highlights the point that skilled worders may be let down by lack of training/education and the additional destruction caused by Covid-19 and Brexit (Fig. 1. – Research Framework) Has quality management been affected?

To summarise, the literature covers the understanding that the number of skilled workers within the industry are expected to fluctuate over time. Table 1 highlights the summary of the relevant past studies.

Further literature which delves into the history of the skill shortage within UK determined that the source could be lack of training, Brexit, Covid-19 and an ageing workforce, each of which directly impacted the number of skilled workers. These factors have been repeatedly mentioned throughout literature.

Additionally, the literature explores quality management within the industry and how each element impacting the skill shortage has similarly influenced the quality management of projects.

Past and present impacts on the industry show that a skilled workforce and quality take place hand in hand and barriers will need to be broken to determine a way to establish an effective solution to the skill shortage that the UK is facing. From the research I expect to see a clear representation of how the lack of skill within the industry has an overall impact on the quality management of a project.

3.0 Methodology

This section will outline the approach that will be taken to gather secondary data which can be used to make a comparison against the primary data. It will explain the process used for gathering data and how effective the methods will be. Using these techniques will allow for analysis of primary and secondary data against one another to understand the trends and contradictions in the information.

3.1 Research Methods

There are two types of data collection methods, these are desk study and fieldwork. Desk study involves a review of literature including articles, reports, case studies and books previously written, with similarities to the hypothesis. However, the fieldwork approach is broader, encompassing three different techniques for gathering data. These techniques are surveys, case study and problem solving (Naoum, 2013).

Research methods are used to gather information relevant to the hypothesis, quantitative and qualitative methods give a variation of detail in the data. Quantitative techniques focus on surveys, where numerical data is gathered, and trends are visualised through graphs and charts to determine trends. Qualitative techniques allow for greater gathering of more detailed information from the research, looking at the quality of the data which is being received; usually gathered through interviews and expert opinions (Dźwigoł, 2019).

3.1.1 Quantitative

"The quantitative methodology seeks to obtain accurate and reliable measurements that allow a statistical analysis" (Queiros, et al., 2017). By using quantitative methods of data collection within the research a greater understanding can be gained of the impact that people within the construction industry think the skill shortage have had on the overall quality of the construction projects. This will be determined by gathering data surrounding the impact of events from Covid-19, Brexit, an ageing workforce and lack of training, which can then be analysed against primary data.

Surveys and questionnaires allow for data collection to be numerical and can be categorised and analysed to determine trends in the response offered by participants. Surveys are useful for collecting vast amounts of data as it provides a high yield of results if the survey is carried out correctly and to a high standard, for this reason it is used a lot in research (Queiros, et al., 2017).

The downfall of this approach is that there needs to be a considerable number of responses collected. If the "snowballing sampling" techniques does not encourage more responses it could limit the data collected to a handful of participants rather than a plentiful assortment of results (Queiros, et al., 2017).

3.1.2 Qualitative

"The qualitative methodology intends to understand a complex reality and the meaning of actions in a given context" (Queiros, et al., 2017). The use of qualitative methods of data collection within this research will increase the depth of knowledge and information surrounding the primary data as interviews and expert opinions should offer comparable results gained during the primary data collection stage.

Interviews can be used to gather data which has more validity as well as improved reliability as the source is a trusted professional. Additionally, they offer an "in depth and extensive understanding of a complex reality" (Queiros, et al., 2017). Interviewees first-hand experience offers a significant element of data which shows the impact that is taking place, this would be useful to extract from participants during interviews.

Unstructured interviews have been widely utilised previous research as it acts as a semi-formal way of gathering data from participants without them feeling pressured or inclined to answer the question the way the interviewer would like them to. For example, starting the interview in a conversational manner and allowing the participant to develop their train of thought (Johari & Neeraj Jha, 2019) (Queiros, et al., 2017).

In previous research the reliability of responses can be poor due to variety in interview results. They are also "time intensive" as it takes extended periods of time to gather information from multiple sources as well as the information gathered being less collective and conclusive (Queiros, et al., 2017).

3.1.3 Case Study

A case study is an investigation into a particular situation that is or has previously taken place, meaning that the views of the researcher play a vital part in the data collection. Case studies are widely used in "practise orientated fields such as: education, management, public administration, and social work", this research method has been deliberated between researchers for a while as they cannot determine whether it is a qualitative or quantitative method (Starman, 2013).

The data that is investigated in this research will be qualitative as it is taking direct information from an individual case and then using that to analyse the effects that these factors have had. Quantitative elements may be present within the case study; however, the analysis of data will be reliant on the quality of information provided and how it impacts the research (Starman, 2013).

3.2 Data Collection Approach

3.2.1 Case Study

The case study used for this research is an active construction site in Durham City Centre. Milburngate Development is currently under construction by Tolent Construction Limited (principal contractor), and it offers a vast amount of data relating to quality implications because of a lack in skilled labour; as a result of Covid-19, Brexit, ageing workforce and lack of education.

Using information from the case study, this research will show where the effects of Covid-19 affecting labour attendance to site has had an impact; Brexit delaying the import of goods and materials across the border, and the impact from lack of training during this difficult period. This can all be deduced from information which is readily available on site.

3.2.2 Questionnaire

In this research, questionnaires are used to extract data from professionals within the construction industry and gather quantitative and qualitative information surrounding the causes of skill shortages. The questions are centred around gathering opinions relating to Covid-19, Brexit and training. The trends discovered are analysed alongside the anomalous results which stray from the hypothesis.

The use of the questionnaire allows for better analysis of information gathered from people who are actively working within the industry and will provide a more present representation of what effects the skills shortage within the UK is having upon the quality of construction projects. Result graphs will show responses gathered with participant numbers on the y-axis and likert scale on the x-axis.

3.3 Measurement and Instrumentation

Data collection comes under a combination of questionnaire survey and a case study of Milburngate Site which is currently under construction by principal contractor, Tolent Construction Ltd. This data gathered will contain information from individuals from the industry as well as a direct review of the impacts on the case study by using information gathered from the site.

The questionnaire contents are drawn from a variety of sources to assist in formulating appropriate questions to determine the best results from the participants. Questions have been gathered from Mohamed, et al., (2017), Gamil & Alhagar, (2020) and Guillemard, et al., (1996). The questions are structured on a Likert Scale system which provides the participants to answer from strongly agree (5) to strongly disagree (1) on how much they agree with the statement presented to them.

3.3.1 Brexit Related Questions

Skilled labour from Europe has reduced since Brexit.

Project quality has suffered due to Brexit.

With less labour supplied by Europe, construction projects have suffered.

Brexit has negatively impacted supply chain for construction projects.

Brexit delays are common on construction projects. (Mohamed, et al., 2017)

3.3.2 Covid-19 Related Questions

Covid-19 has impacted labour attendance on projects.

Quality in workmanship has been impacted by Covid-19.

Managing workforce was more difficult during Covid-19.

Project duration has been impacted by Covid-19.

During Covid-19 supply chain has been affected.

Covid-19 has impacted quality of workforce.

Construction project spending has increased due to Covid-19. (Gamil & Alhagar, 2020)

3.3.3 Ageing Workforce Related Questions

Having an older workforce decreased productivity

Quality of workmanship decreases as labour get closer to retirement.

Age is a key characteristic in a higher skilled workforce.

Older members of the construction industry produce better work.

Age and experience are of importance when hiring labour. (Guillemard, et al., 1996)

3.3.4 Training and Development Questions

Training workforce is a necessity for improved quality.

Investment into workforce has improved productivity.

There is an expectation to see better workmanship after training.

It takes more than training to get a skilled workforce.

3.3.5 Cost and Time related Questions

Quality workmanship is reliant on cost and time.

Productivity is increased with higher skilled labour.

When time is short it benefits to have a skilled workforce.

Investment into training and development can see cost and time reductions when completing projects.

Quality management is made easier when time and cost can be maintained through a skilled workforce.

3.3.6 General Questions

How can the industry prepare to overcome labour shortages?

With the consideration of the limited skills within the industry, what do you think could be done to improve this?

Do you think the skill shortages within UK construction projects are impacting the quality of projects at handover?

3.4 Distribution of Questionnaire

The questionnaire is formulated on an online software called Google Forms as it allows for easy distribution. Electronic distribution offers a higher chance of receiving a response from participants, this is due to the ease of access that technology currently offers as well as the increased response rate due to the lack of failures in other methods such as letters via post. Sending questionnaires by letter poses a range of difficulties, i.e.: acquiring addresses for participants, failure of receipt, failure of response and security of responses from participants (Naoum, 2013).

Questionnaires have been formed and distributed online to industry professionals that are currently working within the industry, personal details will not be taken from participants however, age range and gender would be acquired to see difference in opinions across the fields (Naoum, 2013).

3.5 Case Study Information Gathering

Information has been gathered from the case study by looking into elements that have been affected by Covid-19, Brexit, ageing workforce; whilst also looking into productivity, time and cost elements of the project. The Milburngate Development in Durham was selected as the key case study due to the ability to assess each element separately. As the large-scale project started during the Brexit negotiations, took place throughout the Covid-19 pandemic and has seen every element of trade working within the industry it was a clear candidate to assess each element of the research.

4.0 Analysis

4.1 Case Study – Milburngate Development, Durham 2019 – 2022

Milburngate Development was a project which started on site in the spring of 2019 where Tolent won the contract for the brownfield site and started enabling works. During the last 3 years this construction project and staff have experienced the impacts caused by Brexit (January 2020), Covid-19 (December 2019 to 2022) and the effects of an ageing workforce. Therefore, it makes it a perfect "candidate" to be used as a case study for this research.

The Milburngate Development consists of a variety of units and buildings all offering their own challenges and constraints; The project is split up into a Premier Inn Hotel, three Private Rented Sector Apartment blocks, a nine floor "open plan" office space, three story car park, four cinemas, and a selection of retail and leisure units, amounting to £85,000,000.

4.1.1 Time Delays

When Tolent tendered for the project the initial handover date was set at November 2021, giving just over 2 years to complete the project. As of March 2022, the project is still under construction and is expected to hand over in May 2022.

Due to time delays from the Covid-19 Pandemic, Tolent appealed to the client for extensions of time to allow them to complete the project. A six-month extension was granted because of the delay caused by Covid-19. The time lost during the project was down to a substantial number of the skilled workforce being out of work and isolating from Covid-19. The reduced labour on site led to significant delays and there was a rush to get works completed on time. Tolent staff focused on productivity rather than quality during Covid-19, therefore inadequate quality was missed early in the project which means that the quality later was not as high as it could have been. Now that the impacts of Covid-19 are getting easier to manage it means that quality is improving across the site and Tolent staff can focus more on the performance of each trade.

Brexit has led to significant delay in getting required materials to sites across the UK, this also applied to

Milburngate. The setbacks caused by Brexit meant that importing materials for the façade, including glass and stone were exhaustive. This setback has meant that the workforce on site is limited in the materials that they can use. Consequently, a large majority of the works inside the building were delayed due to the need for the external façade to be finished before internal works can be complete. The time delay caused by Brexit has meant that temporary materials were required during the waiting period, which needed to then be replaced further into the project to meet the clients specification. Staff had to focus more on improving the quality of temporary measures rather than installing the high-quality material/product first time, leading to an increase in costs and time spent "double-handling".

4.1.2 Training and Development

The effects of Covid-19 meant that a significant amount of training courses were suspended during the pandemic and it meant that Tolent could not train their own staff and labour. This was seen throughout the subcontractors as well, expired or close to expiration CSCS cards were being shown at induction, however nothing could be done as the courses were not running. Tolent experienced a lack of skilled labour, for example the groundwork subcontractor struggled to provide more shuttering joiners due to the lack of interest in joinery apprenticeships.

Subcontractors on site had significant issues trying to source labour as it was more difficult to come by. It was often seen that labour that was employed through agencies would be "passed around" the contractors on site. In some cases, labour that was employed at the start of the project with the groundwork subcontractor, was seen towards the end of the project with the partition contractors. The reason for this labour shortage was suggested by many on site to be the effects of Brexit and Covid-19.

4.1.3 Quality on Site

Milburngate has seen that maintaining high quality due to the effects of the Covid-19 Pandemic and Brexit was challenging. Monitoring quality site-wide with reduced management staff as well as labour on-site, keeping on top of quality became demanding and was often overlooked in favour of production.

As the site developed and finishing trades started commencing work on site it meant that completing areas of work was made difficult with the sheer scale of the project. For example, delays caused by the glazing contractor meant that the perimeter of the building could not be sealed, therefore the mechanical and electrical trades could not commence work inside of the building. The glazing contractor expressed that the delay was not their fault and Brexit, and Covid-19 had a significant impact, however the other trades needed to start so temporary measures were put in place to continue production. Long delays and higher costs caused by Brexit, Covid-19 and other supply chain issues meant that there was little room for error as lead times were increased on top of the project already being off schedule.

4.2 Demographic Results

Table 1. Demographic Results

Characteristics	Category	Frequency	Percentage
Gender	Male	54	83.1%
	Female	10	15.4%
	Prefer not to say	1	1.5%
Age Group	18 - 24	16	24.6%
	25 - 34	10	15.40%
	35 - 44	14	21.5%
	45 - 54	17	26.2%
	55 - 59	5	7.7%
	60+	1	1.5%
	Prefer not to say	2	3.1%

Table 2 represents the participants who took part in the questionnaire. The information was used in a software called SSPS which calculated the frequency of the data and the percentage for was characteristic of the data sets.

4.3 Relative Importance Index (RII) for Quantitative Data

Relative Importance Index (RII) has been used to determine significance of the factors highlighted within the questionnaire to determine the factor in which the participants thought had the largest impact on the skilled labour shortage within the UK construction industry and its impact on quality management systems. The formula used to calculate the RII is shown in the equation below (Waziri & Vanduhe, 2013):

$$RII = \frac{\mathrm{Ni1} \times 1 + \mathrm{Ni2} \times 2 + \mathrm{Ni3} \times 3 + \mathrm{Ni4} \times 4 + \mathrm{Ni5} \times 5}{(\mathrm{Ni1} + \mathrm{Ni2} + \mathrm{Ni3} + \mathrm{Ni4} + \mathrm{Ni5})\mathrm{A}}$$

Where:

Ni1 = Strongly Disagree Ni2 = Disagree Ni3 = Neither agree or disagree

Ni4 = Agreement Ni5 = Strongly Agree A = Highest value in the Likert Scale

1. Most Significant 0.76 and above
2. Significant 0.67-0.75
3. Less Significant 0.45-0.66
4. Not Significant 0.44 below

RII findings from the questionnaire are presented in Table 3 - Relative Importance Index (RII) for Questionnaire Impact Responses.

4.3.1 Relative Importance Index for Questionnaire Responses

Table 2. Relative Importance Index (RII) for Questionnaire Impact Responses

Factor	1	2	3	4	5	RII	Category Rank
Brexit						0.708718	
Skilled labour reduced.	1	4	16	28	16	0.766154	3rd
Quality suffering.	8	8	26	15	8	0.621538	5th
Less supplied labour.	2	7	20	26	10	0.707692	4th
Negative impact supply.	0	3	14	25	23	0.809231	1st
Time lost.	1	7	14	22	21	0.769231	2nd
QM difficult.	9	15	20	16	5	0.578462	6th
Covid-19						0.877363	
Labour attendance.	1	1	1	11	51	0.938462	3rd
Quality workmanship.	6	9	11	23	16	0.704615	7th
Managing workforce.	0	3	2	15	45	0.913846	5th
Project duration.	0	0	1	9	55	0.966154	1st
Supply chain.	0	0	3	12	50	0.944615	2nd
Lack of training.	4	5	17	15	24	0.753846	6th
Increased spending.	0	1	5	13	46	0.92	4th
Ageing workforce						0.607179	
Decreased productivity.	6	14	17	19	9	0.633846	4th
Quality decline with age.	16	22	11	12	4	0.495385	5th
Key characteristic.	5	12	15	27	6	0.652308	3rd
Cannot produce better.	27	25	9	2	2	0.375385	6th

Factor	1	2	3	4	5	RII	Category Rank
Age and experience hire.	2	3	8	37	15	0.784615	1st
Hesitation to invest.	2	9	18	26	10	0.701538	2nd
Cost and Time						0.800615	
Quality reliant.	0	3	10	32	20	0.812308	2nd
Productivity increased.	0	6	4	28	27	0.833846	1st
Benefits to have skill.	5	6	2	20	32	0.809231	3rd
Training & development.	3	6	11	24	21	0.766154	5th
Easier to maintain.	4	4	7	29	21	0.781538	4th

Table 3 represents the RII for the impacts on the skill shortage within the industry and quality management systems. As can be seen from the RII, Covid-19 rated highest on the scale with 0.877363 meaning it is most significant in the research allowing for the conclusion that in recent years Covid-19 has had the greatest of impacts within the UK construction industry. It was also seen that ageing workforce received 0.607179 making it not significant on the RII scale.

4.3.2 Relative Importance Index for Training and Development

Table 3. RII for Training and Development

Factor	1	2	3	4	5	RII	Category Rank
Training and Development						0.886154	
Improve quality.	0	0	1	14	50	0.950769	1st
Improve productivity.	0	1	8	27	29	0.858462	5th
Expectation for better.	0	0	2	33	30	0.886154	2nd
More than training.	0	1	6	27	31	0.870769	3rd
Improves quality & time.	0	1	4	33	27	0.864615	4th

Table 4 represents that significance of the training and development within the construction industry, as can be seen the high average of the RII 0.886154, shows us that the participants agreed that issues surrounding skill shortages and quality management can be further improved by more training being provided.

4.4 Open Ended Questions

The final set of questions is an opportunity for the participants to express any additional information that was necessary to form part of the research getting their views and opinions on skill shortages within the industry, what can be done to improve the declining skilled workforce and overcoming the labour shortage that is taking place within the UK. Their answers have been summarised (including key words/phrasing) and are represented in the Table 5.

Table 4. Findings of Open Ended Questions

Questions Asked	Participant Answers
How can the industry prepare to overcome labour shortages?	"More apprenticeships/ increase apprenticeships. Training. Improve training. Intensive training courses. Improve funding for training. Encourage younger generations. Improve image. Welcome "non-traditional" industry members. Raise awareness / advertise industry jobs more. Invest in youth / Make it more attractive to school leavers. Mechanisms to be put in place to attract young people / Work with schools. Salaries and job prospects. Employers to offer more training. More realistic project durations. Quality training programmes that can be quickly rolled out."
With the consideration of the limited skills within the industry, what do you think could be done to improve this?	"Employers pushing to up-skill workers. Apprenticeships. Greater direct employment of labour, less agency, more reason to train and develop. Encourage young people into the industry. Incentivise personal skill development. Maximise off-site construction. Free training. Training in areas that require skills. Government funded training. Young people to have long and stable work environments to become established. Designers and architects to incorporate designs that facilitate current construction methods and to avoid the lack of knowledges. More construction courses."
Do you think the skill shortages within UK construction projects are impacting the quality of projects at handover?	38 participants responded with a single word: "Yes", in this section. "Quality suffers due to current labour not having enough time to complete projects. Self-employment encourages labour to cut corners on quality to increase productivity. Quality drops when unskilled workers are tasked to complete skilled jobs. Less skills in the industry will affect the quality. Projects require skilled labour, direct correlation between loss of quality and lack of skill. No, time scales and deadlines affect the cost. No, it costs more money and time to get the job done. Industry seems to be going backwards. Employers should ensure the quality is there before handover. Skilled labour working on price causes less consideration for quality and more on productivity. Large amounts of snagging, trades lack the care of each other's work."

5.0 Conclusion

To conclude, the review on the skill shortage within the UK construction industry, and the impact on quality management, it has been made apparent from the literature and the survey that change will be required to the training and development areas of the industry to improve on the skill shortage seen as an effect of the aforementioned impacts.

Employers have the ability and time to encourage training within their businesses and improving the knowledge of their staff is something that can be easily achieved with correct planning and time considerations put in place. Furthermore, skills need to be honed and developed, for the younger generation this needs to be established to set the standard for what companies want and expect to achieve. Apprenticeships, volunteers and taking on school leavers with little to no skill is a risk to a business, however the risk can be minimised if the right level of investment is considered. The results from the survey highlighted this massively, there is understanding among industry professionals that work needs to take place with young people, yet little to no investment takes place.

Quality management suffers when skilled labour is unavailable, and works are completed to a standard that is not to the level required by the client leading to delays at handover. Even when skilled labour is available the focus on productivity rather than quality can also be seen. Training should be conducted to improve this and reflect the needs of the client. Cost and time have been mentioned throughout the research and participants of the questionnaire who disagreed with the statement: "Do you think the skill shortages within UK construction projects are impacting the quality of projects at handover." Although they were expressing that they did not believe it was the skilled shortage fault, they confirmed that cost and time

were factors in completing a task and therefore quality is dependent on both.

The skill shortage within the UK has had been affected greatly by Covid-19, Brexit and the ageing workforce and quality management has suffered as a product of the issues raised. Training and development into skilled workforce will improve quality management and the ability to achieve exacting standards that are required.

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Rashid Maqbool, PhD. is a Senior Lecturer at the Faculty of Engineering Environment, Northumbria University, UK. His research interests and publications focus on Construction Project Management, Sustainable Built Environment, Renewable Energy Projects, and Sustainable Urban Development. Dr. Maqbool has written various research papers, which have been published in top ranked Journals in Construction Project Management and Sustainable Development. He is also an active reviewer and board member for many top Journals on Construction Project Management and Sustainable Development. He has also collaborated actively with researchers in several national and international funded projects. He can be contacted at rashid.maqbool@northumbria.ac.uk

Luke Oldfield is a Bachelor candidate in Northumbria University. He has his research interests about Construction Project Management in particular to Skill shortage in UK Construction Industry. He has completed some research works on the mentioned areas.

Saleha Ashfaq is a PhD candidate in School of Economics and Management at Fuzhou University, China. Her research direction is Financial Engineering, Energy and Engineering Management.

Mohammed Rayan Saiba is a Masters candidate in Faculty of Engineering and Environment, Northumbria University, UK. His research direction is Construction Project Management, Building Information Modelling, Sustainable Development.

Paper no. 117

The Effects of Scope Creep on Project Success

Allan Niel Osborne[1], Kelechi Theophilus Anyigor[2] and Martin Nesbitt[3]
[1]Associate Professor, Construction Project Management Subject Group, Department of Architecture and Built Environment, Northumbria University, United Kingdom, E-mail: allan.osborne@northumbria.ac.uk
[2]Assistant Professor, Construction Project Management Subject Group, Department of Architecture and Built Environment, Northumbria University, United Kingdom, E-mail: kelechi.anyigor@northumbria.ac.uk
[3]MSc Candidate, Construction Project Management Subject Group, Department of Architecture and Built Environment, Northumbria University, United Kingdon, E-mail: m.v.nesbitt@northumbria.ac.uk

Abstract: For as long as society has procured engineering and construction projects, spectators and theorists have observed and studied project management practice and its influence on project success. Many scholars have pondered and theorised the spectrum of good and bad project management practices and how they engender successful and unsuccessful projects. Often, these pundits have overlooked the impact of scope creep on project success. Scope creep is the incremental process of undocumented changes in a project's requirements that begin sometime after stakeholders have ratified the project's objectives, schedules, tasks, deliverables, and performance. This paper aims to contribute to the limited number of studies that have examined scope creep by focusing on its manifestation in a sample of construction projects in a single case study construction company operating in the gas and oil sector in the UK and US. Using a bilateral quantitative research approach, the authors received responses from 70 of the company's project managers and interrogated the financial details of 201 of the company's historic construction project documents. The online survey results suggest that a general lack of understanding of scope creep among all stakeholders, its implications, and the project managers' certitude to refuse additional client requirements significantly contributed to its manifestation. The desktop study of the company's historical project documentation yielded an unexpected discovery concerning unexplained scope creep. The company had classified many of its projects as call-off contracts, which meant it had agreed to additional work on an ad-hoc basis, thereby expanding the project's scope. The authors concluded that unknown, undocumented, unmanaged scope creep would become a significant dysfunctional factor adversely affecting project success. The study concluded by underlining four factors that should influence the project managers' abilities to manage scope creep successfully to ensure project success: clear understanding of the project scope, stakeholder involvement at all stages, schedule and budget management, and change management.

Keywords: scope creep, project management, project success.

1. Introduction

Most spectators and theorists agree that a project is successful if the team delivers it to the agreed quality, within budget, and within the specified timeframe set by the stakeholders. In 2019, the Association for Project Management (APM) confirmed this viewpoint in its Body of Knowledge (BoK) by defining project scope as the totality of outputs, outcomes, and benefits and the work required to produce them. Any ambiguities and uncertainties in the scope of a project often result in scope creep, which could cause the project to fail.

In project management, *scope creep* is a phrase used to account for the expansive change in essential requirements that begins after requirements are baselined at the beginning of the project and continue throughout the project's life. With scope creep, additional works come without revisions to the original project budget or timescale. This effect imparts immediate pressure on what is often an already ambitious delivery timescale and tight budget for designers, engineers, and contractors. Dekkers and Forselius (2007) have explained that when the scope of a project is not clearly and completely defined, it results in modifications that have negative implications for timely completion, cost, and quality.

2. Does Scope Creep Matter?

According to the British Standards Institution (2019), project management involves "planning, monitoring, and controlling all aspects of a project and the motivation of all those involved to achieve the project's objectives". This definition underpins the need to understand the planned scope of the project while monitoring and controlling the progress through to completion. When planning and

managing complex projects, project managers should consider scope creep as the antithesis of this mantra.

Over the years, there have been numerous attempts to measure the effects of scope creep on projects. While it sometimes may not necessarily be measured explicitly in terms of direct costs, researchers have invariably identified scope creep as a significant contributing factor in project cost and schedule overruns. For example, a study on government construction projects in Qatar showed that the calculated costs of scope creep accounted for up to 9% of additional project costs (Hussain 2012). In another study by Baig and Kuresh (2018), the direct costs of scope creep in some Pakistani hydropower projects ranged from 39 to 63% of the total cost escalation.

Similarly, Bresnen and Haslam (1991) found that 40% of the projects in their study had budget overruns because of scope creep or design variations. Managing the level of changes to the project's scope is, therefore, essential to ensure that projects remain under control. Madhuri et al. (2018) have subsequently explained that any uncontrolled pressure on a project's original schedule or budget presents a significant threat to realising its potential success. As the APM has stated in its BoK (2019), project managers should deliver projects in an affordable, profitable, value-for-money manner. The APM's stance reflects Khan's (2006) argument that scope management is one of the most critical functions of a project manager.

Theorists—such as Larson and Larson (2009), Abbasi et al. (2014), Alami (2016), and Komal et al. (2020)—have argued that scope creep remains one of the leading causes of project failure. With scope creep, additional work comes without changing a project's original terms and conditions. This undesirable situation means there is no revision to the original project budget or timescale due to uncontrolled scope changes. It imparts immediate pressure on what is often an already ambitious delivery timescale and tight budget.

Shirazi and his associates (2017) have explained that scope creep harms project performance instead of managed change control that adds measured scope to a project with the appropriate adjustments to the project baselines. Besides the financial losses and delays associated with scope creep, it also decreases client satisfaction and increases frustration for project teams (Larson and Larson, 2009). Scope creep is, therefore, considered to be an inevitable and undesirable aspect of project execution.

Hanna and Gunduz (2004) argue that scope creep harms labour productivity. Constant changes and never-ending adjustments to project milestones can demoralise workers and result in reduced productivity and poor quality delivery. Scope creep also affects how quickly project returns or earnings can be realised (Simushi and Wium, 2020). The longer the delays, the longer it will take to realise project revenues. The additional costs associated with scope creep, such as delayed compensations and reduced return on investment, can sometimes be up to four times the initial budget (Teye Amoatey and Anson, 2017; Gurlen, 2003).

Following a quantitative study of construction projects, Oladapo (2007) found that deviation is a significant cause of increased project cost and time overruns. Sutrisna et al. (2003) and Zaneldin (2005) have argued that most project claims, which ultimately lead to cost overruns, often result from scope creep. Sutrisna et al. (2003) and Chan and Suen (2005) have also identified scope creep as a typical cause of contractual disputes in the construction sector.

Against this complex background, the authors of this paper designed their study to investigate the consequences of scope creep on construction projects and identify what measures project managers can implement to mitigate its impact on previously defined requirements to safeguard the project's success.

3. What Causes Scope Creep?

Sliger (2010) has defined scope creep as the expansive change in requirements that begins sometime after requirements are baselined at the beginning of the project by its stakeholders and continue throughout the project's life.

It is important to note that scope creep does not necessarily confine itself to a single episode. Retana (2014) describes scope creep as an incremental expansion of the project's scope without additional work requests to make the necessary readjustments to the cost or schedule. Simply put, scope creep happens in a sequence of often independent minor changes. Kuprenas and his colleagues (2003) have explained that this definition refers to the fact that scope creep tends to occur in minor, numerous modifications and is often not as noticeable as a single fundamental change to the project's agreed baseline.

As Winch (2013) reported, these potentially small incremental changes to project scope can lead to the catastrophic overruns seen in projects such as the Channel Fixed Link project. Scope creep amounts, therefore, to any changes to the original project scope not covered by approved change orders (Madhuri, 2018). When the benefit of project scope changes outweighs the cost and time loss, Roy (2020) explains it should be accepted and implemented accordingly.

Previous research has identified countless reasons for the prevalence of scope creep on projects. Several studies and papers have shown that traditional projects, especially construction projects, suffer significant amounts of scope creep due to the project manager's adopted management style. Suma (2013) and Sliger (2010) have reported that IT project stakeholders have significantly reduced scope creep using agile project management techniques. Table 1 below summarises the possible reasons cited by past researchers for scope creep's occurrence.

Most studies identify a lack of clarity at the project initiation stage as a meaningful cause of scope creep. According to Mirza et al. (2013), there is little hope of achieving success without an agreed and documented scope. Turk (2010) similarly noted that a poor set of requirements or objectives could lead to disaster when changes or additions come as they inevitably do, especially in construction projects.

Most project management professionals and scholars agree that additional time spent at the project initiation phase is time that will pay for itself many times over during the project's life. Shirazi et al. (2017) broadly categorised several factors they consider part of the leading causes of

Table 1. Potential causes of scope creep identified from the literature review's findings

	Bellenger (2003)	Kuprenas and Nasr (2003)	Turk (2010)	Hussain (2012)	Farok and Garcia (2016)	Moneke and Echeme (2016)	Amoatey and Anson (2017)	Shirazi et al. (2017)	Baig and Kureshi (2018)	**Total**
Poor or no scope definition	●		●	●	●	●	●	●	●	**8**
Lack of understanding of project	●				●	●		●		**4**
Additional scope added	●			●			●			**3**
Poor project management			●		●	●		●	●	**5**
Poor project performance										**0**
Poor or no change control		●	●	●		●	●	●		**6**
Poor design		●				●			●	**3**
Poor or no schedule management						●			●	**2**
Pleasing the client			●							**1**
Poor project kick-off					●					**1**
Stakeholders not involved/changed		●		●	●		●		●	**5**
Lack of technology					●					**1**
Poor risk management						●	●	●		**3**
Other				●	●		●		●	**4**

scope creep as *poor documentation*. These include inexperienced personnel responsible for project scoping, lack of understanding of the client's needs at the scope definition phase, unrealistic project goals, and the lack of clarity of system boundaries. All of these can lead to an inferior definition of project scope and the misconstruction of the contract.

Of three distinct causes of scope creep studied by Hussain (2012), 65% of the respondents identified poor scope definition as the most common cause. Baig (2018) identified scope definition and scope control as essential factors influencing project success. Even when all parties agree, an unclear scope can lead to unexpected changes in previously defined requirements (Amoatey, 2017).

Another common cause of scope creep discussed in the project management literature is poor or absent project change control. According to Winch (2013), projects are fundamentally vehicles of planned change. Indubitably, change control when managing projects is imperative if the agreed budget and schedule are to be maintained.

Change is inevitable in projects, and the more complex and extensive a project is, the more likely changes will be necessary during its conception and execution. Project stakeholders—experienced and inexperienced—may not know the numerous influential factors that change a project's scope after it has started. It is inevitable that these significant factors cannot be measured or quantified but will remain a project requirement. These uncertainties can be in scope development, scope increase, or even straightforward changes requested by the client. Millhollan (2008) has explained that whatever the reason behind a change, project managers must robustly manage it to secure the project's success.

Turk (2010) argues that project managers must learn to say no in some circumstances. When pressure is exerted on a project manager to accept change without the requisite updates to the project's cost and schedule, there will be an inevitable negative impact on the project's performance. No matter how insignificant, these unmanaged changes inevitably result in scope creep. Moneke and Echeme (2016) argue that poor scope definition leads to constant demands by clients for additional work. While this may turn out to be scope creep, extra work can benefit the project if it is closely monitored and managed through an agreed change control process.

Stakeholder management plays a vital role in defining a project's mission to avoid scope creep (Morris and Pinto, 2004). Ajmal et al. (2021) argue that poor communication with and between project stakeholders significantly contributes to scope creep. Shane et al. (2009) argue that educating third parties to projects about costs and schedules helps to avoid scope creep.

Although individual stakeholders often have their motives, stakeholder ignorance can lead to demands for scope changes (Farok and Garcia, 2016; Flyvbjerg, 2017). Each stakeholder tries to shape those requirements to meet their particular interests, as evidenced by the TAURUS project on the London Stock Exchange. This project suffered unmanageable scope creep leading to budget and schedule escalation and the eventual project cancellation after a project total spend of approximately £80M (Nelson, 2007).

In his study of scope creep costs in government construction projects in Qatar, Hussain (2012) identified the ignorance of stakeholders concerning project management tools and practice as the leading cause. The inescapable involvement of stakeholders and their contribution to the occurrence of scope creep led Hussain to recommend the

prerequisite use of stakeholder analysis techniques to mitigate their negative impact.

Despite the circumscribed studies that have explored scope creep, few have postulated the existence of a possible distinction between avoidable and unavoidable scope creep. However, Berry et al. (2010) and Puhl and Fahney (2011) are notable exceptions. By way of example, Puhl and Fahney have stated that while "avoidable creep results from stopping requirements engineering effort too early, e.g., for cost-saving reasons", unavoidable creep results from a lack of or limited knowledge of what to expect from the system.

4. Agile Approach to Scope Creep Mitigation

One industrial sector that has suffered tremendously from scope creep is software development. Bjarnason et al. (2012) and Kumari and Pillai (2013) have argued that scope creep is responsible for most software development failures. To illustrate this point, Thakurta (2013) discussed massive failures in managing project outcomes, noting that only about 30% of software projects achieve their process estimates. One of the significant causes identified was requirement volatility, which Davis et al. (2008) redefined as *changes in project scope* or *scope creep*. Sliger (2010) proposes that project managers can control the expansive change in requirements typical in software development projects through an *agile approach*, which necessitates the strategic fragmentation of substantial project tasks into smaller work packets.

The APM (2022a) has explained that *agile project management* adopts iterative or agile life cycles, composed of several iterations or incremental steps towards project completion. The APM stipulates that "iterative approaches are commonly used in software development projects to promote velocity and adaptability" but clarifies that *agile* does not just prescribe one unique approach to project management. By way of illustration, the APM (2020b) uses the word *agile* to categorise a family of project management methodologies where requirements and solutions are developed by stakeholders iteratively and incrementally throughout a project's lifecycle. These methodologies include Scrum, Kanban, and XP, each system presupposing the adoption of a moving target for the project scope is acceptable.

In the fast-moving software development sector, many industry pundits consider these pliant agile methodologies essential project management tools to avoid outdated project outcomes arising before project delivery. However, in the more traditional, slower-paced, fragmented construction sector, stakeholders tend to fix a project's deliverables at the outset because they also must set its scope to establish a fixed cost and schedule. Furthermore, the agile method can contribute value to the construction sector's pre-design and design phases: the agile process can be applied in the pre-design stage to enhance concept development; procurement strategy, time, and cost; and the preparation of briefs (Best and de Valence, 1999).

During the design phase of construction projects, the agile method can also contribute value to the integration between design and production and the dynamic process of requirements capture (Owen et al., 2006). According to Owen et al. (2006, p.53), the agile approach has been successfully applied in the construction sector to "significantly improve productivity, quality, predictability and both development personnel and managerial organisational skills." As a secondary, perhaps more tangible benefit, it has also contributed to a significant reduction in cost.

A further benefit of using an agile method is adjusting as you go along rather than following a linear path. With this approach, project planners can break the project into smaller work packages with a known scope that teams can complete before reviewing and planning the scope for the next stage. This approach is effectively a moving change management system where the project manager understands that the scope is not fixed or fully understood but accepts this and revisits the scope at regular agreed stages. Carkenord (2014) summarises this viewpoint by saying that project planners welcome changes within the confines of a product vision or roadmap when using an agile approach.

5. Stakeholder Influences on Scope Creep

Scope change is inevitable; therefore, it should be carefully managed (Kahn, 2006). One of the leading causes of scope creep is the lack of scope definition and management. Thakore (2010) has suggested that effective scope management is one of the most effective ways of avoiding scope creep.

Once project stakeholders set the scope, there should be little or no change to it outside of a managed change control system. Kapur (2004) and Turk (2010) have explained that a significant amount of scope creep can be attributed to the project manager conceding small incremental changes to satisfy the client. They go on to say that project managers must learn to say no! Otherwise, as discussed above, these gradual changes can significantly affect the project's deliverables.

Leeman (2002) and Khan (2006) argue that the development of a work breakdown structure (WBS) helps to control the scope of a project. They say that a successful project should spend up to 45% of time and resources on planning. This development underpins the need to spend enough time upfront on developing the scope and getting it agreed upon before delivery commences.

Once the project's stakeholders have established the scope, change control is the next step to avoid scope creep. Shirazi et al. (2017) have argued that change is inevitable due to the inherent nature of projects, but the project manager can choose to control it. Uncontrolled change often results in scope creep (Kerzner, 2013). Therefore, project managers can significantly reduce scope creep, avoiding unchecked change and associated cost rises.

Every change in scope (positive or negative) should be recorded, measured, quantified, and finally agreed upon by all stakeholders before implementation (Bellenger, 2003). The project team should reflect the resulting change in an updated cost forecast and the schedule adjusted accordingly, dependent on the cost and time impact. Modifications to any aspect of the infamous iron triangle shown below in Figure 1 will influence project delivery, not just changes to scope and should, therefore, be managed equally by project managers. In this way, although there will be changes to the outcome cost and schedule, all stakeholders will be aware and will have accepted them.

Fig. 1. Iron Triangle adapted from Bronte-Stewart (2015)

Another aspect of project management identified as a causal factor in scope creep is the lack of involvement of key stakeholders (Komal et al., 2020). Gurlen (2003) emphasised this point by arguing that unclear project scope is one of the significant causes of scope creep. He says that at every project stage, but especially in the initiation stage, clarity of all aspects of the project is imperative. Cooke-Davies (2002) highlights this point by reiterating the importance of factoring in stakeholders' interests in every decision to ensure consistency of the project's scope.

Farok and Garcia (2016) have stated that stakeholders should educate themselves on the full implications of every aspect of the project and any initiated change. These should be unambiguously worded, and the project manager should confirm that the project's stakeholders have read the scope and are fully aware of what they have and have not omitted. This approach supports the value of developing a stakeholder management plan at the early stages of any project. Such a programme would enable the project manager to identify and inform all relevant parties of any changes at the appropriate time.

6. Research Method

To ascertain a dependable understanding of unavoidable scope creep and the extent to which it arises in construction projects, the authors elected to restrict the potential influences of extraneous factors by limiting the study design to a single case study organisation. By doing so, the authors intended to compare their empirically-derived data with their theoretically-grounded understanding of unavoidable scope creep from their review of the extant literature. This approach to the data collection and analysis processes enabled the authors to identify new insights into the prevalence of scope creep in construction projects, the prerequisites contributing to its occurrence, and the categories of projects most susceptible or affected by its manifestation.

6.1. Employee Questionnaires as Data Sources

Empirical quantitative data were collected using an online survey of a population of construction project managers working full- or part-time for the same gas and oil private-sector company operating in the UK and US. The authors invited all 70 project managers employed by the specialist gas and oil company to participate in the study voluntarily, with 49 project managers responding by submitting their anonymised questionnaires within the two-week specified timeframe for the data collection phase.

The authors designed the questionnaire around three critical characteristics of project managers exposed to project-related scope creep identified from the literature review: age and work experience, project performance perception, and scope creep understanding. The authors planned to use the questionnaire to capture data relating to the project managers' demographics to explore possible causal relationships between participants' age and their understanding of scope creep and competence in delivering successful projects. They also used the survey to capture data relating to the appropriate work experience of the project managers to determine the extent of their understanding and competence of scope creep awareness and their experience in handling its presence. The authors viewed this line of enquiry as critical to elicit their knowledge of each participant's ability to identify scope creep manifestation during a project's lifetime and to initiate project management strategies to mitigate its undesirable impact. In the same spirit, the authors considered the value and duration of the construction projects managed by each project manager to be quantitative indicators of the likelihood that scope creep could potentially materialise. The authors considered complex projects with a long delivery period involving multiple stakeholders more at risk of scope creep than their smaller, less complicated counterparts. In other words, few opportunities exist for the contributory factors identified in the literature review to stimulate the occurrence of scope creep and adversely affect the project's performance. For this reason, the authors asked respondents to categorise the projects they had worked on and specify their geographic locations.

The main body of the survey focused on asking the project managers to comment on project performance. Rather than asking each project manager to undertake a desktop study of their archived project files to extract quantitative metrics, the authors asked each manager to answer an array of questions using a five-point Likert perception scale, i.e., *always*, *sometimes*, *rarely*, and *never*.

The authors tactically designed the questions in this section of the online survey to complement their desktop study of the company's past projects. To this end, the main thrust of the questions was around project scope, project delivery times/schedule, and project financial performance. As clarified above, the elicited responses gave the authors an understanding of the competence of each project manager participating in the study to deliver successful construction projects.

The survey's final section focused on discovering the reasons for underperforming projects and scope creep's existence. The section asked participants to share their opinions on why projects were not performing as expected and their understanding of the phrase *scope creep*. The authors anticipated a correlation between the project managers' cumulative responses to this section's questions and the literature review's key findings.

At this point in the paper's proceedings, it is perhaps worth noting that the literature review's key findings illustrated that it is difficult to elicit definitive quantitative data that are reliable measures of scope creep. A plausible explanation for this assertion is that scope creep is a phrase used by a spectrum of interested parties to describe several undesirable attributes that arise from the absence of scope definition to the scarcity of an agile change management

system. As a result, varying opinions could potentially exist on whether it is appropriate to describe specific areas of poor project performance as scope creep. For this reason, the authors designed the online survey to elicit project managers' perceptions and opinions of scope creep and project characteristics and performance rather than quantitative project-related data and traits. This approach's intention in collecting questionnaire-derived data was to compare the findings with the data acquired from the desktop study of the company's historical project data.

6.2. Historical Company Documents as Data Sources

Secondary quantitative data were collected using a desktop study of archived files for construction projects that started and finished over five years up to the beginning of 2020 from the same specialist gas and oil private-sector company. The harvested data allowed the authors to review each completed project from a financial performance standpoint. The company had conveniently separated these data into two broad economic categories: anticipated or planned financial performance and final outturn financial performance.

The desktop study data allowed the authors to measure how the project managers delivered each project on the company's behalf and compare their findings with how the company had initially organised each project to perform when the client had awarded the contract. The following four datasets allowed the authors to compare how the project manager delivered each project against the project's outcome from a financial perspective: purchase order (PO) value, cost budget, selling price, and additional PO value.

7. Results

Using descriptive statistics to analyse, structure, and present appropriate sets of the numerically-based data extracted from the online survey questions completed by the project managers participating in the study, the authors compared these findings with the literature review's conclusions. The authors also compared their online survey-derived inferences with the insights they gained from their data analysis of the desktop study archived files of the company's past projects. This dual approach to data collection and analysis allowed the authors to elicit some anticipated and unanticipated observations into the prevalence of scope creep, its potential reasons for being present, and the types of projects most susceptible to or affected by its manifestation.

7.1. Age and Experience

The project managers were aged evenly from 22 to 57 years. Each respondent's project management experience level correlated closely to their age; as expected, the eldest participant had the most experience. Comparing each project manager's age to their project management experience showed that they varied between inexperienced project managers with less than one year of relevant work experience and those with more than 30 years of working as project managers. The authors again noticed a uniform distribution of pertinent work experience levels with age.

The managed project locations covered all regions, with almost half limited explicitly to US regions. The remaining were distributed evenly between the UK and the rest of the world.

The online survey asked the project managers how many projects they had completed in the last three years to elicit a general appreciation for the types of projects they had delivered. Figure 2 below shows that 82% of the project managers indicated they had completed at least ten projects, with 24% having completed more than 100. This finding would seem to suggest that most projects conducted by the managers invited to participate in the survey have a short duration or that the managers are coordinating multiple, less complex projects with a longer timeframe. Figure 3 illustrates that 75% of the project managers estimated the average value of their projects fell between $10K and $100K, which would seem to support the assumption regarding projects with a short duration or a less complex nature.

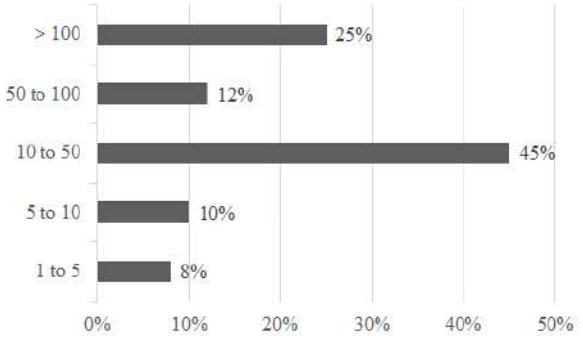


Fig. 2. How many projects have you completed in the last three years?

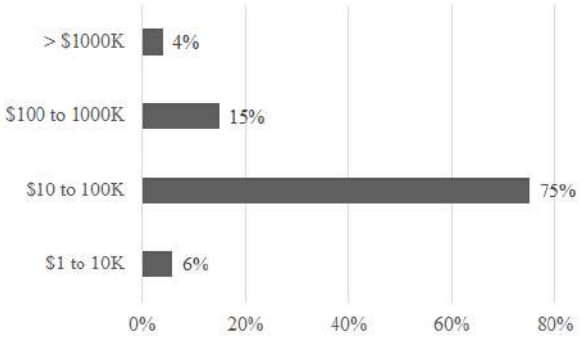
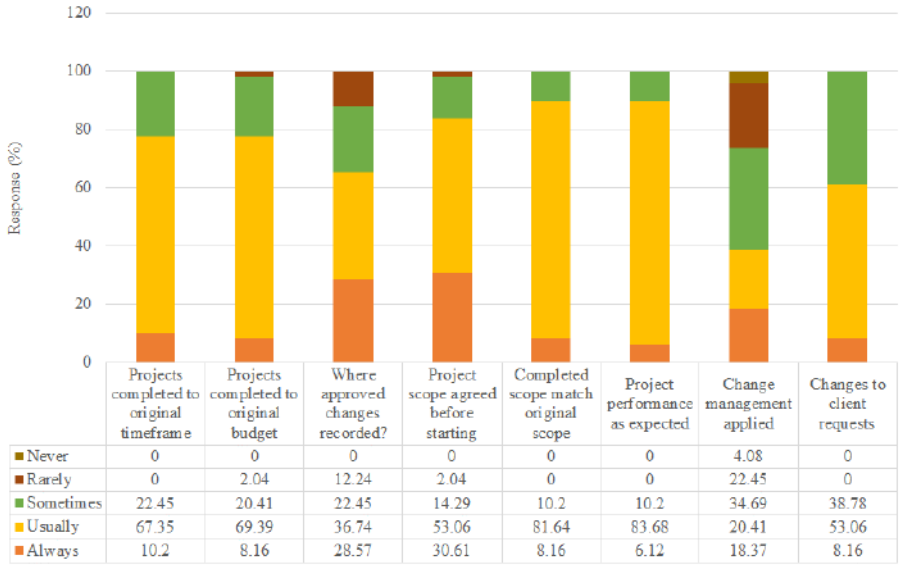


Fig. 3. What is the average size of these projects?

7.2. Project Performance Perception

The next set of questions that the project managers considered was related to their perceptions of how the projects they had been responsible for performed when measured against initial budgets and schedules, change management processes, and defined project scopes. The authors tabulated the project managers' responses in Figure 4 to give a cumulative overview of how the project managers responded.

The authors designed the first two questions to measure the extent to which the managers delivered their construction projects within the initial timeframe and budget. The project managers were overwhelmingly positive, with 77% answering either *always* or *usually* to each question. The figure dropped to 67% when the authors



	Projects completed to original timeframe	Projects completed to original budget	Where approved changes recorded?	Project scope agreed before starting	Completed scope match original scope	Project performance as expected	Change management applied	Changes to client requests
Never	0	0	0	0	0	0	4.08	0
Rarely	0	2.04	12.24	2.04	0	0	22.45	0
Sometimes	22.45	20.41	22.45	14.29	10.2	10.2	34.69	38.78
Usually	67.35	69.39	36.74	53.06	81.64	83.68	20.41	53.06
Always	10.2	8.16	28.57	30.61	8.16	6.12	18.37	8.16

Fig. 4. Project performance perception

looked at each project manager who had responded favourably to both questions.

The next question asked the project managers if they had documented when they failed to deliver their projects on time and within budget. The number of positive responses reduced to 67% when viewed as a standalone question. But, when coupled with the project managers who answered positively to the previous two questions, the rate dropped to 51%. This result highlighted some concerns for the authors: one-third of the project managers' completed construction projects had undocumented changes when either the project schedule or financial budget was unmet. Any additional costs associated with the delivery of these projects are, therefore, unlikely to be recoverable; thus, evidence that the projects were affected by scope creep. Of the 32 project managers who reported they had not documented the approved changes, 17 stated there was no formal change management system at the time of project delivery.

When the authors looked at the question asking the project managers to indicate if there was initial agreement among the stakeholders about the project's scope before work started on site, 84% responded positively, which was the highest response rate of *always* answers in the question set. This result illustrated that a good understanding among the stakeholders existed concerning the need for definitive initial project scope to ensure success.

The following two questions—whether the *completed* and *initial* scopes corresponded and whether the project's performance met stakeholder expectations—received the most positive responses of all questions in the set, with 90% responding either *always* or *usually*. Unexpectedly, this result highlighted a somewhat contradictory outcome: 33% of the project managers reported their projects did not satisfy schedule or budgetary targets. This result indicated that some project managers expected their projects to fail if the measure of success was to deliver a project on time and within budget.

The change management question received the most negative responses, with 39% of managers indicating that they regularly applied change management techniques on their projects. This result could help to explain why a small percentage of the project managers reported a positive response when asked if they documented approved changes when their projects failed to perform. Regrettably, the authors forgot to ask the project managers whether a change management system was in place for projects that would have allowed them to record changes consistently. Nevertheless, the authors' inferences from the data gathered from the online survey suggested that a formal change system was not in operation.

Of the project managers who responded unfavourably to the survey questions asking if they had completed their projects on time and to budget, none responded favourably to having used change management systems on their projects.

This section of the online survey's final question was whether the client instigated changes. There was a mixed response to this, with 61% of project managers reporting modifications were in response to a client request. As the authors anticipated, this result in advance of the data collection and analysis stages: in any regular project, variations commonly happen, even when stakeholders have agreed to an initial scope. This finding highlights the need for stakeholders to ensure a robust change management system is operational at the project's outset.

7.3. Scope Creep Understanding

The final section of the questionnaire asked the project managers their views on poor project performance and scope creep. The first question asked the project managers to report the three most prevalent factors that prevent any project from performing. The authors purposely avoided asking the project managers to convey their opinions based on their managed projects to gain a broader understanding of the factors at play. Furthermore, the authors did not suggest reasons for project underperformance to the project managers.

When analysing the data gathered from this questionnaire section, the authors grouped the data

alongside the literature review's findings, as illustrated in Figure 5 below. Using this method, the authors could compare actual project managers' *real-life* thinking with the theoretically-derived explanations from the literature review. The x-axis data labels display the influencing factors employed by the authors to group the project managers' responses, with *resource issues* and *communication* combined into *poor project management*.

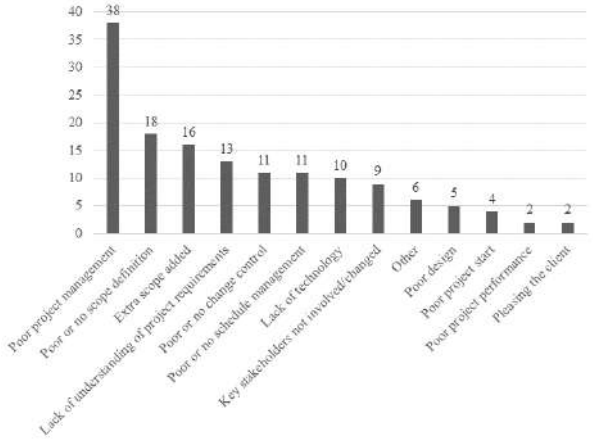


Fig. 5. Reasons for projects not performing tally

Poor project management was the most common reason for under-performing projects reported by the respondents. This finding is slightly at odds with the conclusions drawn from the literature review, where the most commonly cited reason was poor or no scope definition. However, the authors included communication and resource issues in their tally in Figure 6 below.

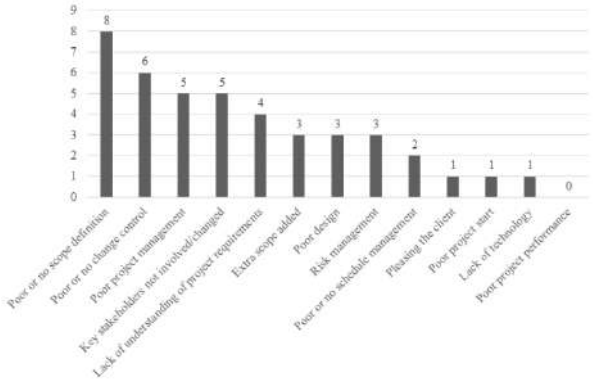


Fig. 6. Literature review's findings tally

The literature review tally presented in the figure shows the commonality of the findings in the top reasons, with stakeholders being an anomaly. In contrast to the literature review's conclusions, the project managers did not perceive stakeholder involvement as an influential factor affecting project performance. The size and type of the projects managed by the project managers could contribute to this result, but to be confident, the authors would need to conduct another study. Although some project managers did identify change management as a factor, the authors concluded it was not of sufficient importance because the project managers did not report it widely enough. This conclusion supports the project managers' responses in the early section of the questionnaire, during which the influence of change management systems on project success received the most unfavourable responses. However, the authors identified an unanticipated divergence in the project managers' opinions. They discovered a variation in the project managers' views between those who responded favourably to delivering their projects on time and within budget and those who responded less favourably.

Figure 7 below shows that the project managers considered *extra scope added* and *poor schedule management* significant contributory factors to poor project performance. The managers who did not deliver projects on time or within budget disagreed. The same managers reported the absence of change management as a contributory factor, while those who considered it less important perceived their projects had performed well.

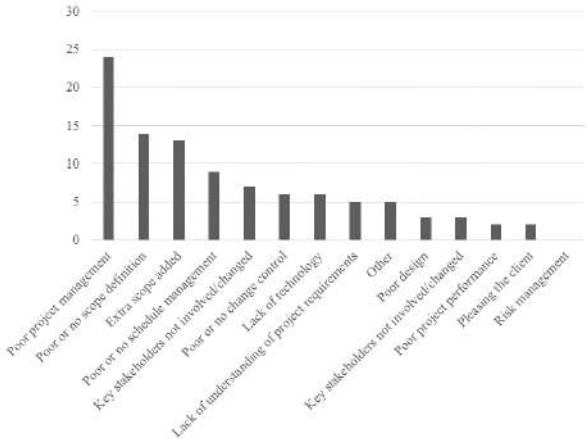


Fig. 7. Projects completed on time and within budget tally

The questionnaire also presented questions to ascertain the project managers' understanding of what is meant by the phrase *scope creep*. Ninety per cent (90%) of the project managers surveyed reported they did understand; however, out of 147 potential reasons listed in the questionnaire for poor project performance, scope creep was listed only six times. This result would indicate that the project managers do not understand the whole meaning of scope creep, or they do not consider it a significant factor adversely affecting project performance.

The final question asked the project managers to report their top five causes of scope creep (or unapproved scope changes). The authors grouped the project managers' responses in the same format as the previous question to allow them to compare with the literature review's results. Only one project manager did not respond to this question, which was understandable as they were new to project management and commented that they did not understand the phrase *scope creep*.

The data presented in Figure 8 below highlights some exciting differences concerning the reasons for poor project performance. The managers reported a lack of understanding of project requirements as the leading cause of scope creep when it was ranked only fourth for poor project performance. Once again, this finding suggests that the project managers do not consider scope creep to be one of the significant factors adversely affecting project outcomes. Schedule management was low on the reasons given for scope creep while holding a middle ranking for poor project performance.

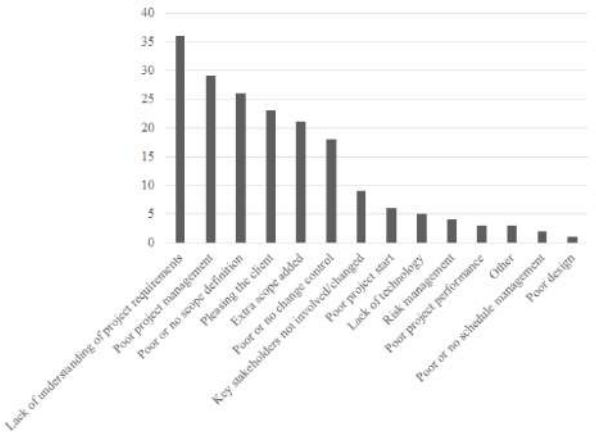


Fig. 8. Ranked reasons for scope creep/unapproved changes total tally

One significant difference in the data presented in Figure 8 is the number of times the managers reported *pleasing the client* was a potential cause of scope creep. In Figure 7 displaying the data for poor project performance, the managers almost ignore this. When the authors examined this phenomenon in more detail, they discovered that for all incidents when the project managers reported the client as the primary reason for scope creep, 87% of the project managers had ten years or less industrial experience and 78% with six years or less. These deductions indicate more experienced managers consider clients as being much less of a contributory factor to scope creep, possibly because of their higher client and stakeholder management competencies and skills.

7.4. Historical Project Performance

The authors completed a desktop study of archived files for the company's completed projects to extract critical quantitative data illustrating how well the company's project managers had delivered their projects. Of the 201 past projects studied by the authors, 93 evidenced cost rises compared to the original budget. Only 18% of these projects had any additional payments authorised to the project by the client, effectively making these projects less profitable than planned and turning them into loss-making business enterprises. Regrettably, because of commercial sensitivity, the authors were not granted access to the documented reasons behind these cost increases. However, it was clear that these underperforming projects did not include an effective change management system as part of the project management toolbox.

Only 17% had documentation to confirm the client authorised additional payments above the original PO value when the authors explored all projects for which data was available. The authors did not anticipate such a low percentage considering the complex nature of the work undertaken by the company. The authors postulated they would not have uncovered any documented changes in the remaining 83% of projects included in the sample.

To further exacerbate the authors' unanticipated discovery, the company had classified a number of these projects without documented change as *call-off contracts*, meaning the company had issued an initial PO against a contractual agreement with additional POs agreed as the scope changed. The implications of the authors' discovery mean project managers likely authorised more POs for call-off contracts rather than documenting them as a product of change orders.

7.5. Limitations

Limitations of this research method became apparent as the data was collected and collated.

First, because the case study company did not grant the authors complete access to its archive of past projects, the authors could only investigate a narrowly defined range of possible factors affecting the performance of the sample projects. As a result, on a few occasions, the authors made some inferences; however, in most cases, these were later validated by the project managers' responses to the online survey questions.

Second, the authors examined the specific project performance criteria from a purely financial performance basis. While many theorists, practitioners, and business analysts consider this the ideal approach, other researchers, such as Belassi and Tukel (1996), have proposed several other indicators not considered by the authors.

8. Discussion

Analysis of the project managers' responses to the questions in the questionnaire elicited some exciting insights into current project management thinking, especially related to scope creep and the factors affecting project success. The authors anticipated some project managers' responses, but not all. For example, the authors identified poor project management practices as the most significant reasons for poor project performance and dysfunctional complications associated with the project scope. In contrast, the project managers gave change management systems an unexpectedly low prominence.

The project managers' demographics did not correlate with any apparent opinions or biases: responses from one group were no more distinguishable than others. The authors initially assumed that the project managers' professional experience levels would affect their views concerning project performance. Yet, the data analysis indicated that project managers with less than ten years of experience responded similarly to those with more experience. Therefore, the authors concluded the professional experience of early career project managers does not change over time.

When the authors considered the data arising from the question in the questionnaire that focused on the project managers' reported reasons why their projects performed poorly, a couple of anticipated outcomes emerged. When looking at the straightforward responses to this question, the factor that contributed most significantly to poor project performance was poor project management or poor performance in activities associated with project management not separately classified, such as communication and resourcing. Next in order of impactfulness were reasons involving scope management, whether at the scope definition stage or additional scope arising throughout the project's lifetime.

The literature review's findings identified several contributory factors associated with scope definition and management as the leading causes of scope creep. As anticipated, the authors uncovered the same conclusions

from their analysis of the data collected during their study. However, the authors discovered a factor not identified in the literature review: the stakeholders' general lack of understanding of project requirements. This situation can arise because clients or contractors lack knowledge or, as is often the case, share the same lack of experience. In such cases, the client and contractor have different opinions concerning the project's outcomes; even when both parties initially agreed to the definitively defined scope creep, they often demonstrated conflicting expectations on what the project scope would deliver. Project managers can potentially reduce this risk by arranging a comprehensive project start-up meeting with input from all stakeholders. The surveyed project managers responded favourably to this question, with more than 80% responding either *always* or *usually* when asked if all stakeholders had ratified the project scope before work commenced. When the client and contractor do not share a common understanding of the initial project scope, this is crucial to achieving project success, avoiding scope creep, and agreeing to change requests.

When the authors separated the project managers' responses according to who did and did not deliver their projects on time and within budget, some noticeable exceptions became apparent. Both groups identified poor project management as the most significant contributory factor. In contrast, the project managers who responded unfavourably gave poor no change control as the next most common factor. Although there were only a few managers in the latter group, the implication of this outcome illustrates they understood the importance of change control because respondents neglected to report that the extra scope added was not a reason.

Despite the authors considering change management one of the most effective tools in controlling scope creep, the project managers surprisingly gave little attention to this influential factor. The survey question about using change management systems had the most unfavourable responses. More than 60% of respondents indicated that they did not consistently use change management systems when coordinating their projects. This result became more evident when the authors analysed the desktop study data. Of the 201 projects with archived data, 93 had final costs more significant than the original budget, 13% of which included documented additional payments from the client. This finding suggests clients did not submit an official written notification in support of their change requests, assuming the project scope in the original contact documentation was accurate. As indicated earlier, the case study company did not permit the authors to interrogate the full extent of their project archive. Even though the authors could not elicit a definitive conclusion about the application of change management systems from the project managers' questionnaire responses, they postulated it was unreasonable to assume the project managers did not use change management tools.

The authors discovered evidence to suggest there was a lack of understanding among the project managers about scope creep. While the empirical evidence indicates that the project managers understood scope creep to include the extra scope added during project execution, the project managers did not seem to acknowledge that this additional scope needed to be identified or measured. In a somewhat contradictory manner, the project manager's questionnaire responses did seem to suggest they had accepted their projects would change by the absorption of negatively impacting unavoidable scope creep.

It would be a rare occurrence for a construction project with a clearly defined scope at its outset to be delivered by the stakeholders without any change. It is not uncommon for stakeholders to change the project's scope throughout a project's lifecycle. These official changes to the project's scope do not equate to scope creep: they only become scope creep when the project manager does not identify or control them.

It is an accepted construction contract administration practice for contractors and project managers to receive reasonable, documented client requests to change live projects. This study, however, has identified the adverse impacts of undocumented change requests when submitted by a client to an early career project manager. Client change requests are within the client's contractual rights, whether for additional scope, revisions to the project delivery schedule, or any other essential change. However, the authors have identified that undesirable complications, such as escalating costs and longer project durations, can arise when these requests are not quantified or submitted using official documentation. These complexities are especially detrimental to projects when a change management system is notably absent.

9. Conclusion

The authors have concluded that scope creep can become a significant dysfunctional factor affecting projects because stakeholders do not seem to possess the prerequisite knowledge to understand it or the competencies to manage it effectively. The study's findings underline four influential factors that influence the project managers' abilities to manage scope creep successfully: clear understanding of the project scope, stakeholder involvement at all stages, schedule and budget management, and change management.

The project managers' questionnaire responses confirmed that poor or absent scope management is a dominant factor in scope creep's manifestation. The authors' observation that change, schedule, and budget management were not reported by the project managers more prominently indicates that the surveyed project managers lack a detailed understanding of scope creep. The project managers seemed to be confusing scope creep with added scope. Added scope, scope development, or scope growth constitute a natural dimension to a live project and do not necessarily equate to undesirable outcomes, provided project managers identify and manage them appropriately. This circumstance leads to the unwanted manifestation of scope creep, which becomes problematic when the additional scope remains unrecognised. The authors considered the project managers' ambivalence towards change management to be a significant factor explaining their underperforming projects.

While having a definitive baseline scope is critical to project success, it must go hand-in-hand with a regular schedule of budget reviews alongside progression measurement to identify unapproved changes. When the client requests changes of this nature, the project manager should document them using an agreed change

management system to monitor their impact on the agreed budget and schedule. Only when project managers implement these essential project management procedures will they acquire confidence, knowing they have taken appropriate, positive steps to minimise the adverse effects of scope creep.

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Dr Allan Osborne is an Associate Professor in Project Management in the Department of Architecture and Built Environment, Northumbria University, Newcastle upon Tyne, United Kingdom. Allan's research interests include project team dynamics, project leadership, project governance, social conflict, inter-organisational relations theory, and teaching and learning. He has successfully supervised over a dozen PhD candidates in construction and project management. Allan has acquired an array of academic leadership experience, including Faculty Director of Postgraduate Research, Director of Education, Head of Subject for Construction and Project Management, Teaching Excellence Framework and Student Outcomes Lead, and Postgraduate and Undergraduate Programme Leader.

Dr Kelechi Anyigor is an Assistant Professor in Project Management in the Department of Architecture and Built Environment, Northumbria University, Newcastle upon Tyne, United Kingdom. Before taking up an academic post, Kelechi was Head of the Research and Training Department of a UK-based charity with operations in Asia and Africa. His research interests include the interplay of deprived urban communities' social, economic, and environmental aspects to deliver sustainable improvement projects. He is also interested in project leadership and knowledge management for effective project delivery. Kelechi is the Programme Leader for the Department's Postgraduate Project Management Framework at Northumbria University's Newcastle and Amsterdam campuses.

Mr Martin Nesbitt is a postgraduate student in the Department of Mechanical and Construction Engineering, Northumbria University, Newcastle upon Tyne, United Kingdom. Martin has a long-established engineering project management career, working in senior leadership roles in the gas and oil sector.

Paper no. 118

Intangible Success Factors Key to Marine Projects Performance – A Bipolar Case Study

Vivekanand M. Bankolli[1] and Karuna Jain[2]
[1]CEO, Jolle Group, Examba, Chikodi, Dist- Belgaum, Karnataka, India, E-mail: vivekarati@gmail.com
[2]Professor, Sailesh J. Mehta School of Management, I.I.T.Bombay, Powai, Dist - Mumbai, Maharashtra, India, E-mail : kjain@iitb.ac.in

Abstract: Project management (PM) is enabling organizations to add significant value to expand their business and achieve the set strategic goals. However, fewer marine projects in India achieve the desired success, despite project managers adapting the latest project processes. Thus, indicating gaps in present practices which need to be identified and included in present practices. Industry experts and project participants attribute this to unrecognized human factors attributes which are veiled in the present PM practices and defined processes, thus impacting the project performance. This paper, therefore, attempts to understand these imperceptible issues in PM and find whether intangible factors contribute to project success and improve project performance through exploratory and empirical bipolar case studies.

The paper validates the insufficiencies identified which are attributable and can be distinctly categorized into tangible and intangible factors. Therefore, the study concludes with success criteria and factors influencing the project performance. The intangible factors present in the system play a vital role in achieving the pre-set project performance against the success criteria. However standalone intangible factors cannot assure the project performance, since secondary success criteria and tangible factors being the primary success criteria governing the project deliverables. Embedding these factors into the present PM practices will enable the project team to achieve the intended performance with significant benefits.

Keywords: Project performance, Success criteria, Tangible factors, Intangible factors, PM.

1. Introduction

Project management (PM) came into existence around 5000 years ago and has evolved as a vital value-adding managerial discipline to achieve the set strategic objectives, yet very few projects accomplish the defined project success. The reason is project managers are incessantly confronted with numerous issues and challenges whilst executing the projects known as "messes" (Ackoff, 1994). Projects are undertaken to achieve deliverables, defined by the "iron triangle" (Atkinson, 1999) – project, quality, cost, scope, and time. Achieving these deliverables entails managing project processes, broadly classified into two major groups as tangible and intangible factors, which encompasses all the knowledge areas (PMBOK, 2013). Tangible factors are quantifiable, such as scope, time, cost, and quality, which directly influence the project. However Intangible factors are difficult to define but can be differentiated and categorized, as factors embedded in the system due to the presence of human resources. They influence projects indirectly, such as the way of communication, type of procurement, teamwork, leadership, innovation, resolution of issues, approach towards risk, and environmental factors.

Project success is dependent upon how issues, challenges, and uncertainties are identified and attended to for its resolution. Therefore, this study explores identify and addresses them from a different perspective, which is atypical to each industry. The objective is to identify and evaluate the role and the effect of tangible and intangible factors on the project performance in the marine industry- success criteria being, time, cost, scope, and quality.

PM literature reveals that less study has been undertaken in the marine (Shipbuilding and oil & gas construction) industry, with no formal study in the Indian context. Marine projects in India are affected by time as well as cost overruns, placing the project viability at risk (KPMG-PMI, 2013). This indicates that organizations are still facing challenges in the execution of projects to meet the required success criteria, time, cost, scope, and quality. These challenges were identified as insufficiencies in the present practices by the marine project managers. With the motive to enhance the project success rate, empirical studies were carried out to address these insufficiencies and provide insights to the project practitioners. Earlier studies on project success or failure are clustered broadly under success criteria, cooperative and collaborative approach, Contract type, environment, and typology.

Success criteria - Projects are acknowledged as successful if completed on time and within budget. Several studies consider project success criteria as meeting predefined targets of cost, time, and quality (Broome and Perry, 2002, Anton and Yao, 1990) also known as the "iron triangle" (Atkinson, 1999). Few authors suggested benchmarking, customer satisfaction, goal accomplishment, and cost modelling (Barber, 2004, Jugdev and Muller, 2005, Olugboyega and Windapo (2019), Shenhar et al, 2001) as success criteria.

Cooperative and collaborative approach (CCA) - CCA within the project team is vital for the project success, integration of teams within organizations, clients, and contractors (Rodrigues and Williams, 1996, Davenport, 1998, Vaaland, 2014), integration of intra-organization team members (Caron, 1998), information and system integration for a collaborative approach (Lee, 2001, Murphy and Simon, 2002, Serra et. al. (2021), Wonzy et al., 2009), project manager leadership styles (Turner, 2005). The factors identified are teamwork, risk management, information sharing, system learning, trust, incentives, project manager leadership, open and effective communication, innovation, and motivation. Most of the studies focused on tangible, cost, and schedule aspects of success criteria. Few indicated the necessity of intangible factors as the success criteria to enable CCA to lead to the project's success.

Type of contract – Several studies indicate that type of contract also influences the project performance, cost is the success criterion. Formulation of the contract defines the type of contract, and the type of contract influences the project performance. The contracts are mostly formed based on cost (Chappell et al., 2001, Yildirim, 2004). Hence projects defined by the type of contract (EPC, EPCM, EPM, etc.) are governed by cost. Few papers have also discussed project performance constructed on cost-based risk management (Broome and Perry, 2002, Ward and Chapman 2008, Fuentes-Bargues et al. 2020). Taking a different approach, Ahola et al. (2008), proposed a value-based type of contract. Value creation is defined as the difference between the benefits and sacrifices acceptable to the customer. Contracts give significance to a mix of tangible and intangible factors; short terms contracts typically ascribe more value to tangible factors and long-term contracts to intangible factors.

Success criteria were identified as cost and schedule and the critical success factors as cost, time, quality, scope, costs established on risk, incentives, bidders involved in the competition, and value creation for the customer. Most of the factors identified were related to cost and schedule which are tangible. However, a few studies have recorded intangible factors such as customer satisfaction and value creation.

Project environment – The project environment (Cleland and David, 1999, Gary and Larson, 2000, Meredith and Mantel, 2000, PMBOK, 2013) plays critical role in influencing the project's success or failure. All projects are subjected to external and internal environmental factors. Internal and external factors (Chase, 2005, Long, 2009) come into play thus making the projects more complex and vulnerable to failure. Therefore, it is necessary to understand the interplay of external factors to devise an appropriate resolution.

Earlier studies discuss both internal and external factors as supplementing each other (Ward and Chapman 2003, Chase Michael S, 2005, Engwall, 2003, Fleming, 1967, Joseph et al., 2010, Shambaugh, 1996, Soderholm, 2008), Serra et. al. (2021), Tur and Bayindir, (2019)). The specific internal and external factors identified are; External – Government policies internal to the country and policies formulated with specific foreign countries, relationships with foreign countries, strategic alliances, regional power, site location, risk management, etc. Internal – Organization policies and procedures, processes, PM knowledge, project manager, skills of project team members, organization structure, and culture.

The ecological aspects impacting the environment have been addressed by Hochschorner and Finnveden (2006) & Hochschorner and Goran (2006). A model of life cycle assessment (LCA) has been proposed to consider the product life cycle to be included in the contract. To make it effective, national and international level policies need to be framed, considering the project life cycle analysis and life cycle economic costing. Currently, businesses happen across countries, and ecological issues have assumed global proportions from both business and social perspectives. Factors influencing the project performance were indicated as training, knowledge sharing, the inclusion of LCA requirements in contracts, and international cooperation.

Typology – Few studies have suggested the need for different PM approaches in managing projects. It was proposed that the projects should be clustered and classified under similar groups, to improve the project performance. Typology theory suggested are based on; two-dimensional cost and time, resources, management styles of the project manager, success repeatability and

organization structure (Doty and Glick, 1994, Irani and Love, 2000, Luu et al., 2008, Shenhar and Widerman, R. M, 2000, Shenhar and Dvir, 1999, Shenhar et al., 2001). In contrast, benchmarking (Barbar, 2004) as typology has also been defined based on the lesson learned of the industry standards. The success factors in the benchmarking typology vary as per the learning curve and the rate of evolution of better practices.

It is noted that limited formal study has been undertaken on the marine industry concerning project performance. The only study was undertaken (Olsen et al., 2005), that discusses the CCA in procurement. A study by Olsen et al. (2005) and Mishra and Bhandari. (2018), identifies possible improvements in project performance based on contracts and governance mechanisms for handling complex procurements through CCA. A study by Bankolli and Jain, (2017), through project participants, survey identified the factors influencing performance in the marine industry. The identified factors which influence the project performance from the literature analysis can be clustered and grouped as tangible and intangibles. The factors identified are as follows: -

a. Tangibles – Cost, time, quality, and scope

b. Intangibles - Project manager skills, trust communication, customer satisfaction, teamwork, team skills, collocated teams, risk management, information sharing, and learning curve, relationship with foreign countries, strategic alliances, regional power, organization culture, structure, training, and knowledge sharing within the project team.

Earlier studies have considered time, cost, scope, and quality as the success criteria; very few have indicated the requirement to look beyond these criteria (time, scope, and cost). The only additional criterion suggested is benchmarking to the organization best in the industry, enabling influencing the project performance. In addition, factors such as project goal and customer satisfaction have been identified for achieving success criteria. Despite the studies, ambiguities still exist in defining the specific success criteria in the construction industry. However, no such attempts have even been made to identify such criteria for the marine industry and specifically in the Indian context. The critical success factors identified by the earlier studies are from the construction industry, except for the study by Alka et,al (2021) and Olsen et al. (2005), wherein the factors identified has limitation to the formation of the contract.

A study by Bankolli and Jain (2017), identified 04 success criteria and 14 success factors (SFs) in marine projects. The identified success criteria are Time, cost, quality, and scope, and the success factors were into two categories as: Tangible - Time, Cost, scope, and quality, the Intangible factors - Project manager's leadership skills, Trust, Communications, Environment, Motivation, Project participants' skills, Ethics and Moral values, Contract negotiation, Project stakeholder analysis, and Innovation. These factors as per the ranking in descending order are shown in Fig 1.

The identified success criteria remained the same as Time, Cost, Scope, and Quality in alignment with other industries. These criteria were also identified as the success factors which contributed to the project performance for project success when measured against the success criteria.

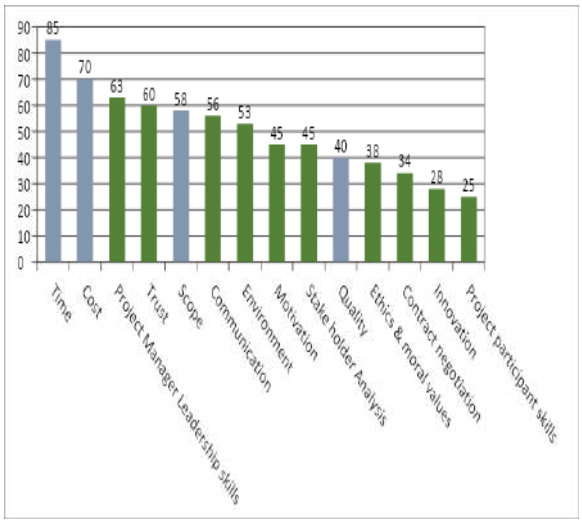

Fig. 1. Tangible and Intangible success factors (Source: Bankolli and Jain, 2017)

The earlier studies indicated insufficiencies in the present practices which are summarized as follows: -

a. Fewer studies have been undertaken on the marine projects in shipbuilding and oil & gas sectors with regard to the project performance, and no formal study conducted in the Indian context.

b. Studies undertaken are independent and mutually exclusive, hence holistic approach across knowledge areas toward PM necessary

c. Need to identify appropriate success criteria and classify factors influencing project performance in Indian marine projects with empirical primary data.

The validation of the success criteria, factors, and their impact on the project performance was undertaken by empirical study.

2. Methodology

A hybrid research method, an exploratory study (Yin,2003, Eisenhardt, 1989) and descriptive research are carried out through the Bipolar case study method to validate and check the interplay of identified factors by Bankolli & Jain (2017). The research included qualitative and quantitative methods with inclusion of semi-structured (Cresswell, 2007, Yin 2003, Baxter 2008) open-ended questions to capture the micro details of the project dynamics, the framework of the research methodology is indicated in Fig 2. The adequacy of the factors identified and for any additional factors that affect project performance was undertaken by Semi-structured interviews (Cresswell, 2007, Yin 2003, Baxter 2008) with project participants (samples) across the project channel members (Fig 3). The structuring of the identified factors and building of theory from the

findings was undertaken as suggested by Eisenhardt (1989, 2007).

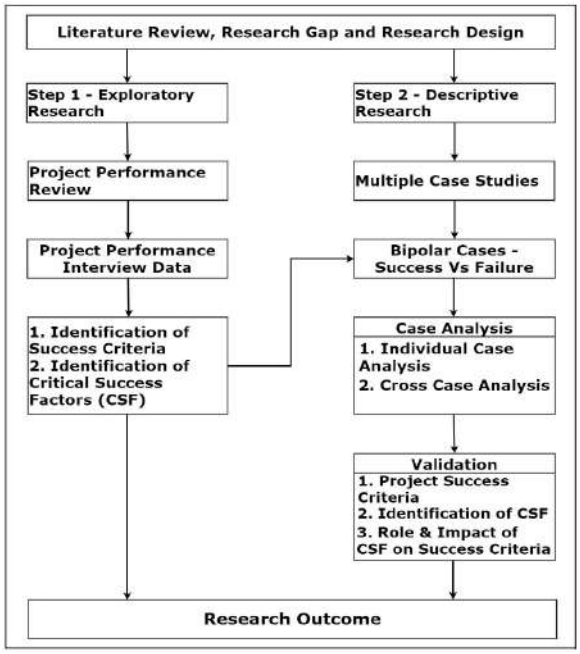

Fig. 2. Research methodology framework

A questionnaire was developed based on the tangible and intangible factors identified in the literature and verified by project experts to undertake the empirical study using bipolar cases. These identified tangible and intangible factors (Bankolli & Jain 2017) were considered for the evaluation of the project performance of the projects in the cases.

Fig. 3. Project channel members (Source: Bankolli and Jain, 2017)

3. Case Study

A bipolar case study was considered for validation and checking for any additional success criteria and success factors influencing project performance. The bipolar cases were identified as per the respective project success or failure when measured against the success criteria defined by Bankolli and Jain, 2017 for the study. Two cases with similar scope of supply and the same channel members (see Fig 3) were considered for generalization (Creswell, 2007, Eisenharldt, 2007 and Yin, 2003). The channel members are the different organizations participating in the value added to a product or service to achieve the objectives set by the end user. In both cases, the channel members remained the same, except for the main contractor. The main contractor in these two cases were the key contributors impacting the project performance. Semi-structured interview with project participants abreast of the project channel members was undertaken at all levels of the organization structure. 42 and 44 samples for Case A & B respectively were considered to understand and collect the primary data which provided insights into the project and management of the project. The selection of samples from the population were based on Polkinghorne (1989) and as recommended by Cresswell, (2003). The sample size was based on the repeatability and saturation of the outcomes as defined by Polkinghorne (1989).

An in-depth study of the main contractor (Yard /shipbuilder), project operations, and organizational culture was also undertaken to understand the interplay of the success factors on success criteria.

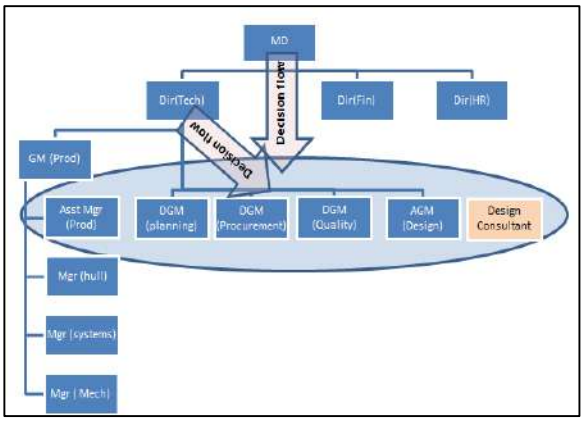

Fig. 4. Case A - Project organization and management

In the channel members, main contractors also known as shipbuilder/ yard, are the main engineering and construction (E&C) contractor, who accepted the shipbuilding construction projects and are responsible for the delivery of vessel. In this study, similar project of the main contractors, wherein same original equipment manufacturer (OEM) is considered to develop the theory for generalization. As per the contract, scope of the project in both cases was to supply and commission the stern gear system. The stern gear system is a critical part of the vessel being built by the main contractor.

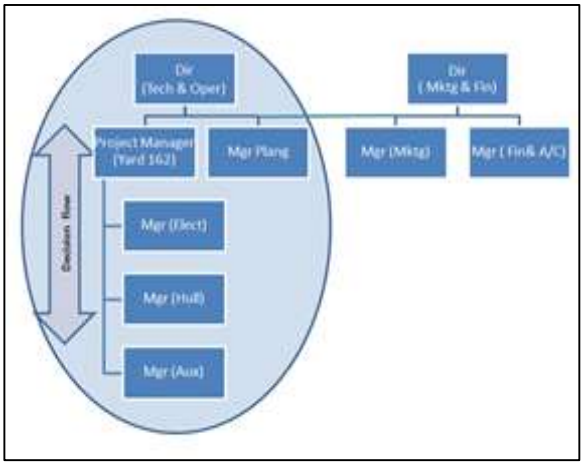

Fig. 5. Case B - Project organization and management

Though the scope of the project was fixed in both cases, the project creep was observed in Case A, however, neither additional compensation nor time was extended for the additional scope. The initial price by the yard to OEM in Case A was lesser compared to Case B. It is to be noted that in Case B, additional 20 percent of the contract value was released to the OEM on submission by the OEM for the wrong estimation despite the acceptance of the contract. Contract type: Engineering Procurement and Management (EPM) which included Installation, commissioning & supervision, channel members remain the same, and the duration in both cases was similar. However, in Case A OEM expertise was used for design requirements without additional cost instead of engineering consultant, in contrast to Case B wherein engineering consultant was indirectly part of the team. The Organization structure in both the cases was different, in Case A it was functional as shown in Fig 4 against a strong matrix in Case B shown in Fig 5. The details of the cases are provided in table 1.

Table 1. Case details

Criteria	Case A		Case B	
	Data/ Information	**Remarks**	**Data/ Information**	**Remarks**
Scope	Supply & commissioning of equipment (Stern gear system)	Fixed – Yet increased without additional cost and schedule	Supply & commissioning of equipment (Stern gear system) and STP	Fixed
Cost (Rs)	2.75 Crores	Fixed (51.5 lakhs/ship set) for 5 ship sets	1.26 Crores (90Lakhs for stern gear system)	Fixed (60 lakhs/ship set) for 02 ship sets. 3 lakhs/ ship set (20 percent) extra STP due to wrong estimation by OEM
Time (Project duration)	08 months for 1st Ship set 10 months for 2nd & 3rd ship set 12 months for the last two ship sets	Contractual terms - Project duration –from the release of PO and advance. LOI provided. PO and advance payment delayed by 02 and 07 weeks. Delivery dates not changed	08 months for both ship sets	Contractual terms - PO and advance released in time
Contract type	EPM	OEM expertise is used for design requirements without any extra costs.	EPM	The consultant was involved in design issues as required by end-user
Organization structure (OS)	Functional (Kerzner, 2013, PMBOK, 2008)	The OS restricted the PM functions thereby affecting the project execution for the desired success criteria	Strong matrix (Kerzner, 2013, PMBOK, 2008), with a lean team	OS enhanced the authority of the project manager, hence better resolution of issues.
Channel members	Four	Engg consultant not part of the team during execution phase along with other stakeholders.	Four	Engg consultant was directly handled by the main contractor

4. Case Analysis

Organization and its functioning adopted by the main contractor in managing their respective case projects affected the project performance. The skills of the project managers in both cases were a contrasting in nature; in the case of A, the project manager was less skilled due to inexperience in the PM, also the project manager was at a lower level in the organizational hierarchy as shown in Fig 3. The project manager in Case B was experienced, skilled and at a higher level in the organization hierarchy, as indicated in Fig 4. The communication in Case A was less and was restricted to formal type, however in Case B the communication was adequate and was of both formal and informal type. The

organizational structure played a critical role in the PM approach and same contributed to the interplay of the success factors towards the project performance. When the channel partner's relationship was compared between the two cases, Case A lacked any formal and informal requests for issue resolutions, whereas in Case B it was observed with higher a degree of participants' satisfaction, this was due to the main contractor attending to differences/opinions on priority resulting in a better relationship. Stakeholder analysis and management were given the least importance in Case A in comparison to Case B. In Case B, the project team had undertaken the stakeholder analysis and the project requirements of stakeholders were taken care of in the contract. The decision-making vested only with top management in Case A which led to an adverse effect on the project team's success but in Case B the project manager and team were empowered to take decisions in their capacity to ensure that the project objectives are met in time, and this yielded in better project performance. Consideration of cost as a success criterion in Case A constrained positive interplay of intangible factors both inter and intra organization thus leading to the project failure in contrast to Case B. In Case B customer satisfaction, schedule, and flexibility in the scope enhanced the positive interplay of intangible factors both inter and intra organization thus leading to project success. Due to the absence of intangible interplay, the cooperative and collaborative approach among the project team members was less observed in Case A. This affected the integration of stakeholders for a unified focus on a common objective, thereby hampering the project's success. However, in Case B the main contractor un-intently did engage in the channel partner integration for the business project objectives even prior to the kick-off of the project, since project negotiation.

External environmental factors did not have much influence on the project outcomes, however, in both cases, internal environmental factors did impact the project outcome. The project in Case A was failure, conversely to Case B which was a success due to a healthy internal environment and organizational structure which was contrasting in Case A.

There were no considerations with regards to the ecological factors neither in the contract nor in the policies formulated in both cases. Moreover, the study did not notice any negative influence from the type of contract. However, in Case B, the contract included the supply of sewage treatment plant (STP) equipment required for ecological compliance by the International Maritime Organization (IMO). The main contractor on request from the end-user agreed upon and supplied equipment with higher compliance (Scope creep) without any additional cost impact to subsequent channel members or the OEM. This is despite the main contractor providing additional price post award of the contract for the wrong estimation by the OEM. This enabled both end users and main contractors to meet a higher degree of ecological compliance and social commitment.

The contract negotiation and execution did play a vital role in project performance. In Case A, the OEM obliged the end user's insistence to participate in the bidding. OEM was reluctant to enter into the contract with the main contractor post stakeholder analysis including the main contractor. The analysis of the main contractor yielded a higher risk in the contract if undertaken. The negotiation with the main contractor was mainly based on the cost, due to high bargaining power with the main contractor as a buyer. However, in Case B, the contract negotiation was undertaken by means of collective participation of the channel partners, with an emphasis more on time and quality which formed the basis for a positive interplay of intangibles. The contract negotiation and execution in a mutually respectful and trusting environment played a vital role on project performance in the success of the project in Case B. The influence of typology on the project success could not be analysed since the main contractor in both cases did not have any classification of the projects. The study did not distinguish any influence of the type of contract on the project outcome since the type of contract remained the same in both cases.

The impact due to the type (positive/ negative) of success factors interplay, either led to success or failure of the project in their respective cases. There was a positive interplay of the tangible and intangible factors in Case B as against Case A. The project cost on completion in Case A resulted in negative profits of 23 percent for OEM, however, in Case B the estimated profits of 10 percent exceeded to 15 percent. The other performance parameter in respect to the schedule (time), a delay of 04 months (50 percent) occurred in the first ship set and this resulted in the cancellation of the last two ship sets in Case A. On contrary, there was a delay of 01 months (13 percent) which was acceptable to the end user. In relation to scope, there were 05 changes in Case A; 03 minor changes which were accepted by OEM, but 02 being major, same was not accepted, in contrast, Case B there was only 01 scope, this was with respect to the STP being supplied with higher compliance and same was well appreciated by all channel partners and other stakeholders. The vessel sailing out was delayed by 11 months out of the total duration 36 months in Case A. In Case B though there was no delay in the vessel sailing out, but commissioning of the vessel was delayed due to non-availability of berth, caused by end-user end. The project success in Case B enabled the main contractor to award of additional orders for not only of similar ship sets but also for higher segment wherein they got a direct qualification. The factors that impacted the project performance in brief, is tabulated in table 2.

Table 2. Impact of project success factors on project

	Case A		Case B	
Factors	**Data/ Information**	**Remarks**	**Data/ Information**	**Remarks**
Cost	23% cost overrun.	OEM incurred loss	OEM achieved 15% profit	10 percent was budgeted margin
Time	Delay 04 months (50 percent)	04-month delay against 08 months for first ship set.	Delayed by 13 percent	01-month delay, acceptable by stakeholders
Scope	Major 05 scope changes	03 accepted being minor, 02 not accepted by OEM	Major 05 scope changes	03 were accepted being minor, two were not accepted by OEM
Vessel sailing out	11 months delay/ 36months	Vessel schedule affected. This project also contributing factor	No delay	There was no delay in the vessel sailing out, but commissioning of the vessel was delayed due to unavailability of berth
Trust	Less trust	Channel partners did not trust the main contractor due to their reputation and inconsistency in commitments and payments	High	Informal interaction had induced trust within the participants
Decision Making	Decentralized Empowered project participants	Reduced the time and increased trust in the team.	Decentralized Empowered project participants	Reduced the time and increased trust in the team.
Motivation	Low – highly stressed team and less empowered	High attrition	High - Relaxed atmosphere	Nil attrition
Strategic difference	The last two ship set not delivered.	No future MOU and due to financial losses company has taken over.	MOU for future projects & symbiotic alliance for an additional portfolio	The Main contractor had additional orders for similar ships and for different segments.

5. Success factors interplay

The interplay of the success factors and their influence on the other success factors and project performance can be well established from the average scores received from the survey. The average tangible score provided by project participants in both cases is shown in Fig 6.

The scores indicate an average of scores of the factors that dominated and influenced the project outcome by their respective main contractor organization. In Case A, project participants of the main contractor focused more on the cost and scope of the project to enhance the project performance. Focusing on these factors affected inversely the performance of the other two tangible factors which are also the success criteria viz. time and quality. In contrary to Case B, the main contractor focused on time and quality in alignment with the end user's objective requirements. This enabled a positive effect on the remaining two tangible success factors which are the success criteria.

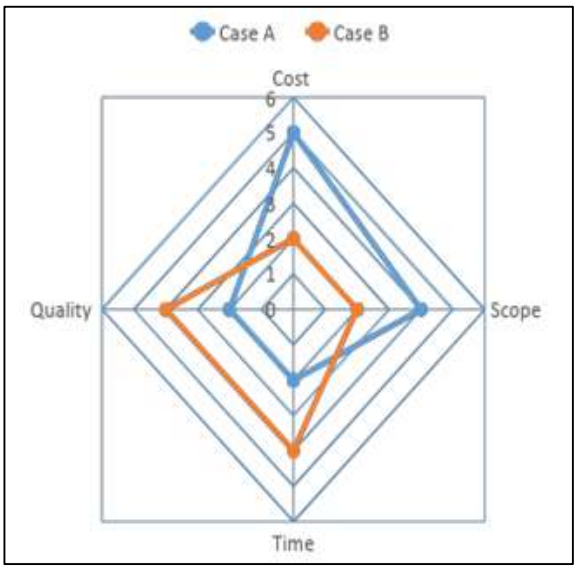

Fig. 6. Tangible success factors

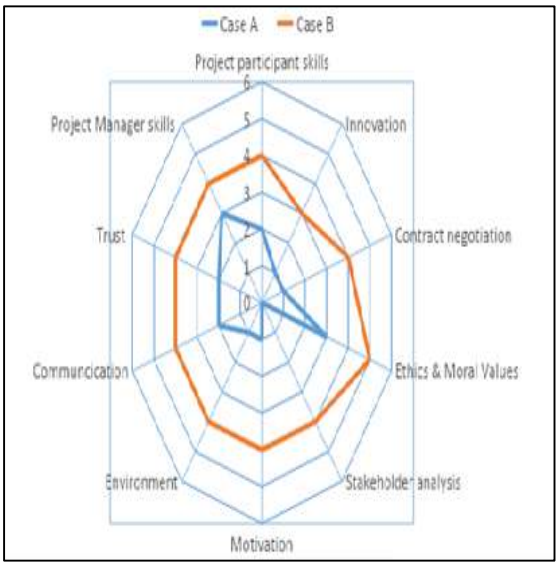

Fig. 7. Intangible success factors

This clearly indicate that interplay of tangible success factors influences the realization of the project performance as success or failure. It is also evident that controlling project cost and scope will enhance the project margins, which has been falsified by this study. In addition, the study infers that controlling the quality and time directly, not only influenced the other factors to cost and scope positively but also the time as well the quality itself. The average score of the tangible factors influencing the management of the project for both cases is indicated in the graph as shown in Fig 6.

Similarly, the average scores for the intangible success factors in both cases are indicated in the graph shown in Fig 7. The graph shows the average scores provided by project participants illustrating the influence of the intangible factors in managing the project. The average scores provided by project participants in Case B are much higher and the graph is evenly spread with a larger area against the average scores provided by the project participants of Case A. The scores indicate that PM team in Case A experienced less interplay of the intangible factors. The rigorous control of cost and scope restricted the positive interplay of the intangible factors within the project environment leading to the failure of the project performance. However, in Case B the project participants focused more on the project objectives and were in alignment with the end user's and stakeholder's requirements.

The flexibility in accommodating minor scopes is deviant from the PM approach but did enhance the positive outcome of the project performance. Consideration of the end user requirements with high ethical and moral values to meet the schedule and ensuring the quality regardless of the cost and scope influenced the positive interplay of the intangible factors. The organization structure was also a vital contributor to the project's success as it allowed the positive influence of the intangible factors in managing the project. The strong matrix with appropriate empowerment to the team in the organization enabled the positive influence on the project success in Case B as against the failure of the project in Case A. The organizational structure coupled with centralized decision-making disallowed positive interplay of the intangible factors in Case A.

6. Findings

Exploratory and descriptive studies validated the success criteria that need to be considered in the Indian marine project. The study indicated success criteria should include not only the iron triangle but also stakeholder satisfaction, mainly end-user satisfaction in the alignment of the project objective, which is vital towards the project performance. The success criteria identified by this study are time, cost, and stakeholder satisfaction. This study identified 06 critical success factors that stimulate other tangible and intangible factors responsible for the project's success. These critical success factors are tangible – Time, Cost & OS, and Intangible – OS, Project manager's skills and Experience, Trust (intent), and, Communication (informal). OS was identified as both tangible as well intangible success factors by the project participants in this study. The OS as a tangible factor provides the appropriate structure that facilitates the appointment (position in OS) of an individual with proper skill sets for the defined role. This also administers the reporting structure necessary for the project organization.

The tangible OS factor induces intangible factors and provides a facilitating environment for organization culture, internal environment, motivation, innovation, and empowerment. The application of the skill and role as an individual and the team is responsible for the intangible factors, as the standalone tangible OS will not ensure the application of the skills or the tacit knowledge which is required for project success. Therefore, OS

needs to be considered as a tangible factor that lays the foundation to stimulate the intangible factors.

In addition, to the identified critical success criteria and success factors, the following were the major findings of this study:

a. Appropriate success criteria supplement the positive interplay of tangible and intangible factors which in-turn enhances the project performance.
b. "Iron triangle" as success criteria limits the project performance hence intangible criteria need to be included in the success criteria.
c. The Positive interplay of tangible and intangible factors is necessary for project success.
d. The Intent attribute of trust was considered as a critical aspect of creating trust among the team.
e. Despite awareness about its importance, ecological issues are being ignored while making PM decisions. This needs to be attended to appropriately.
f. A holistic approach is necessary for an appropriate positive interplay of tangible and intangible factors to attain the project's success.
g. There is little awareness about the typology of projects among the project practitioners and participants, as very few organizations have adopted typology for managing projects.

7. Contribution to Theory

Several studies undertaken for Success factors in construction and general projects, are in specific knowledge areas of the PM, disengaged with each other. In addition, there are nil studies supported with empirical evidence in the marine industry. This study has extended the earlier studies with a specific theoretical contribution to the marine industry and specifically to the Indian marine industry wherein no previous formal studies are available. Earlier studies were clustered on the macro basis as stated in the literature review. Qualitative and quantitative research undertaken strengthens the findings of previous studies carried out in general engineering projects and fewer marine projects. This study's unique contribution to theory includes the validation of success criteria and the success factors on holistic macro and micro approaches.

The validation of the 04 success criteria and 14 SF's are unique contributions for any research study and specifically in the marine sector. The study indicates the need for a paradigm shift in the overall success criteria for the project: from fixed tangible criteria to a combination of flexible tangible and intangible criteria. The inference states that each project is different and should be executed accordingly; a paradigm shift from "A project is a project is a project" is practiced presently by most organizations. The cost and scope as a success factor, controlled significantly by most of organizations does affect negatively on both tangible and intangible success criteria. In contrast to earlier studies, there is a deviation from the results of the type of contract. It was found that the type of contract did not influence the project performance; however, the process of contract formulation influenced the project performance.

8. Contribution to Practice

Novel insights are gained from the study on the management of marine projects in the Indian context. Findings suggest that organizations should consciously define appropriate success criteria and clearly demarcate tangible and intangible critical success factors. Consideration of the factors identified in managing projects will ensure project success, which is objective and stakeholder oriented, as required by the project practitioners across channel members.

Deriving from the findings of this study, we recommend that along with cost and time, organizations need to align their objectives and integrate their efforts towards end user objectives as success criteria. In contrast to the existing traditional practices, the project objective needs to be evaluated in the process. If necessary, additional time and cost should accepted be provided and accepted for the scope extension to attain the end user objective.

In extension to the earlier studies, this research study suggests that within the organization, efficacy of communication can be increased by inclusion of informal channels of communication along with formal channels. Such inclusion supports in strengthening the intent aspect of trust that needs to be understood and implied in practice.

9. Limitations of the Study

The limitations of this study stem from the fact that the case studies included in this study spanned very few organizations. The limited sample mix of the organization, interview project participants and practitioners may limit the generalization of the study findings to other types of organizations. The Researcher had access to all the data and requisite information as he was part of the organization, hence information accessed may be biased. Nevertheless, due care was taken to increase the validity of findings by triangulating data from different sources. In addition, the quantification of the qualitative data is only an indication and not a precise statement, however, appropriate rigor was ensured in the research methodology by the triangulation and Delphi method along with inputs from practitioners to retain objectivity.

10. Scope for future Research

As mentioned earlier, there is very little research undertaken in the marine sector globally in regard to project success or failure with a holistic approach. This study has limitations in regard to the Indian context and the type of projects selected for the case study. Therefore, study can be extended to a global context with a comparison of the PM approach by the various countries. Further, there is scope for narrowing the research to shipbuilding and the oil and gas sector and if necessary for the government and private organizations. Further, quantitative analysis of the identified success

criteria and success factors with the correlation between them can be checked to generalize the findings.

11. Conclusion

The study concludes that insufficiencies do exist in the present PM practices in the marine industry and the same can be attributed to the absence of the right emphasis on intangible factors. These factors are necessary to enable appropriate interplay in the system for developing a cooperative and collaborative approach for the project execution.

The study conducted establishes that several intangible factors come into play during the project execution the from pre-phase of the project (during contract negotiation to authorizing a project manager to till the execution of the project). The intangible factors that are predominant in the marine industry are identified, listed, and grouped to facilitate proper analysis and systematic inclusion in the PM process. It is also found that these identified factors play a critical role in the various phases of the project.

Similar to Ahola (2007), it is established that a collaborative and cooperative environment is important for maintaining good relationships with the channel partners as observed in Case B. Nevertheless, it is to be noted that role clarity among channel partners is crucial in selecting the project alliance type.

Even though earlier studies have cited that contract type is a key factor in project performance, this study did not find any conclusive evidence of the contract type influencing project performance. Similarly, the classification of projects could not be evaluated in this study due to the non-availability of the required data, since most organizations included in this study did not have any formal typology.

The project participants and practitioners did not have adequate knowledge of typology. Further, consideration for the ecological environment was observed only in Case B. Most of the project participants and practitioners did agree that ecological considerations should be accorded importance beyond the terms specified in the contract. Such belief was tempered by the perceived impact on project costing leading them to conclude that laying many stores by ecological considerations is financially unviable.

The study provides 04 success criteria and 14 success factors that organizations may consider as suitable for the respective internal and external environments obtained in their organizations for projects to be successful. The study has further established 03 critical success criteria and 04 success factors. These factors induce and allow positive effects on other intangibles which enhance the overall project performance of the project, and the absence or negative presence of these factors affects the project performance adversely.

An appropriate organizational structure empowers project managers to utilize the available resources. The right project managerial skills will enable the manager to have a positive impact on the project environment under her/his control. To ensure that the project is in control and proceeding towards achieving the planned objective, it is necessary that proper and adequate interactive communication is carried out constantly. Communication helps in building the intent part of trust within the team and with all stakeholders critical for ensuring a successful project.

However, it should be noted that the project team's focus on the accomplishment of set project objectives than the intangibles becoming the objectives, may result in the performance reversal into project failure. This situation arising should be checked during the project execution and re-coursed if any towards to project objectives.

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LtCdr Dr. Vivekanand M Bankolli (retd.) has degree in Mechanical engineering, Post graduate diploma in Marketing Management and Ph.D (IIT B). His additional qualifications/ Certifications include, MEPC, GMP, PMP, CIPM, CeCPM, CePRM, IEDPM (GWU (USA) & NASA) and Black belt in Six sigma. He has experience in Portfolio, Project, Operation, Strategic management, and Business development. His experience involves green and brownfield projects in Power, Marine, Real Estate, Facility Management, Dairy, industries, and Education whilst in defence and corporate organizations. He was associated with organizations; Filtron Engg Ltd, Indian Navy, Larsen & Toubro Ltd, Wartsila India, Oil States Industries (I) Pvt Ltd, and JLL. Presently he is CEO of Jolly Group of companies.

Prof Karuna Jain has a degree in Electrical engineering and Ph.D. from IIT Kharagpur. Presently she is a professor at IIT Bombay - Shailesh J. Mehta School of Management with more than 35 years of experience. She was Director of NITIE Mumbai for six years plus. Her research interests are in Technology & Innovation Management, Technology Audits, Technology & Innovation Policies, Intellectual Property Management, Application of Patinformatics for business discussion, Project management, and Application of supply chain management. Her teaching interest is Strategic management of technology, Management of R&D and Innovation, Project Management, Management of Technology Transfer, and Intellectual Property management.

Paper no. 120

Enhancing the Sustainability of Low Carbon Steel by Controlling the Annealing Temperature Using N_2 Gas

Safwan Al-Qawabah[1], Nabeel Abo Shaban[2]
[1]Mechanical Engineering Department, Al-Zaytoonah University of Jordan, Amman, Jordan, E-mail: safwan.q@zuj.edu.jo (corresponding author)
[2]Mechanical Engineering Department, Al-Zaytoonah University of Jordan, Amman, Jordan

Abstract: In this study, mild steel (low carbon) is widely used in industry in many traditional applications, structural steel is the premier green construction material, it has high recycling rate exceed those of any other construction material, however, one of important issues is to enhance of low carbon steel properties, then it will be used instead of high carbon steel, so the effect of annealing process using N_2 gas at constant flowrate 2.5 L/hr. and 880 ˚C, varying holding times, 8, 16, 24, and 32 hr. on microstructure, microhardnes, thermal conductivity, and electrical resistance is performed, a pronounce finding are; increase in the average grain size, decrease in the thermal conductivity, and increasing in the electrical resistance, so the sustainability of low carbon steel will increase especially where the low carbon is recycled.

Keywords: annealing temperature, mild steel, microhardness, surface finish.

1. Introduction

Steel can be recycled multi times compared to other product as well as the Co_2 emissions is also low compared to other types of steel. Today plain carbon steel is the most used steel which has a 1.5 % carbon in maximum, where the low carbon steel contains 0.15% to 0.45% carbon. On the other hand, it satisfies the required mechanical properties i.e. ductility, low tensile stress and this due to low carbon content. low carbon steel can be heat treated to enhance its mechanical characteristics, more over certain elements can be added to enhance its mechanical properties. Other processes as carburizing nit riding that can enhance the surface properties like surface finish and surface hardness. Kumar (2015) reported that many heat treatment process require a precise control of temperature and the energy used from 2% to 15% from the total production cost. (Bai et.al., 2014) reported that annealing in nitrogen gas resulted in enhancing the mechanical properties regardless of annealing temperature, where (Zhou et al., 2016) reported that nitrogen-induced planar slip enhance the dislocation transport of hydrogen. (Zhang et. al., 2017) revealed that N_2 gas facilities the primary austenite formation in the heat affected zone (HAZ). (Ochoa et. al., 2013) reported that low energy noble gases pretreatment increases the diffusion of N_2. (Shahri et. al., 2016) reported that decreasing the grain size improve the hardness of nitride layer. (Hosseini et.al. ,2016) large grain size and nitride precipitations will increase the N_2 loss. (Nikiforov et.al., 2017) reported that the substantial decrease in the diffusion coefficients. Now a days annealing treatments in high temperature N_2 are performed on stainless steel alloys to enhance the hardness and mechanical characteristics as reported in,(Akita et al., 2015).The use of N_2 gas as a shielded resulted in improving the corrosion resistance, (Lai et al., 2016). (Zheng et al., 2016) reported that depth to width ration in welding process is affected by N_2 and this due to change of surface tension temperature coefficient of molten metal area. (Taweejun and Kanchanomai, 2015) reported that high N_2 content in the austenite in low carbon steel resulted in reducing the hardness values and the strength. (Zhu et.al., 2017) reported that the addition of N_2 increase the mechanical strength and its ductility. (Deepashri et. al., 2006) revealed that 1% of N_2 is needed to increase the weldment strength and it consistent with (Nabav et. al., 2015) study. (Mubarak et. al., 2006) reported that the increase in N_2 flow decrease the surface roughness. (Pawar and Krishnamoorthy (2011) study the N_2 as a shield gas to improve the corrosion resistance of stainless steel. (Keskitalo et. al., 2015) revealed that using N_2 show less effects on the hardness but increase the ductility of steel. (Al-Qawabeha, 2007) reported that the roller burnishing process affect the surface layer microhardness of carbon steel.

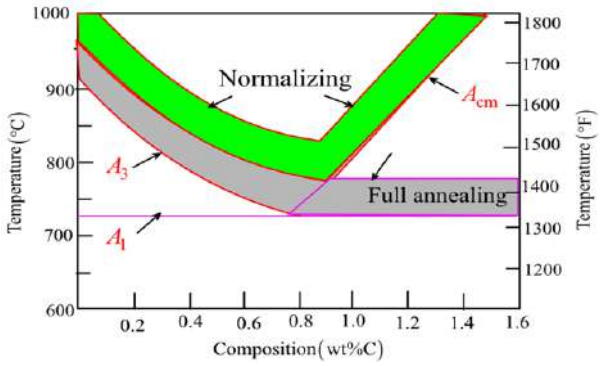

Fig. 1. Phase diagram of annealing process for mild steel alloy (Manchanda, Narang, 2005).

In this study the effect of annealing temperature using N_2 gas at constant flow rate on microstructure, micro hardness, thermal conductivity, and electrical resistance are studied and presented. The purpose is to relive stress in a cold worked carbon steel with less than 0.3%wt., also as the thermal conductivity decrease this will make the structures is more save when it expose to fire, and to use low carbon steel instead of high carbon steel is so important in the emission of carbon during recycling process.

2. Materials, Equipment and Procedures

2.1. Materials. The general chemical composition of mild steel that used in this study is shown in Table 1.

Table 1. Chemical composition of mild steel

Elements	C	Mn	Si	S	P	Bal.
Composition wt.%	0.17	0.8	0.4	0.04	0.04	Fe

Where it purchased as hot rolled from engineering road company.

2.2. Experimental Procedures. The working condition of annealing at 880 ˚C and nitriding of mild steel is shown in Table 2, where A, B, C, and D designation is referred to the holding time in hrs. four work pieces mild steel were heat treated using computerized electric furnace (NABERTHERM-B310) of 1750 ˚C maximum temperature, where the nitrogen gas can be flow at constant flowrate 2.5 L/hr and 880 ˚C in heating cavity. One of the main limitations is performing the heat treating at 880 ˚C and this based on the phase diagram of low carbon steel.

Table 2. Working conditions of this project

Materials Conditions	Holding Time under N_2 (hr)	N_2 Flow Rate (L/s)
Mild steel	-	-
Mild steel (A)	8	2.5
Mild steel (B)	16	2.5
Mild steel (C)	24	2.5
Mild steel (D)	30	2.5

2.2.1. Thermal Conductivity Test

A H112A Linear heat conduction instrument (Hilton Type) is used to investigate the thermal conductivity of different low carbon steel work pieces. The work piece is inserted as shown in Fig. 2, then the values of thermal conductivity is measured.

Fig. 2. H112A Linear heat conduction instrument (Hilton Type) used to investigate the thermal conductivity

Calculations of thermal conductivity**.** The thermal conductivity of a material is a measure of its ability to conduct heat. In the International System of Units (SI), thermal conductivity is measured in watts per meter-kelvin, where the conditions of work pieces for both thermal conductivity and electrical resistance are presented in Table 3, where A, B, C, and D designation is referred to the holding time in hrs. as shown also in Table 3.

Table 3. Thermal conductivity of mild steel and its heat treated work pieces

Materials Conditions	Holding Time under N_2 (hr)	N_2 Flow Rate (L/s)	Thermal conductivity (W/m.K)
Mild steel	-	-	0.0155310
Mild steel (A)	8	2.5	0.0079298
Mild steel (B)	16	2.5	0.0084690
Mild steel (C)	24	2.5	0.0074151
Mild steel (D)	30	2.5	0.0112901

3. Results and Discussions

3.1. Effect of annealing process at 880 ˚C using N_2 gas at different holding times on the microstructure

Fig. 3 shows the general microstructure of mild steel before and after annealing using N_2 gas at 8, 16, 24, and 32 hr. holding time respectively. It can be seen also that the grain size increase up to 16hr. holding time then it will decrease as the holding time increase to 32 hr.

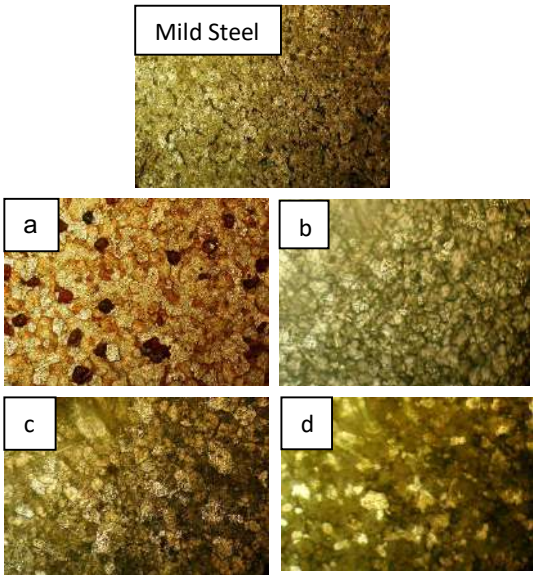

Fig.3. Photomicrographs at 200x shows the general microstructure of mild steel and it nitriding conditions, a) holding time 8 hr., b) holding time 16 hr., c) holding time 24 hr., and d) holding time 30 hr.

3.2. Effect of annealing process at 880 ˚C using N2 gas at different holding times on the average grain size

It can be seen from Fig. 4 that in general the effect of annealing process resulted in an increase of the grain size up to 16 hr. holding time by 108.1 %, then it decreased by increasing the holding time to 32 hr. by 20.5%, and this is consistent with (Shahri et. al., 2016) study.

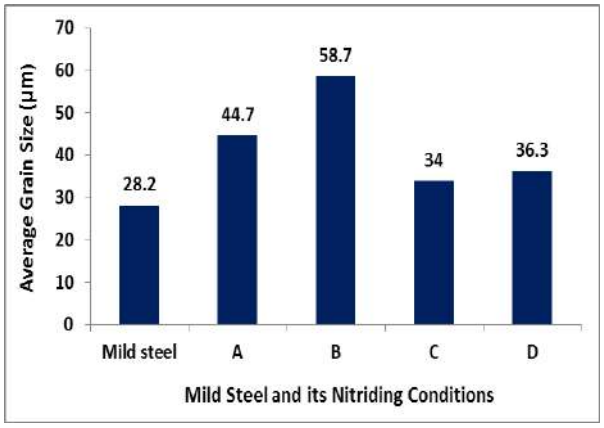

Fig. 4. Average grain size of mild steel and its nitriding conditions

3.3. Effect of annealing process at 880 ˚C using N_2 gas at different holding times on the average microhardness

Fig. 5 shows in general that the microhardness is decreased after annealing using N_2 gas flow, the maximum reduction is 48.12 %, this also an indication about the ductility that also attained, and this consistent with (Keskitalo et. al., 2015) revealed that using N_2 show less effects on the hardness but increase the ductility of steel.

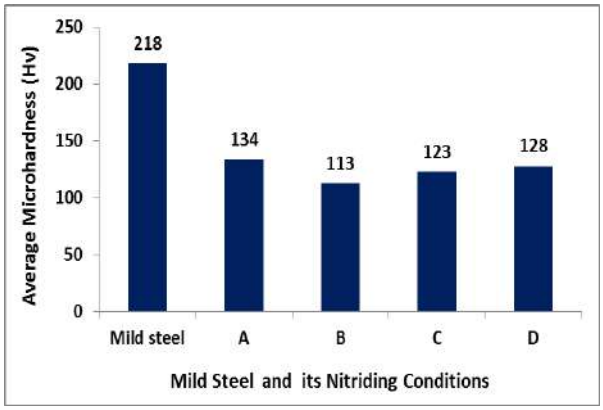

Fig. 5. Average microhardness of mild steel and its nitriding conditions

3.4. Effect of annealing process at 880 ˚C using N_2 gas at different holding times on the thermal conductivity

The thermal conductivity of a material is a measure of its ability to conduct heat. In the International System of Units (SI), thermal conductivity is measured in watts per meter-kelvin. Fig. 6 shows that by increasing the holding time up to 24 hr. there is a decrease in the thermal conductivity to 0.0074157 KW/m.k then it increases to 0.01129 KW/m.k at 32 hr. holding time.

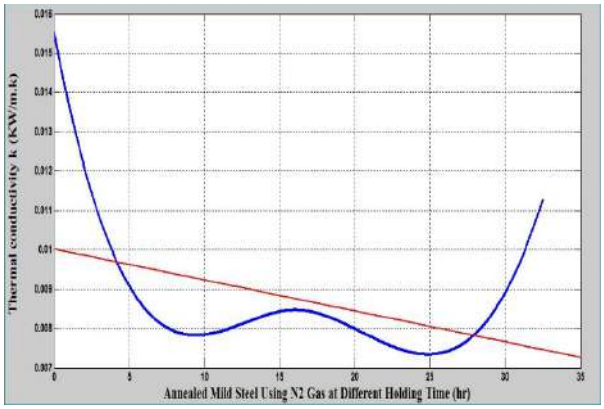

Fig. 6. Effect of annealing using N_2 gas at different holding time on the thermal conductivity

3.5. Effect of annealing process at 880 ˚C using N_2 gas at different holding times on electrical resistance

Fig. 7 shows an increase in the electrical resistance up to 16 hr. holding time, where the maximum increase is 0.75 %, however there is a relation between R and the average grain size which is cleared in Fig. 4.

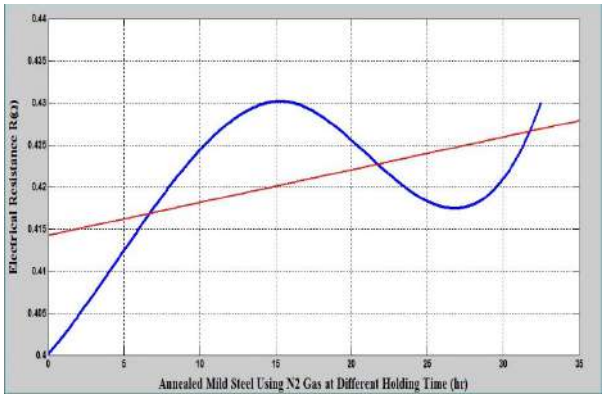

Fig. 7. Effect of annealing using N_2 gas at different holding time on the electrical resistance

4. Conclusions

The following points can be concluded:

- The annealing process resulted in microhardness reduction, this will have reflected on the recycling cost of low carbon steel.
- There is a slight change in the electrical resistance R.
- It resulted in reduction of thermal conductivity so it will have resulted in decreasing the heat transfer especially in building constructions.
- It resulted in an increase of the average grain size up to 16 hr. by 108.1 % holding time then it reduced up to 32 hr. holding time.
- There is a direct relation between the grain size and the electrical resistance R.
- Enhancing the properties of low carbon steel will make it to be used extremely in many applications, so the emissions of carbon as it recycled will be small this will enhance the sustainability of its usage.
- The microhardness is decreased after annealing using N_2 gas flow, the maximum reduction is 48.12 %.

Acknowledgments

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Author Contributions

Safwan Al-qawabah contributes to conceptualization, methodology, validation, analysis, investigation, data collection, supervision, project administration. Nabeel abo shaban contributes to software, validation, analysis, investigation, data collection, draft preparation, manuscript editing, visualization, project administration. All authors have read and agreed with the manuscript before its submission and publication.

Prof. Safwan Al-Qawabah, Associate Professor in Mechanical Engineering. Currently, he is the Dean of Faculty of Engineering and Technology at Al-Zaytoonah University of Jordan, ZUJ. In 2017, he was appointed Vice Dean of the Faculty of Engineering and Technology at Al-Zaytoonah University of Jordan. In 2014, he was appointed chair of mechanical engineering department at Tafila Technical University. He has obtained his PhD. in Mechanical Engineering from University of Jordan, Jordan 2008. In 2001 he has obtained his MSc. In Industrial Engineering, CAD/CAM from University of Jordan, where in 1995 he has obtained his BSc. In Industrial Engineering, CAD/CAM from University of Jordan. His interest area is in design and manufacturing, smart materials, and advanced manufacturing. He has about 25 research publications in highly recommended journals and more than 15 international conferences. He has projects with real industry in Jordan among FFF program. He is a consultant engineer, JCE in Mechanical Engineering / Engineering Education. In 2017 Al-Qawabah has the best session presentation of the 8th international conference on engineering, project and product management, EPPM. In 2003 he was accreted as an expert in CNC machines technology, programing, maintenance, and training from EXCEL machines tools, Coventry, UK for the Middle East zone. resolution 200.

Nabeel Abu Shaban is an Assistant professor. He is currently the dean of Engineering Technology Faculty, at Al-Zaytoonah University -Jordan. He received the B.S. degree from Aleppo University -Syria and the M.S. and Ph.D. degrees from University of Jordan, all in mechanical engineering. His interests include manufacturing, energy, renewable energy and thermal power sciences. Since 2002, Dr. Abu Shaban has taught a lot of courses at the University of Jordan and Al-Zaytoonah University related to fluid and thermal power systems.

Paper no. 121

Utilizing the Natural Palm Tree Fibers (NPTF) in Block Manufacture as Thermal Insulator for Energy Saving in Jordanian Residential Buildings

Nabeel Abu Shaban[1], Ali M. Othman[2] and Safwan al-qawabah[3]
[1]Mechanical Engineering Department, Al –Zaytoonah University of Jordan, Amman 41911, Jordan, E-mail: n.shaban@zuj.edu.jo
[2]Alternative Energy Technology Department, Al –Zaytoonah University of Jordan, Amman 41911, Jordan, E-mail: am.othman@zuj.edu.jo
[3]Mechanical Engineering Department ,Al-Zaytoonah University of Jordan, Amman 41911, Jordan, E-mail : Safwan.q@zuj.edu.jo

Abstract: Several ways and methods are used for energy saving in residential building regarding to its highly demand of energy in cooling and heating by means of air conditioning systems. One of favorable, cheap and effective method is utilization of new and natural low thermal conductivity martials in the constructions of the residential building. Natural fibers of plants such as palm tree waste and harvesting residuals can also help to minimize energy consumption in cooling and heating during summer and winter seasons when it is used as insulators. Furthermore, mixing these fibers in bricks industry as insulator instead of synthesis insulators help to reduce the environmental bad effect such as global warming, resource depletion, and toxicity in buildings. This work utilizes, the influence of mixing and blended natural palm tree fibers in cement bricks to get low thermal conductivity materials. This mixing helps in minimizing the thermal conductivity of the bricks unit by permitting the NPTF to act as a thermal insulator in the bricks industry. Utilizing the NPTF bricks in constructing buildings in Jordan as a case study is simulated and investigated. In addition, a certain amounts of weight percentage to the cemented blocks are carried out in previous study to show the influence on its thermal conductivity, fracture compressive stress, water absorptivity and resistivity It was found that the utilization of the NPTF, is effective and feasible to reduce the high consumption of the electricity when air conditioning systems are used, which encourage utilization NPTF in construction technology in both cold and hot weather.Furthermore, a simulation by HAP 4.2 software of proposed residential house in Al Mafraq (city at the north of Amman) where the NPTF bricks are employed in this house to show the energy saving influence in heating and cooling purposes. It was found that utilizing NPTF for heating purposes is better than in cooling purposes. Energy saving percentage in heating purposes is about 32% and 18% in cooling purposes.

Keywords: Enrgy saving, NPTF, Low thermal conductivity, HAP 4.2, Embodied energy, Bricks and sustainability

1. Introduction

Recently, the construction technology and its industries are widly, utilized and looking for materials with low carbon footprint and environmental impact Mahidin et al.(2017).Moreover, the embodied energy consumed in manufacturing of construction materials is considered very high and has bad environmental impact Buchanan et al. (1994).The huge mass production of Ordinary Portland Cement (OPC) yields the sever growing emission of carbon dioxide into the environment leading to greenhouse effects which indeed needs efforts to minimize the cost of this impact Summerbell et al. (2017)..

Adding layers of thermal insulation in cement walls and roofs construction are very essential issue in the building technology to help for reducing the embodied energy in construction materials technology Usage of the available waste and residual materials in developing new low thermal conductivity blocks by mixing clay and concert blocks has always encouraged the civil engineers to explore and construct sustainable , suitable and comfortable spaces for the Lower classes in third world countries.

Consequently, natural waste and harvested remaining of plants, fruits and vegetables processes, have been conducted and tested by researchers either as additives and/or reinforcement component in cement bricks industry

to enhance the mechanical properties of soil bricks, [4-6]. These investigations in engineering properties caused more interest to researchers of civil engineers and other researchers in many investigating to utilize of the available natural fibers to replace the conventional synthetic materials, because of their good environmental impact, social significance, economic and to their low-cost structural benefits in construction and industries technology. They offer good way for agricultural workers to reduce the volume, and weight of the waste instead of being burned or buried deep in the ground. This utilization decreases the emission rate of carbon dioxide and the cost of needed to be buried or burning.

Cement blocks without and with NPTF were tested, an enhancement in stress behavior of the fiber-reinforced blocks is noted compared to that one without fibers. Donor .P and Obonyo,(2016).

Danso H, et.al. (2015) showed in their study results of a tested coconut blocks and oil palm fibers approved an increasingin strength stress when aspect ratio is increased, also the bigger aspect ratio leads to get better mechanical properties.

Marwan Mostafa and Uddin,(2016).Used banana fibers in ground blocks as a gradient acted better than the bricks without fibers in both mechanical properties of compressive and flexural strength .

Y. Millogo, et.al. (2014), pressed Blocks with the addition of several percentage weight of 30 mm long fibers showed that fibers which have been added in these blocks reduced the sizes of the pores enhancing of their strength.

J. Lucía, et.al. (2016), found that natural fibers in cement blocks improves the strength tensile, compressive strength and reducing the water absorption..

It was found that the durability properties of the clay and blended fibers blocks were generally improved ,Danso, et.al., (2015).

New bricks are developed from mixing gluey and coherent soil.Existance of the fibers in this bloks add a positive influence on the thermal properties of ground constructing materials because of their mechanical strength properties. (P. Zak, et.al. 2016).

B. Taallah and A. Guettala, (2016), found that Using of palm fibers in cement block lead to a good reduction in thermal conductivity values as well as a negative effect on the thermal conductivity of CEB was also had been noted with chemicaly treated palm fibres.

Lahcen Boukhattem et.al. (2017), showed that the thermal conductivity and density has a positive effect when date palm waste is utilized as reinforcement to produce new bio-composites concret blocks.Also they determined all mechanical properties of this new bio-composits cement blocks.

The moisture content effect on the thermal conductivity of NPTF mesh was investigated experimentally by Kim Hung. Et.al.(2017).. The result showed that the thermal conductivity of wet increases with volumetric water content increase (λ = 0.033 to 0.147) W/m.K.

Mohamed E. and A. Abdelkarim, (2017), found that the microstructure of NPTF surface could be, used as an alternative building insulation material.The results showed that the minimum and maximum values of its thermal conductivity.

EA Abdelhafez et al.(2017),used Artificial Nural Network (ANN) technique was used to study the dissipation of a heat through two composite walls. Each wall is made of homogenous layers with an insulation layer, all of which were made of raw local materials. The used technique was helpful to show the temperature distribution between the layers and sucssefully predicted the energy losses through the wall layers.

In this work 16 specimens of palm fibers, sand, and cement were prepared in order to determine their thermal conductivities, water absorption and compression stress. Six specimens (300x300x20) mm, (1,2,3,4,5, and 6) fabricated as shown in table 1 and figure (1) to determine the thermal conductivity and water absorption of the bricks. Six other specimens (100x100x50) mm (7, 8, 9, 10, 11 and 12), having the same composition were prepared for compression test as shown in table (1). Finally, four specimens (13, 14, 15 and 16), (300x300x7) mm was prepared from pure palm fibers with different densities as shown in table (2).

The main aim of this research is to conduct the employing of prepeared NPTF bricks in constriction technology for energy saving in residential buildings.

The following materials were used to manufacture the brick specimens: NPTF, desert sand, Portland cement and local water, the manufactured samples will be tested to determine their thermal conductivities, water absorption and compression strength. Table 1 shows the percentage mixture of used materials.

Fig.1. Prepared NPTF bricks Samples

Table 1: NPTF Bricks mixtures and percentages (by Dr. Ali)

Sample NO.	*Material Percentage Dimensions (300x300x20) mm*	*Sample NO.*	*Material Percentage Dimensions (100x100x50) mm*
1	*0 % palm fiber, 70 % Sand, 30 % Cement*	*7*	*Same materials percentage as samples (1 -6)*
2	*0 % palm fiber, 70 % Sand, 30 % Cement*	*8*	
3	*2.5% palm fiber, 68.25 % Sand, 29.25 % Cement*	*9*	
4	*5% palm fiber, 66.5 % Sand, 28.5 % Cement*	*10*	
5	*7.5% palm fiber, 64.75 % Sand, 27.75 % Cement*	*11*	
6	*10% palm fiber, 63 % Sand, 27 % Cement*	*12*	

Table 2: Palm fibers mass in the samples

Sample NO.	*Mass[kg]*
13	*0.172*
14	*0.160*
15	*0.150*
16	*0.0140*

2. Methodology

2.1. Preparation of the brick specimens

The used NPTF in this study for showing the reduction of energy consumption was prepered and tested by Ali as shown in reference [17]

2.2. NPTF bricks tests

Several tests were carried out to obtain mechanical, thermal and physical properties of the produced blended cement bricks with palm fibers to ensure the possibility of utilizing these bricks in construction of resedintal building in both hot and cold climates regions.

2.2.1 The Thermal Conductivity tests

Figure (2) shows the used apparatus for determining the thermal conductivity of NPTF bricks . The method of detrmining of the thermal conductivity is presented and shown in reference [17] .

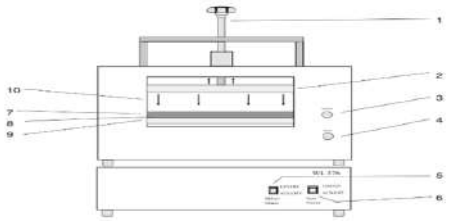

Fig. 2: Thermal conductivity apparatus

2.2.2. The Uniaxial compression tests:

Figure 3 shows the apparatus which is used to determine mechanical properties of NPTF by compression- tensile tests.

Fig.3. Testing the Bricks by Universal Testing Machine

2.2.3. The water absorption tests

After finishing the thermal conductivity. A tests to determine the influnceof the NPTF percentage on the water absorption is carried out by wepping and weeting the bricks by wet. The water absorption percantage, W, is given by:

$$W = \{(M2 - M1)\, M1\} x 100\,\% \quad (1)$$

3. Theoretical Considerations

According to the with Fourier's Law,energy rate through single or multiple layers wall is given by

i).Energy rate for single layer wall:

$$q = -\lambda . A . \frac{\Delta T}{\Delta x} \quad (2)$$

$$R = \frac{\Delta T}{q} \quad (3)$$

ii).Energy rate for Multiple layers wall or roof

$$q = \frac{A.\Delta T}{\frac{\Delta x1}{\lambda 1} + \frac{\Delta x2}{\lambda 2} + \frac{\Delta x3}{\lambda 3}} \quad (4)$$

$$R = \left(\frac{\Delta x1}{\lambda 1} + \frac{\Delta x2}{\lambda 2} + \frac{\Delta x3}{\lambda 3}\right) . \frac{1}{A} \quad (5)$$

hence,

q: is the energy rate,

λ, $\lambda_{1,2,3}$:are the thermal conductivities, W/m.K,

A: is the wall's area, m^2

Δ x, Δx, 1, 2, 3 is the layers thickness, m

ΔT: is the temperature difference through the wall K,

R: is thermal resistance K/ W

Basically, overall thermal conductivity of a porous medium differs according to the complexity of the geometry of the porous materials and according to the heat conduction flow either parallel or series. If we denote λ_S for thermal conductivity of solid portion and λ_f for thermal conductivity of fluid portion, then the mean thermal conductivity λ_A and λ_H are given by the following two equations 6 and 7, respectively.

In parallel heat conduction flow is given by

$$\lambda_A = (1-\varphi)\lambda_S + \varphi\,\lambda_{Af} \qquad (6)$$

$$\lambda_H = \frac{1-\varphi}{\lambda_S} + \frac{\varphi}{\lambda_f} \qquad (7)$$

4. Results and Discussion

4.1. Effect of the NPTF bricks on the fracture stress

Table 2: Fracture stress for the samples

Percent of palm Fiber (%)	*Stress (N / mm²)*
0	*7.6*
0	*8.82*
2.5	*4.646*
5	*2.7*
7.5	*2*
10	*1.14*

Table 3: Water Absorptivity NPTF bricks

Sample	*Fiber %*	*M_1*	*M_2*	*W%*
1	*0 %*	*6.2*	*6.6*	*6.55*
2	*0 %*	*6.2*	*6.4*	*4.90*
3	*2.49 %*	*5.2*	*5.8*	*9.40*
4	*5.1 %*	*4.95*	*5.6*	*14.3*
5	*7.51 %*	*4.85*	*5.6*	*14.6*
6	*11 %*	*4.25*	*5.2*	*23.80*

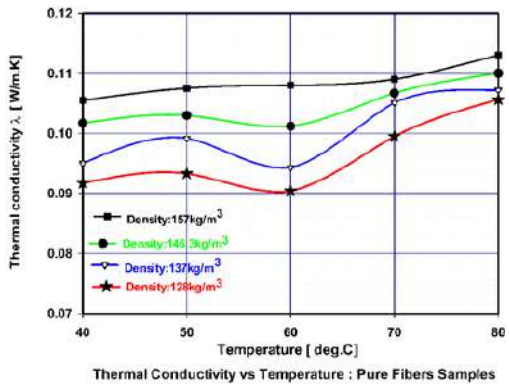

Fig.4. Fibre reinforcement weight percentage vs the water absorption percentage of bricks

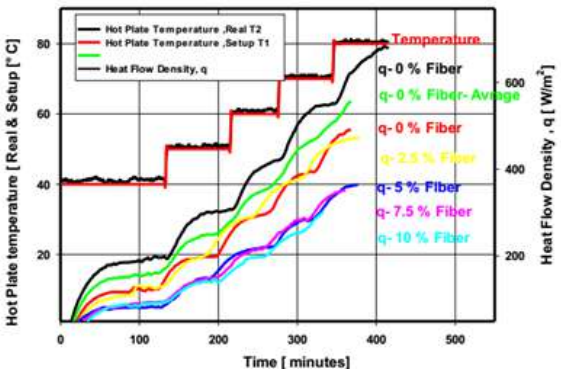

Fig.5. Variation of specimen temperature temperatures

5. Economy study

Human comfort in residential building requires heating, cooling and ventilation systems to be used in wise and suitable manners to achieve sustainability. Cooling heat gain or heating losses through walls and roofs are directly affected by how much these elements could resist heat flux flow, so the resistivity of these walls and roofs depends on the construction details, so to minimize both heat losses and heating gains it is necessary to use insulation layer of low thermal conductivity or use some of blocks with high thermal resistance. Here in as an application of this study, it proposed the residential house in Almafraq -Jordan shown in figure 12. It is once assumed that the walls of this house are constructed with conventional blocks of thermal conductivity λ =1.2 W/m K and once again it is built with new blocks which contains palm fiber of 10% mass basis, with thermal conductivity of λ=0.112 W/m K.

Simulation by using HAP (Hourly Analysis Program) for this proposed design as shown in figure 6 is carried out. The results obtained are summarized in figures 7-9.

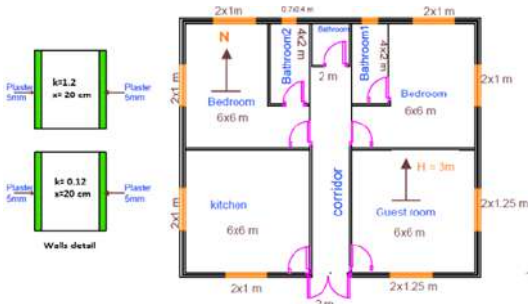

Fig.6. Plan view of proposed residential house

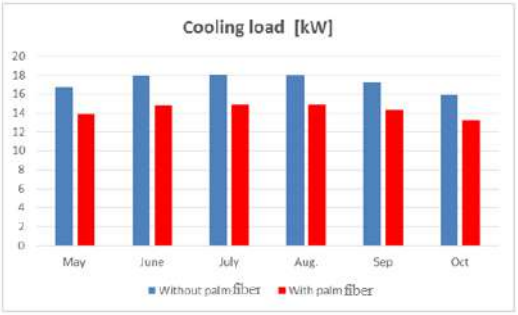

Fig. 7. Cooling load for the proposed house

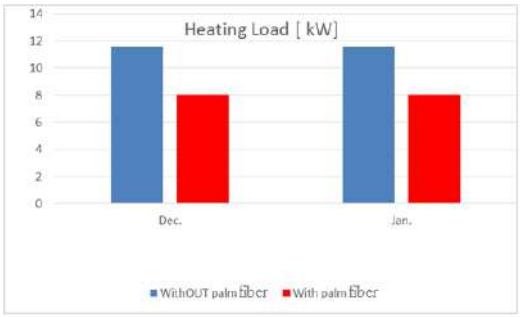

Fig.8. Heating load for the proposed house

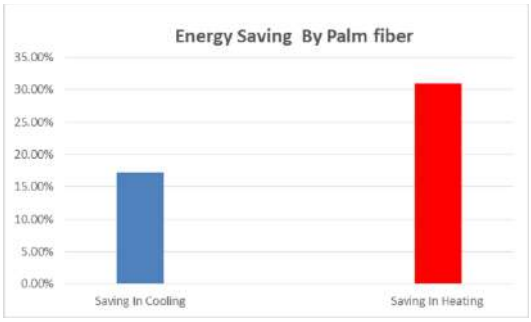

Fig. 9. Energy Saving for the proposed house when Palm fiber is used

6. Uncertainty Analysis

Uncertainty analysis in any thermal experimental work involves temperature measurements, which differ from the true values. In this experiment, Q is constant and steady state conditions are always satisfied during the measurements. Holman, J. (2012).

Thermal conductivity is measured by only considering conduction heat transfer through the specimen, which is governed by re-arrangements of Fourier's law.

$$\lambda = \frac{Q\,\Delta x}{A\,\Delta T} \qquad (9)$$

$$\lambda = f(T, Q) \qquad (10)$$

$$\Delta\lambda = \sqrt{(\frac{\partial\lambda}{\partial T}\Delta T)^2 + (\frac{\partial Q}{\partial T}\Delta Q)^2} \qquad (11)$$

$$\frac{\partial\lambda}{\partial T} = -\frac{Q\Delta x}{\Delta T^2} \qquad (12)$$

$$\frac{\partial Q}{\partial T} = \frac{\Delta x}{\Delta T} \qquad (13)$$

Hence Q is 500 W with $\Delta Q = 0.03\ W$, ΔT = 40 °C with 0.1 °C Accuracy.

Then the percentage of uncertainty in evaluating thermal conductivity is

$\Delta\lambda = \pm 2.6\%$

7. Results and conclusions

According to the previous results obtained from reference Ali et al (2016) for thermal conductivity tests. A study of energy saving for a proposed house built by using NPTF bricks in Al-Mafraq city in Jordan desert as a case study to examine the effictiveness of NPTF bricks as a low thermal conductivity bricks in bulding technology. Results in figures 7- 9 show that it has better saving in energy in heating purposes rather than in cooling purposes. Energy saving in heating purposes is about 32% while 18% is obtained in cooling purposes when NPTF bricks is used. Finally, utilizing NPTF bricks in residential buildings showed good solution for energy saving with reseanable and efficient way because of its low thermal conductivity at low cost.

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Author Contributions

Safwan Al-qawabah contributes to conceptualization, methodology, validation, analysis, investigation, data collection, supervision, project administration. Nabeel abo shaban contributes to software, validation, analysis, investigation, data collection, draft preparation, manuscript editing, visualization, project administration. All authors have read and agreed with the manuscript before its submission and publication.

Nabeel Abu Shaban is an Assistant professor. He is currently the dean of Engineering Technology Faculty, at Al-Zaytoonah University -Jordan. He received the B.S. degree from Aleppo University -Syria and the M.S. and Ph.D. degrees from University of Jordan, all in mechanical engineering. His interests include manufacturing, energy, renewable energy and thermal power sciences. Since 2002, Dr. Abu Shaban has taught a lot of courses at the University of Jordan and Al-Zaytoonah University related to fluid and thermal power systems.

Ali Othman: he is currently serving as associate professor and chairman of alternative energy technology department at Al Zaytoonah University of Jordan. He obtained his MSc & PhD in Mechanical engineering in 1986 and 1990 from Slovakia University of Technology/Slovakia Czechoslovakia Federative Republic. His main research areas include thermal engineering science/Heat transfer and energy efficiency. He published 17 journal papers, and one conference paper. He designed curriculum (graduate and undergraduate programs) of mechanical, engineering management and mechatronics engineering. He worked as lecturer 21 years at Philadelphia University and five years at Taibah University /KSA. For 17 years worked as chair of Mechanical & Mechatronics Engineering departments in Jordan and Kingdom of Saudi Arabia. One-year par time lecturer at German-Jordan University. He served as an organizing committee chair and member for many international and local conferences and workshops.

Prof. Safwan Al-Qawabah, Associate Professor in Mechanical Engineering. Currently, he is the Dean of Faculty of Engineering and Technology at Al-Zaytoonah University of Jordan, ZUJ. In 2017, he was appointed Vice Dean of the Faculty of Engineering and Technology at Al-Zaytoonah University of Jordan. In 2014, he was appointed chair of mechanical engineering department at Tafila Technical University. He has obtained his PhD. in Mechanical Engineering from University of Jordan, Jordan 2008. In 2001 he has obtained his MSc. In Industrial Engineering, CAD/CAM from University of Jordan, where in 1995 he has obtained his BSc. In Industrial Engineering, CAD/CAM from University of Jordan. His interest area is in design and manufacturing, smart materials, and advanced manufacturing. He has about 25 research publications in highly recommended journals and more

than 15 international conferences. He has projects with real industry in Jordan among FFF program. He is a consultant engineer, JCE in Mechanical Engineering / Engineering Education. In 2017 Al-Qawabah has the best session presentation of the 8th international conference on engineering, project and product management, EPPM. In 2003 he was accreted as an expert in CNC machines technology, programing, maintenance, and training from EXCEL machines tools, Coventry, UK for the Middle East zone. resolution 200.

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