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PREFACE

This Special Issue of the *International Journal of Infrastructure Research and Management (IJIRM)* is dedicated to the unwavering commitment and efforts of the Civil Engineering and Construction Department (CECD) at Infrastructure University Kuala Lumpur (IUKL). In its mission to enhance the quality and quantity of research and publications, CECD successfully organized a two-day seminar, bringing together participants from diverse specializations within Civil and Electronics Engineering.

The articles featured in this Special Issue are carefully selected papers from the seminar, focusing on sustainability and technological advancements in the field of Engineering and Technology. These contributions align with Malaysia's National Policy for the Fourth Industrial Revolution, which emphasizes sustainability, digital transformation, and the integration of the Internet of Things (IoT) and emerging technologies to drive the construction industry toward smart and sustainable practices.

This issue explores various challenges and advancements, including the use of online platforms to facilitate information delivery and interaction, as well as cloud-based project management utilizing IoT applications. The selected papers also discuss innovations in structural design and propose solutions to address existing challenges in the construction industry.

In addition to technological advancements, this Special Issue underscores the critical importance of sustainability. The engineering sector is a significant consumer of raw and natural resources, highlighting the need for alternative materials and optimization strategies to preserve these resources. However, extensive research remains necessary to ensure the viability and effectiveness of these materials as alternatives or additives in real-world applications.

We extend our heartfelt gratitude to the Chief Editor of IJIRM, Prof. Dr. Faridah Ibrahim, the editorial board members, language editors, editorial coordinator Nur Amalina Samusi, and the IUKL library for their invaluable support and encouragement throughout the preparation of this edition.

It is our hope that the contributions in this Special Issue will inspire further research in these critical areas and serve as a valuable resource for Civil Engineering professionals and readers alike.

Norul Wahida Kamaruzaman, PhD
Nurazim Ibrahim, PhD
Guest Editors
Infrastructure University Kuala Lumpur (IUKL)
March 2025

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GEOMETRIC DESIGN OF ROAD AT SERI KEMBANGAN, SELANGOR USING AUTODESK CIVIL 3D

Ranjit Singh Dharam Singh & Mohamad Izzat Izzuddin Abd Kadir
Infrastructure University Kuala Lumpur, MALAYSIA

ABSTRACT
Road planning and design involve tasks of understanding different criteria in road geometry. The tasks involved in road design are extracting the heights from the detail and topography drawing, generating the surface to show the contour, designing the horizontal alignment, generating profile along the horizontal alignment, designing the vertical alignment, generating cross sections, creating an assembly, creating corridors and generate the earthwork volume of the design. This study presents a complete geometrical road design of a typical urban road using Autodesk Civil 3D. The results obtained show that Autodesk Civil 3D is applicable in road design such as generating horizontal and vertical alignments, computing the earthwork volume along the alignment and generating 3D views of the alignment.

Keywords:
Road design, Autodesk Civil 3D, horizontal alignment, vertical alignment, earthwork volume

INTRODUCTION

The geometrical design of the road consists of horizontal alignment and vertical alignment. Safety, operational quality, and project costs are important factors in the design of horizontal and vertical alignments. The horizontal alignment consists of straight lines and curves. The types of curves used in horizontal alignment are circular curves, spiral curves, composite curves and reversed curves (Uren & Price, 2018; Manoj et al., 2019; Mojtaba, et al., 2015; Pangesti, et al., 2022; Farid, et al., 2022).

Vertical alignment consists of vertical curves that provide a transition between two slopes at the road. These curves are parabolic and assigned chainages based on the horizontal axis (Khaja, et al., 2017; Raji, et al., 2017; Zulfa, et al., 2022; Ranjit & Yong, 2024).

The earthwork in a road design is to estimate the volume of cut and fill of the soil along the alignment. Ideally, the amount of cut and fill of the soil should be balanced where the amount of cut is equal to the amount of fill (Uren &. Price, 2018; Chakole & Wadhai, 2022; Rifai, et al., 2024; Ranjit & Loh, 2023).

This study will be using Autodesk Civil 3D in designing the horizontal alignment, designing the vertical alignment and estimating the volume of cut and fill along the designed alignment. The objectives of this study are as follows:-

i. To design horizontal and vertical alignment by using Autodesk Civil 3D at Seri Kembangan, Selangor.
ii. To estimate the earthwork volume along the alignment.

METHODOLOGY

The road is designed on a detail and topography drawing of the area of the proposed road. Basically, the procedure of road design consists of determining the design criteria, designing the horizontal alignment, designing the vertical alignment and estimating the earthwork volume.

Design criteria

The design criteria of the road are based on Public Works Department Malaysia (2015) as below:-

i. The design speed is 50 km/h.
ii. The design standard is U2.
iii. The minimum radius of the curve is 90 m.
iv. The minimum length of the spiral curve is 33 m.
v. The marginal strip width is 0.25 m.
vi. The minimum k value for the crest curve is 10.
vii. The minimum k value for the sag curve is 13.
viii. The maximum gradient is 7%.
ix. The lane width is 3.0 m.

Designing the Horizontal Alignment

The survey data comprising points with easting, northing and elevations are imported into Autodesk Civil 3D to generate the surface of the ground. The horizontal alignment is designed on the generated surface based on the design criteria. The profile is then generated along the horizontal alignment.

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Designing the Vertical Alignment

The vertical alignment is designed on the generated profile based on the design criteria. The gradients of the vertical alignment should be less than six percent.

Generating Cross Sections, Creating an Assembly and Creating Corridors

The cross sections are generated along the horizontal alignment at 20 m chainage intervals. The assembly of the road is created based on the U2 design standard. The corridors are then created along the alignment. The assembly of the road is included in the cross sections for earthwork volume estimation.

Earthwork Estimation

The earthwork volume table is generated along the designed alignment at 20 m chainage intervals. The vertical alignment intersection point can be edited to obtain a balanced cut and fill volume for the alignment.

RESULTS

The road is designed based on the U2 design standard as shown in Figure 1. The road carriageway width is 3.0 m, shoulder is 2.0 m, landscape corridor is 3.75 m, drain reserve is 1.5 m and service reserve 3.0 m. The total width of the road is 30 m.

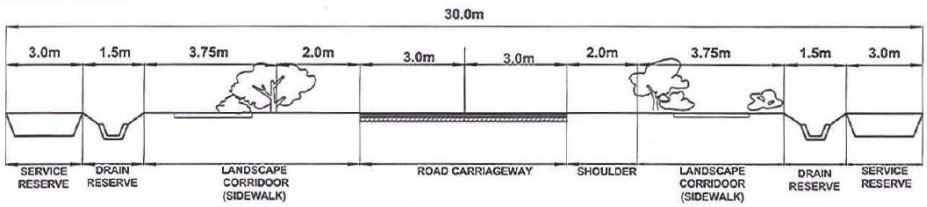

Figure 1: U2 Design Standard (Public Works Department Malaysia, 2015)

The existing ground surface is generated in Autodesk Civil 3D using the coordinates and elevations extracted from the detail and topography drawing of the study area at Seri Kembangan, Selangor. Figure 2 depicts the surface created from the detail and topography drawing.

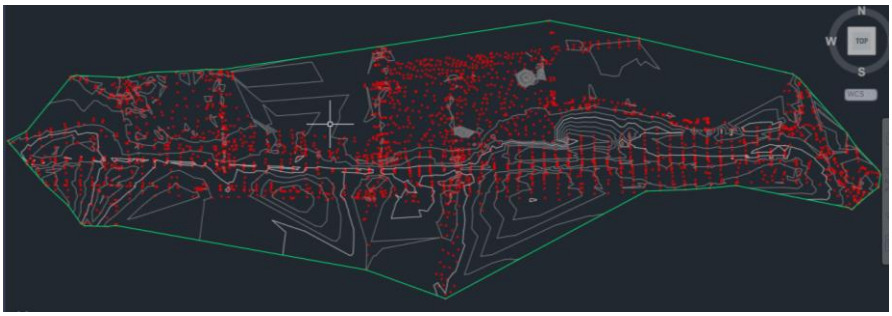

Figure 2: Created Surface of the Study Area

The horizontal alignment is then designed on the created surface (Figure 2) based on the determined design criteria. The length of the designed horizontal alignment is 650.22 m. There are nine horizontal curves along the horizontal alignment which have a radius larger than the minimum radius of 90 m. Figure 3 shows the horizontal alignment of the proposed road.

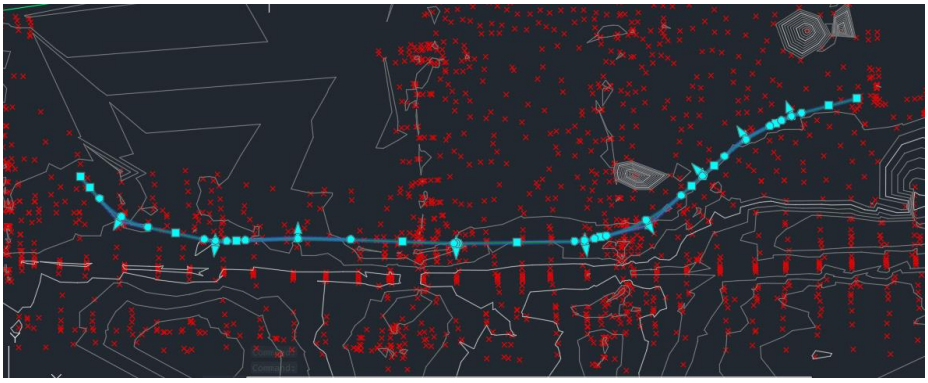

Figure 3: Horizontal Alignment of the Proposed Road

The profile is then generated along the horizontal alignment. The vertical alignment is designed on the generated profile. The gradient of the designed vertical alignment for this study is less than the maximum gradient of seven percent. There are five crest curves and four sag curves along the vertical alignment which have K values larger than 10 and 13 respectively. Figure 4 depicts the profile and the vertical alignment along the proposed road.

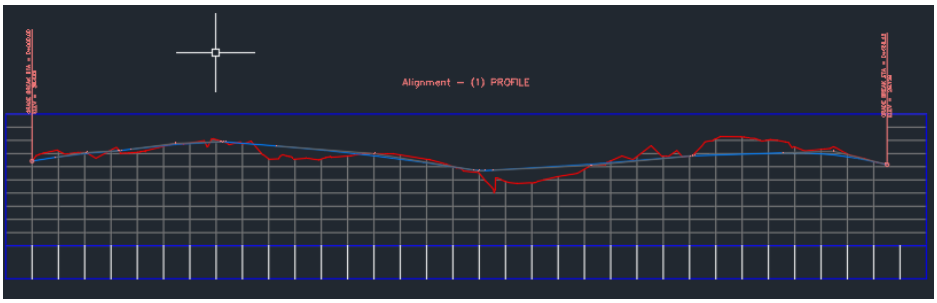

Figure 4: Profile and Vertical Alignment of the Proposed Road

The cross sections are then generated along the designed horizontal alignment at every 20 m chainage internal with offset distance of 50 m. There are 33 cross-sections generated along the designed road. Figure 5 shows the cross section generated at chainage 20 m.

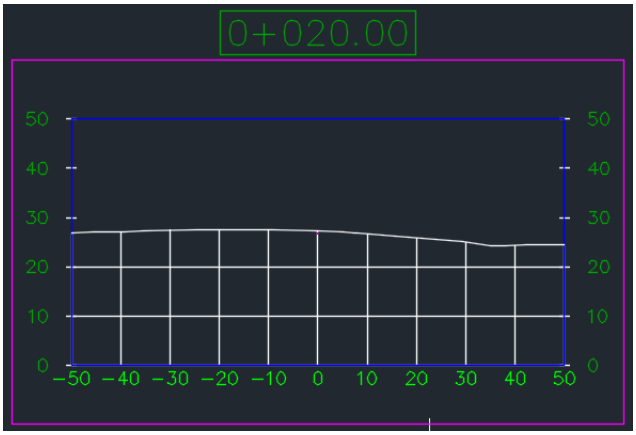

Figure 5: Cross Section at Chainage 20 m

The assembly is then created according to the U2 design standard (Figure 1). The assembly consists of the road carriageway, shoulder, landscape corridor, drain reserve, service reserve and daylight. Figure 6 depicts the assembly of the proposed road based on the U2 design standard.

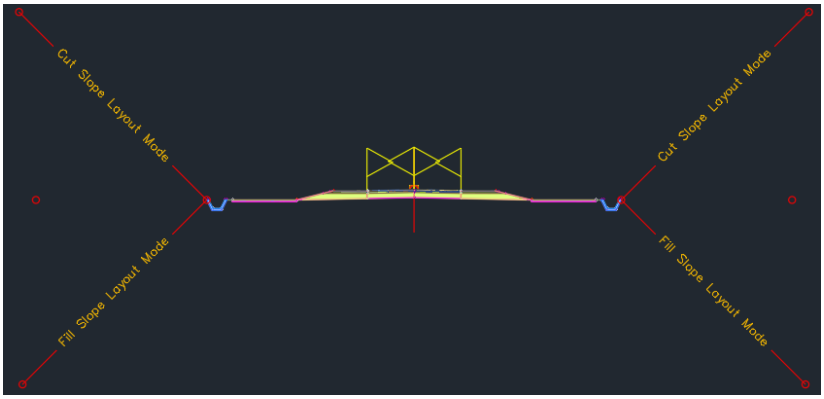

Figure 6: Assembly of the Road Design

The assembly is applied to the designed vertical alignment to create the corridor. The corridor can be converted to solid in order to view the proposed road in conceptual view. The created corridor of the proposed road is shown in Figure 7. The assembly will then be generated in all the cross sections. Figure 8 shows the generated assembly in the cross section at chainage 20 m.

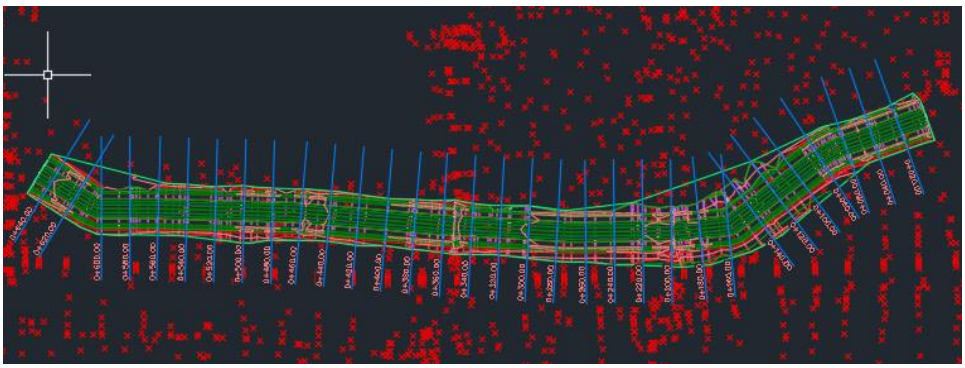

Figure 7: Corridor of the Proposed Road

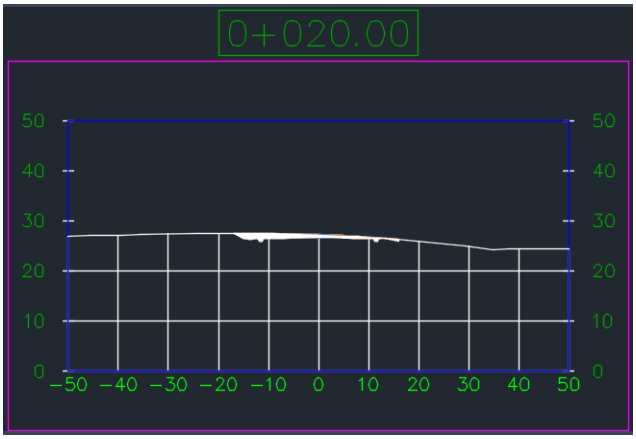

Figure 8: Generated Assembly in Cross Section at Chainage 20 m

The earthwork volume can now be estimated along the proposed road. The total volume table can be generated for the proposed road. The total volume table shows the area of fill, area of cut, volume of fill, volume of cut, cumulative fill volume and cumulative cut volume for every chainage interval of 20 m along the proposed road. The total cumulative fill volume and total cumulative cut volume for the proposed road are 2513.40 m^3 and 17152.25 m^3 respectively. There is an excess of cumulative cut volume of 14638.85 m^3. Table 1 shows the earthwork volume of the proposed road.

Table 1: Earthwork Volume of the Proposed Road.

Total Volume Table						
Station	Fill Area	Cut Area	Fill Volume	Cut Volume	Cumulative Fill Vol	Cumulative Cut Vol
0+020.00	0.02	18.61	0.00	0.00	0.00	0.00
0+040.00	1.03	13.78	10.38	325.75	10.38	325.75
0+060.00	2.15	15.49	31.80	292.64	42.17	618.39
0+080.00	9.75	25.29	88.89	387.26	131.07	1005.65
0+100.00	0.64	22.57	97.28	472.70	228.35	1478.35
0+120.00	4.55	40.66	51.93	632.28	280.27	2110.63
0+140.00	15.36	40.67	199.11	813.29	479.38	2923.92
0+160.00	26.77	41.60	268.88	1075.14	748.26	3999.07
0+180.00	13.11	39.18	398.85	807.85	1147.12	4806.92
0+200.00	35.77	11.45	493.31	515.42	1640.42	5322.34
0+220.00	3.87	13.00	396.38	244.47	2036.81	5566.80
0+240.00	0.43	20.88	42.97	338.79	2079.78	5905.59
0+260.00	0.34	38.62	7.72	595.04	2087.50	6500.64
0+280.00	0.69	38.46	9.90	794.93	2097.40	7295.57
0+300.00	5.13	22.66	58.14	611.19	2155.54	7906.76
0+320.00	0.21	18.75	53.38	414.06	2208.92	8320.82
0+340.00	0.58	25.58	7.95	443.30	2216.87	8764.12
0+360.00	0.22	28.23	8.07	538.16	2224.94	9302.28
0+380.00	0.00	25.81	2.30	543.02	2227.25	9845.30
0+400.00	0.01	21.47	0.06	472.80	2227.30	10318.10
0+420.00	0.00	24.49	0.06	459.66	2227.36	10777.76
0+440.00	0.02	30.03	0.16	545.19	2227.52	11322.95
0+460.00	0.56	23.49	5.75	535.12	2233.27	11858.07
0+480.00	0.09	34.52	6.17	573.35	2239.44	12431.41
0+500.00	0.00	61.24	0.89	957.56	2240.33	13388.97
0+520.00	0.28	23.51	2.82	847.47	2243.15	14236.44
0+540.00	0.09	32.34	3.70	558.43	2246.85	14794.86
0+560.00	0.89	20.72	9.73	530.59	2256.58	15325.46
0+580.00	11.02	23.78	121.73	442.19	2378.30	15767.65
0+600.00	1.17	22.40	121.84	461.76	2500.15	16229.41
0+620.00	0.21	24.09	4.42	492.42	2504.57	16721.83
0+640.00	0.67	18.95	8.83	430.41	2513.40	17152.25

The proposed road which has been converted into a solid can be viewed in 3D. The perspective view shows the assembly (Figure 6) according to the U2 design standard (Figure 1). Figure 9 depicts the perspective view of the proposed road using Autodesk Civil 3D.

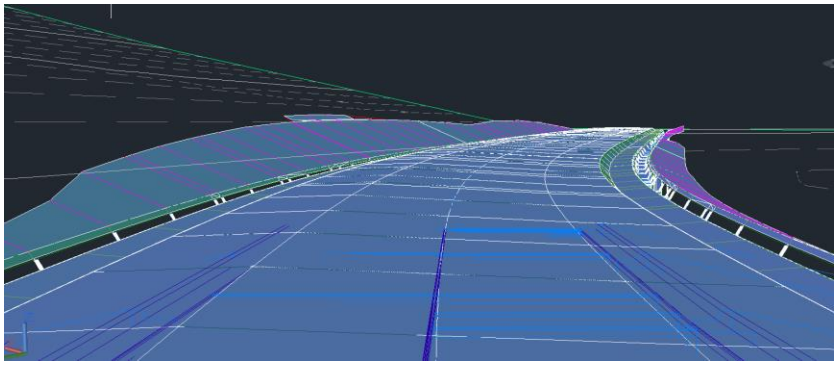

Figure 9: Perspective View of the Proposed Road.

CONCLUSION

The results obtained in this study show that Autodesk Civil 3D is applicable in geometrical design of road. The road is designed according to U2 design standard with a design speed of 50 km/h. The results generated by Autodesk Civil 3D are reliable and acceptable. Autodesk Civil 3D is able to generate the surface for the contour, design the horizontal alignment, generate the profile along the horizontal alignment, design the vertical alignment, generate the cross sections, creating assembly, creating corridors, generate the earthwork volume of the design and generating 3D views of the alignment.

It is recommended that future studies could incorporate traffic flow simulations and safety analysis into the geometric design of road. Software like VISSIM or SIDRA could be used alongside Autodesk Civil 3D to assess the design's performance under various traffic conditions. A comparative study of Autodesk Civil 3D with other design software like Bentley OpenRoads or Autodesk InfraWorks could provide insights into the software specific advantages and limitations in road design projects.

AUTHOR BIOGRAPHY

Ranjit Singh Dharam Singh is an associate professor at the Faculty of Engineering, Science and Technology, Infrastructure University Kuala Lumpur. He holds a Certificate in Land Surveying from Politeknik Sultan Haji Ahmad Shah (1992), a Diploma in Land Surveying from Politeknik Ungku Omar (1994), a B.Sc. (Hons.) in Land Surveying with a first-class honor from Universiti Teknologi Malaysia (1997) and a M.Sc. in Land Surveying from Universiti Teknologi Malaysia (1999). He is the author and co-author of more than 40 technical papers published in journals, book chapters and conferences. He is an elected Fellow with the Royal Institution of Surveyors Malaysia, a Professional Member of the Institution of Geospatial and Remote Sensing Malaysia and a Professional Technologist with the Malaysia Board of Technologists. His industrial experience includes working with prestigious construction companies such as Gamuda Berhad and YTL Corporation Berhad. His current research interest is in engineering survey, route design, terrestrial laser scanning, underground & structure utility detection, deformation monitoring, least squares estimation, photogrammetry, global navigation satellite system, geographical information system and remote sensing. *Email: ranjit@iukl.edu.my*

Mohamad Izzat Izzuddin Abd Kadir is a former undergraduate student at the Faculty of Engineering, Science and Technology, Infrastructure University Kuala Lumpur. He holds a Bachelor in Civil Engineering (Hons) from Infrastructure University Kuala Lumpur. His research interest is in route design and civil engineering.

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ENERGY-EFFICIENT 4-bit FULL ADDER DESIGN USING MODIFIED GDI TECHNIQUE IN 130nm TECHNOLOGY USING MENTOR GRAPHICS SOFTWARE

Mohamad Zarith Zainudin, Jebashini Ponnian, Norazlina Mohamed & Ima Sulaiman
Infrastructure University Kuala Lumpur, MALAYSIA

ABSTRACT
Addition is a fundamental arithmetic operation, essential for various digital circuits. High-performance adders are critical components of Arithmetic Logic Units (ALUs) in Integrated Circuits (ICs). This paper focuses on the design and analysis of 4-bit full adders (FAs) utilizing Gate-Diffusion Input (GDI) technology, an alternative to traditional Complementary Metal Oxide Semiconductor (CMOS) techniques. The objective is to evaluate the power consumption, propagation delay, and transistor count of GDI-based FAs. By comparing GDI-based FAs with CMOS-based counterparts, this research aims to identify potential advantages and trade-offs of GDI technology for low-power, high-performance IC design.

Keywords:
Integrated circuits (IC), arithmetic logical units (ALU), Complementary Metal Oxide Semiconductor (CMOS), gate-diffusion input (GDI), full adder(FA), Modified GDI (MGDI).

INTRODUCTION

Continuous pursuit of miniaturization and low-power operation in integrated circuits (ICs) has led to the exploration of novel device and circuit techniques. Gate-Diffusion Input (GDI) technology, an alternative to traditional CMOS, offers potential advantages in terms of reduced power consumption and improved performance. By leveraging the unique characteristics of GDI devices, it is possible to design energy-efficient circuits that meet the stringent requirements of modern electronic systems. This paper aims to reduce transistor count by utilizing full-swing GDI techniques, compared to conventional CMOS designs. A detailed analysis of design parameters, including transistor count, power consumption, propagation delay, and circuit complexity, will be undertaken.

Recent research has focused on developing energy-efficient full adder architectures using Gate-Diffusion Input (GDI) logic for arithmetic applications. GDI-based designs offer significant advantages in terms of power consumption, area, and delay compared to conventional CMOS approaches (Aggarwal & Garg, 2021; Bilal N Md et al., 2020). Full-swing GDI-based adders have been proposed to address low-swing and noise issues at low supply voltages, demonstrating improved signal integrity and driving capability (Aggarwal & Garg, 2021). These designs have shown power savings of up to 14.8% over hybrid designs and 55% reduction in area (Aggarwal & Garg, 2021). Performance analyses have revealed that GDI-based arithmetic circuits can achieve more than 41% improvement in delay and 32% in energy consumption compared to conventional CMOS full adders (Bilal N Md et al., 2020). The GDI technique allows for reduced transistor count and power consumption in digital circuit design, making it particularly suitable for embedded systems (Batta et al., 2012; Chandralekha et al., 2020).

Majid Amini-Valashani & S. Mirzakuchaki (2020) proposed two new MGDI-based full adders that achieve full-swing operation and demonstrate significant improvements in power consumption and power-delay product. Kumar et al., (2019) proposed a new hybrid 1-bit full adder circuit design that combines GDI logic and MVT transistors to achieve minimum energy consumption and small area, with simulation results showing >57% energy savings and 92% EDP savings compared to prior designs (Sanapala & Sakhtivel, 2019). The research introduced a hybrid full adder design combining GDI logic and multi-threshold voltage transistor logic, achieving substantial energy savings at ultra-low voltages. The paper presents two new low-power, energy-efficient full adder cell designs based on MGDI logic

that show 24-56% and 36-66% improvements in power consumption and power-delay product, respectively. Their design showed robustness against process variations and scalability to smaller technology nodes. Deepgandha Shete & Anuja Askhedkar (2021) compared full swing GDI and CMOS techniques for full adder design, noting that GDI offers better speed and lower complexity while maintaining low power consumption. These studies collectively demonstrate the potential of GDI and MGDI techniques in creating power-efficient, area-efficient, and high-performance full adder designs for modern computing systems.

According to Zain Z. (2019, April) his research CMOS first by doing The full adder which is constructed using a conventional CMOS topology and consists of 28 transistors. However, this high transistor count can result in increased power consumption and a larger usage of area per die. Regardless, the research was able to provide a full swing output, good noise resistance, and good ranges of operating temperatures. The author found that with a supply voltage of 1.8V and an ambient temperature of 27 degrees celsius, and considering that all PMOS and NMOS transistors have a minimum channel length (Lmin) of 180 nanometers, conducted a transient analysis over a 50-millisecond time span and examined the output voltage at various nodes. Findings from [4] revealed that the circuit exhibited power consumption within the range of 1084 nanowatts (minimum) to 1217 nanowatts (maximum). The range of propagation delay time was determined to be 22.6 ps (minimum) and 31.8 ps (maximum) range.

According to Dhavachelvan and Uma research article (December, 2012) it is inferred that the paper's primary focus is on introducing novel designs for primitive cells and presenting five distinct topologies for circuit-level implementations of full adders using the GDI (Gate Diffusion Input) technique. The modified GDI primitive cells are developed and their differences from conventional CMOS GDI cells are analyzed. While the GDI technique offers advantages like reduced power consumption, fewer transistors, and high speed, it also present complexities during the fabrication process thus implementing GDI techniques using twin-well CMOS or Silicon on Insulator (SOI) processes can elevate both the complexity and cost of fabrication.

Previous research has primarily focused on 1-bit Full Adder (FA) designs, achieving varying levels of full-swing output. Some studies have employed older and larger lithographic nodes, while others have opted for more complex designs requiring larger chip die areas. Despite these differences, all research efforts have successfully reduced transistor count, propagation delay, and power consumption for their respective FA designs. This project aims to further optimize GDI-based FA designs by minimizing transistor count, reducing propagation delay, lowering power consumption, and maximizing full-swing output. By simplifying the design and reducing chip die area, we seek to achieve a more efficient and effective FA implementation. This project aims to further optimize GDI-based FA designs by minimizing transistor count, reducing propagation delay, lowering power consumption, and maximizing full-swing output. By simplifying the design and reducing chip die area, we seek to achieve a more efficient and effective FA implementation.

METHODOLOGY

This paper outlines a methodology that involves Design flowchart. For the software component, Mentor Graphics with Pyxis will be utilized, employing the 130nm process technology provided by Siemens EDA. Primitive logic gates will be designed using GDI full-swing technology. A library of optimized gates will be created, selecting components based on their power consumption, propagation delay, transistor count, design complexity/area, and power-delay product (PDP). This optimized library will be used to design a 4-bit full adder, which will be analyzed and compared to a CMOS equivalent.

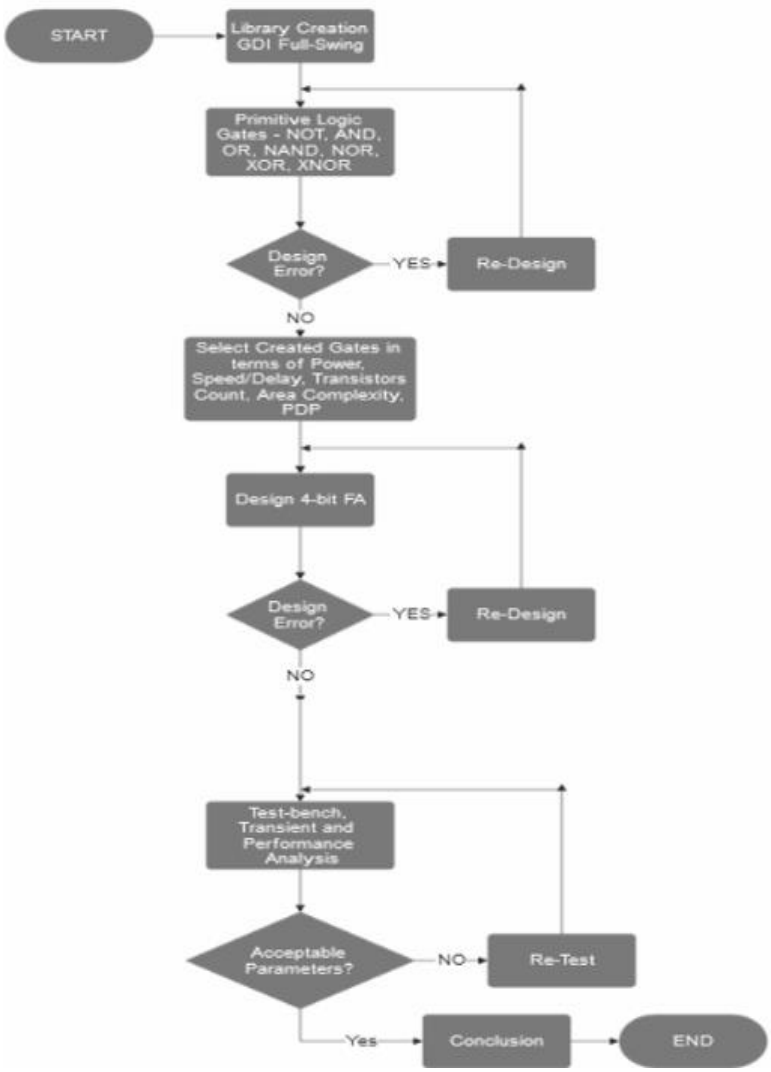

Figure 1: Design flowchart

Design Analysis

The designed FA with GDI technology using 130nm node process along with achieving full swing output will be analyzed in these following terms. The designed FA will be analyzed in terms of transistor count. A GDI cell consisting of the PMOS and NMOS can be designed in such a way that it will achieve n+2 inputs.

$$M=2*2n-1=2n-1+1=2*N=2n \quad (1)$$

$$N=2n-1 \quad (2)$$

Based on the equations (1) and (2) for GDI, where M is the maximal number of transistors that are needed to implement and N is the maximal count of GDI cells and n is the number of input variables. The technology used in this paper is 130 nm size, if we go for nm technology then the size (W/L) of the transistor needs to be changed based on the technology library. The lithographic process node size or the

technology node will also be compared. In the case of this project is a 130nm feature size which often refers to the Length from the W:L ratio or W/L. The designed FA will also be analyzed in terms of its wiring, area and circuitry design complexity. The analysis will be done in comparison to an equivalent CMOS FA and compared by inspections.

The designed GDI-based FA with full-swing output will also be analyzed in terms of its propagation delay. The propagation delay is related to the number of transistors along with its geometric complexity as in the wiring and thus it is determined by the input transition time also known as logical effort/time and also the load capacitance. The delay decreases with high input transition as in less logical effort or time for the output to go from a transient state into a steady-state. Propagation delay of MOSFETs can increase with increase in number of capacitance like load capacitance (fanouts or fan-outs) at the output voltage and the parasitic capacitances that exists at the diffusion terminals along with the wiring complexity which correlates with the area of the design. Thus for the propagation delay of the MOSFETs, it can be generalized with the following formula.

$$Transition\ Time = \frac{1}{Logical\ Effort} \quad (3)$$

$$Transistor\ Propagation\ Delay \propto \frac{Capacitances * Vdd * Vt * Resistance}{Transition\ Time * FrequencyClock} \quad (4)$$

$$RC = Resistance * Capacitance = Tau\ [s] \quad (5)$$

The designed FA will also be analyzed in terms of its power consumption or power dissipation. A high power usage will lead to more generation of heat energy as the acting usage of power would result in the reaction of high heat generation and thus an equal reaction of opposite power efficiency.

$$Static\ Power\ Usage = Vcc * Icc(op) \quad (6)$$

$$Dynamic\ (transient) Power\ Usage = Cpc * Vcc^2 * fclock * N \quad (7)$$

From the above formulas (6) and (7) are that the Vcc is the supply voltage, Icc is the supply current, fclock is the clock frequency while N is the number of transistors input switching. The FA will also be analyzed in terms of the PDP or Power Delay Product. The PDP is the product of the power consumption with the time delay and thus a lower power and/or lower delay can lead to lower PDP noted in equation (8).

$$PDP = Power\ Consumption\ [W] * Propagation\ Time\ Delay\ [s] \quad (8)$$

While not an industrial standard, the product of the entire transistor count along with the propagation delay can also be analyzed.

$$Tr * Delay = Transistor\ Count * Propagation\ Delay \quad (9)$$

The Rise Time (RS) is a measure of the pulses transitioning from Low (minimum) to High (maximum) while the Fall Time (FT) is a measure from High to Low states.

Design Modelling

The design techniques that are going to be checked in this research paper are CMOS and GDI. CMOS is the conventional type technology that is used in Industries. GDI is a technology that is developed to overcome the problems in existing CMOS. The modelling of the design for each digital circuit design techniques are different. This sub-section will discuss the expected design modelling for the CMOS and the GDI techniques.

CMOS Cell Predictive Steps:

- Complementary Boolean expression or equation for the design.
- Pull-Up Network (PMOS cell) – AND operator in parallel, OR operator in series.
- Pull-Down Network (NMOS cell) – AND operator in series, OR operator in parallel.
- Vdd to Pull-Up
- Vss or GROUND or GND to Pull-Down
- Inverter or NOT cell reserved for any complementary inputs.

While the GDI with full swing output cell steps are as predicted below.

- GDI with Full-Swing Output Cell Predictive Steps:
- Two transistors connected in series and the Gate input of both transistor will be fixed with an input. The source input of P-MOS will be P-diffusion The drain of N-MOS will be N-diffusion
- Doing a Karnaugh Mapping (K-Map) of 2x2 of PN/BCB, if P-diffusion = 00 then P to GND. If P = 01 then B to P. If P = 10 then BC to P. If P = 11 then P to VDD.
- If N-diffusion = 00 then N to GND. If N = 01 then B to N. If N = 10 then BC to N. If N = 11 then N to Vdd.
- In order to get complementary output, wherever the diffusion terminals are connected then either PMOS or NMOS will be connected in parallel to it depending on where the diffusion terminal is situated at either the Pull-Down Network or Pull-Up Network.

RESULTS & ANALYSIS

The comparisons of MOSFETs IC logic design using GDI, GDI Full Swing (GDI FS) and CMOS are presented in Table 1, until Table 9.

Table 1: GDI, GDI FS and CMOS for AND Gate

	Power Dissipation (W)	Number of Transistors	Propagation Delay fall to fall time (s)
GDI	3p	2	12n
GDI Full Swing	230p	6	12n
CMOS	343p	6	60n

Table 2: GDI, GDI FS and CMOS for OR Gate

	Power Dissipation (W)	Number of Transistors	Propagation Delay fall to fall time (s)
GDI	12.5p	2	10n
GDI Full Swing	480p	6	10n
CMOS	561p	6	20n

Table 3: GDI, GDI FS and CMOS for NAND Gate

	Power Dissipation (W)	Number of Transistors	Propagation Delay fall to fall time (s)
GDI	184p	4	10n
GDI Full Swing	186p	5	10n
CMOS	188p	4	22n

Table 4: GDI, GDI FS and CMOS for NOR Gate

	Power Dissipation (W)	Number of Transistors	Propagation Delay fall to fall time (s)
GDI	324p	4	20n
GDI Full Swing	408p	5	20n
CMOS	342p	4	21n

Table 5: GDI, GDI FS and CMOS for XOR Gate

	Power Dissipation (W)	Number of Transistors	Propagation Delay fall to fall time (s)
GDI	170p	4	20n
GDI Full Swing	640p	8	20n
CMOS	1111p	8	22n

Table 6: GDI, GDI FS and CMOS for XNOR Gate

	Power Dissipation (W)	Number of Transistors	Propagation Delay fall to fall time (s)
GDI	320p	4	10n
GDI Full Swing	585p	8	10n
CMOS	891p	8	21n

Based on observation from Table 1 to 6, power dissipation and number of transistors for logic gates designed using GDI is lower than GDI full swing. Meanwhile the propagation delay for both GDI and GDI full swing design shows the same performance.

Table 7: GDI, GDI FS and CMOS for Half Adder

	Power Dissipation (W)	Number of Transistors	Propagation Delay fall to fall time (s)
GDI	-	-	-
GDI Full Swing	2200p	14	10n
CMOS	3000p	14	21n

Table 8: GDI, GDI FS and CMOS for Full Adder

	Power Dissipation (W)	Number of Transistors	Propagation Delay fall to fall time (s)
GDI	-	-	-
GDI Full Swing	2800p	34	11n
CMOS	3500p	34	20n

Table 9: GDI, GDI FS and CMOS for 4-bit Full Adder

	Power Dissipation (W)	Number of Transistors	Propagation Delay fall to fall time (s)
GDI	-	-	-
GDI Full Swing	9000p	136	11n
CMOS	15000p	136	26n

DISCUSSION

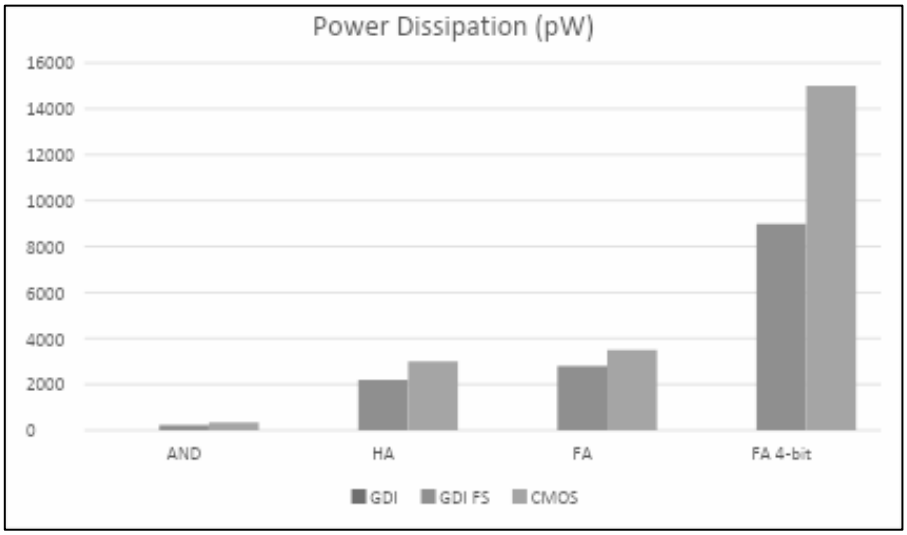

Figure 2 Power Dissipation Comparison

Based on the obtained results from the designed IC logic circuits, utilizing the 130nm MOSFET lithographic process and employing GDI logic, GDI FS logic, and CMOS logic, show that GDI logic achieves the lowest delay and power dissipation, resulting in the least heat generation over time. This is primarily due to the reduced number of MOSFETs in GDI logic, which minimizes propagation pathways and parasitic capacitances, leading to lower power consumption and heat output compared to the other two logic types.

However, this energy efficiency comes at the cost of switching speed. While GDI logic is slower than CMOS, it offers improved scalability due to its lower propagation delay. This advantage is particularly evident when comparing GDI FS logic to CMOS with an equal transistor count. GDI FS logic, despite using the same number of transistors as CMOS, theoretically achieves lower propagation delay and power usage while maintaining comparable speed at the same lithographic node. However, issues arise with simultaneous input/output transitions (rise and fall times), which can cause fluctuations in output, affecting stability.

Additionally, GDI and GDI FS logic face challenges with full-swing output. In GDI, inputs are applied to the gates and sources, while VDD and VSS are tied to the bulk substrates. This design leads to output voltage spikes or fluctuations, in contrast to the ideal full-swing outputs seen in CMOS logic. Potential solutions to mitigate this issue include implementing buffers with comparators or triggers, or reducing internal parasitic capacitances. Another option could involve using alternative semiconductor materials, such as Gallium Arsenide (GaAs), to improve performance and reduce parasitic effects. Finally

the Modified GDI has fewer transistor count and less power dissipation met our goal of this research. The result analysis shows better performance when compared with CMOS.

AUTHOR BIOGRAPHY

Mohamad Zarith Zainudin, is a Bachelor of Electronics Engineering with Honours graduate in the Faculty of Engineering Science and Technology, Infrastructure of Infrastructure University Kuala Lumpur. *Email: z.zarith@yahoo.com*

Jebashini Ponnian has been a lecturer in the Electrical and Electronics Engineering Department, in the Faculty of Engineering, Science and Technology Infrastructure (FEST), at Infrastructure University Kuala Lumpur (IUKL) since 2009. She holds a doctoral degree in Doctor of Philosophy (Ph.D.) Engineering (By Research) from Multimedia University (2024). Her area of specialisation is in analog and digital electronics design. *Email: jebashini@iukl.edu.my*

Norazlina Mohamed has been a senior lecturer in the Electrical and Electronics Engineering Department, in the Faculty of Engineering, Science and Technology Infrastructure (FEST), at Infrastructure University Kuala Lumpur (IUKL) since 2008. She holds a Master of Engineering in Electrical (Electronics & Telecommunications) from Universiti Teknologi Malaysia (2008). Her area of specialisation is in analog and digital electronics design. *Email: norazlina@iukl.edu.my*

Ima Sulaiman is currently working as a senior lecturer in the Electrical and Electronics Engineering Department, in the Faculty of Engineering, Science and Technology Infrastructure (FEST), at Infrastructure University Kuala Lumpur (IUKL) since 2008. She holds a Master of Engineering in Electrical (Electronics & Telecommunications) from Universiti Teknologi Malaysia (2007). Her area of specialisation is in digital electronics design and education engineering. *Email: ima@iukl.edu.my*

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REDUCING ON CONSTRUCTION ACCIDENTS IN KLANG VALLEY: CAUSES. CHALLENGES AND PREVENTIVE APPROACHES

Ashleenjet Kaur[1], Haslina Mohamed[1], Nurul Huda Mislan [2], & Hanah Zakariah[1]
[1]*Faculty of Engineering, Science and Technology, Infrastructure University Kuala Lumpur, MALAYSIA*
[2] *Ranhill Bersekutu Sdn Bhd, MALAYSIA*

ABSTRACT
The dataset on accidents in the construction sector portrays the Malaysian construction industry as the crucial sector which requires a significant reformation on the present site safety measures. Given the rising rates of accidents, ill-health, and safety concerns associated at construction sites, this sector is deemed as the most hazardous among other industries nevertheless, leading to become a matter of concern especially for the stakeholders in this industry. This study aims to investigate the various causes and effects of accidents and suggest effective preventive measures to curb accidents from occurring at the site. Identified the important elements that contribute to accidents in the region's construction industry and investigate viable accident-reduction strategies.The method used in this research is a questionnaire survey which is distributed online to construction professionals within the Klang Valley area. 50 sets of online questionnaires were returned back and the responses were using the Likert scale to scale the answer. Analysis was using frequency distribution and mean score. Findings of this study reveals that accidents are mostly caused by insufficient training and orientation delivered to the workers before the project starts. Meanwhile, the most prominent effect of accidents is that it leads to bad reputation of the company and a major number of respondents agreed that implementing a risk assessment plan to identify the possible risks is the best solution to mitigate high accident rate.

Keywords:
Construction, Accidents, Causes, Effect, Preventive measures, Questionnaire, Construction Parties

INTRODUCTION

Construction industry undoubtedly plays a major role in encouraging growth in the country's economy nevertheless, it is also vulnerable to accidents which can happen at any moment during the building phase placing workers' life in jeopardy as it involves several parties performing dangerous activities in a single environment (Ayob et al., 2018). The rate and statistics of accidents that occur in the construction industry for the country are still high based on a study conducted by Hamid et al, (2018). Latiffi et al. (2017) claim that this is because different construction parties have varying degrees of capacity to embrace and grasp the concept. (Haslina Mohamed et al., 2023).

Accidents occurring at the workplace on a daily basis are quite common in the construction sector culminating in workplace fatalities and also substantial implications for construction firms. The percentage of fatalities at Malaysian construction sites has skyrocketed over the years despite numerous efforts that have been taken to avoid them. Thus, respective authorities and construction companies need to be strict in enforcing safety guidelines at the workplace as an approach to reduce the likelihood of accidents at the construction site. The research's objectives in addressing this issue are to identify the major causes and effects of accidents and to propose proper mitigation measures to minimise accident rates.

LITERATURE REVIEW

Natural occurrences and human errors are the two main factors why construction accidents happen. Construction site mishaps are prompted through the reckless behaviour on the behalf of construction companies or employees of the company. Accidents at the workplace, according to Arachchige and Ranasinghe (2015), not only lead to delays but impact the development's time duration as well as raising expenses, and they also destroy the reputation of the construction companies involved.

Since human production activities are changing so quickly, it is essential to continuously enhance and add to all facets of development, starting with the development of infrastructure. (Freelove et al., 2022; Chen Youle, & Haslina Mohamed., 2024). However, as can be interpreted by looking at construction accident figures, there has been little significant reduction in accident numbers. DOSH (Department of Occupational Safety and Health) The construction industry continues to have the maximum mortality rate, in 2023, accounting for 45 fatalities (DOSH, 2024). Selangor have higher reported cases on construction accident compared to other industries on January to May 2023 (DOSH, 2024)

The safety efficiency of the Malaysian construction industry is subpar, as showcased by the large number of incidents and their increasing frequency. Despite the fact that the accident and death rates have been down in recent years, it is nevertheless unsatisfactory to declare that construction sites are now safer than they were previously. However, problems may arise in building projects that are created by the design because of the inexperience of some construction partners, their unfamiliarity with building materials and construction procedures, the lack of depth in the design, their incapacity to guide construction, or their ineffective guidance (Yu Chunchun & Zulhazmee Bakri., (2024)

Accidents do not happen on its own; they are frequently triggered by a set of conditions or by an individual's behaviour as they are practically unavoidable in every construction project. The preponderance of the accidents that occurred was caused by reckless behaviour as well as acts or through hazardous working conditions at the worksite. According to Ridley (1986), 99 of the accidents are driven by either unsafe behaviour or unsafe condition or by a combination of both. In other terms, accident causal factors can be divided into two categories known as human errors and non-human errors. The Table 1 below shows six main categories of accident causes and their respective sub-causes.

Table 1: Causes of accidents in the construction industry based on reports from DOSH (Hamid et al., 2008; 2019; Halim et al., 2020).

Causes of Accidents	Breakdown Aspects of Causes
Unsafe equipment	• Unavailability of safety equipment • Failure in equipment • Not ergonomics
Worksite conditions	• Poor site management in terms of arrangement of construction materials, equipment and waste materials. • Worksite is slippery and muddy • Excessive noise • Poor illumination • Poor ventilation
Distinctive nature of industry	• Work operation as in rough work, mental and physical requirements, high level of energy required. • Variable hazard • Working at high elevation • Limitation of working area

	• Transient workforce
Unsafe method	• Incorrect procedure of work • Level of knowledge • Inability to abide by the work procedure
Human element	• Negligence • Experience (total working hours and training undertaken) • Body effort (tiredness, pain, drug addiction, intake of alcohol) • Personal Protective Equipment (PPE) • Self-emotion • Attitude
Management	• Education (safety training and orientation) • Poor safety policies • Poor inspection program • Inadequate warning system • Safety not regarded as important criteria • No compliance with safety regulation • Insensitive • Motivation program

Accidents can generate delays in construction, lead to huge costs, and, most importantly, harm the company's public image, including losing employees' faith or being barred from negotiating on government projects (Arachchige and Ranasinghe, 2015). Construction accident repercussions are classified into three categories: humanitarian, economic, and legal. Some of the most major consequences include scheduling time wasted, corporate reputation harm, psychological repercussions on personnel, and medical expense expenditures (Ahmed, 2019).

The construction field has a high-risk potential, with a high likelihood of serious accidents occurring on the jobsite. Since there are various inherent dangers at construction sites, all reasonable precautions should be taken to prevent them. Workers will be more efficient and motivated to work if they are given the idea that they are safe. If the company maintains a high standard of health and safety, its professional image will improve, making it more appealing to potential stakeholders. Some of the safety measures that may be implemented are performing routine inspections of the equipment, using the appropriate protective gear, executing risk assessment before the project is started, and providing sufficient training to workers.

Based on the research from the previous study, thirty (30) causes were classified into 6 main categories, 9 effects and 7 mitigation approaches were determined and tabulated in the Table 2 below.

Table 2: Causes, effects and mitigation approaches.

Causes (Hamid et al., 2008; 2019; Halim et al., 2020)	**Effects** (Ahmed. S., 2019)	**Mitigation Approaches** (Toole, T. M., 2002; MacDonald et al., 2009; Krasno, 2021)
Unsafe equipment	Human suffering exposing workers to injuries, disability and fatalities	Performing routine inspections of the equipment
Worksite conditions	Affect productivity and safety of workers	Using appropriate protective gear
Distinctive nature of industry	Loss of income or decline in wages	Conducting safety meetings on a daily basis
Unsafe method	Increase the risk of mental disorders	Executing risk assessment

Human element	Cause project delay	Providing sufficient training to the workers
Management	Increase in project cost	Comply with OSHA guideline and report unsafe working condition
	Project abandonment by involved parties	Engage in communications
	Reputation of the organization is tarnished	
	Employers is held account for the negligence of workers during work and injuries faced by their workers	

METHODOLOGY

The quantitative method was implemented in this study and the questionnaire survey which was distributed using Google Form tool on the targeted construction professionals in the Klang Valley region. The questionnaire survey contains four sections for the respondent to answer consisting of Section A for the demographic information, Section B for the causes of accidents at construction sites, Section C for the effect of accidents at construction sites and finally Section D for preventive measures to reduce accidents in the construction industry. The collected data was tabulated and analysed in the Microsoft Excel. Data analysis is used Frequency distribution using Percentage formula (Triola, M. F., 2018) and Mean Score formula (Triola, M. F., 2018). The result was later presented in the form of a table and chart. For the objective 1 until 3, the mean score was computed and the ranking was given based on the mean score value. The formula shown below is used to calculate the percentage frequency and mean score.

$$Percentage\ (\%) = \frac{Frequency\ of\ selected\ answer}{Total\ frequency}\ x\ 100\%$$

$$Mean\ Score = \frac{(\Sigma\ f \times s)}{5N}\ \ (1 \leq MS \leq 5)$$

ANALYSIS AND DISCUSSION

For methods of verifying the results, activities such as assuring methodological coherence, sample sufficiency, creating a dynamic link between sampling, data collecting, and analysis, thinking theoretically, and theory creation are examples of verification techniques that assure data dependability and validity (Morse et al. 2002; Hanah Zakaria et al., 2023).

Through the online questionnaire, fifty (50) respondents out of 200 targeted respondents have responded within the duration of 1 month and 18 days. Based on the analysis conducted for Section A, the highest number of responses was obtained with a percentage of 3% (3 of 50) from JA Consult which is a traffic consultancy firm meanwhile certain companies have 2 respondents (2%) and the rest only one respondent (1%) from each company.

From Figure 1, 54% (27 of 50) of the respondents are working with companies that handle infrastructure projects and 4% (2 of 50) of the respondents are companies involved with industrial projects. In Figure 2, it can be seen that 42% (21 of 50) of respondents come from the contractor background while 12% (6 of 50) are working in fields apart from those mentioned in the questionnaire.

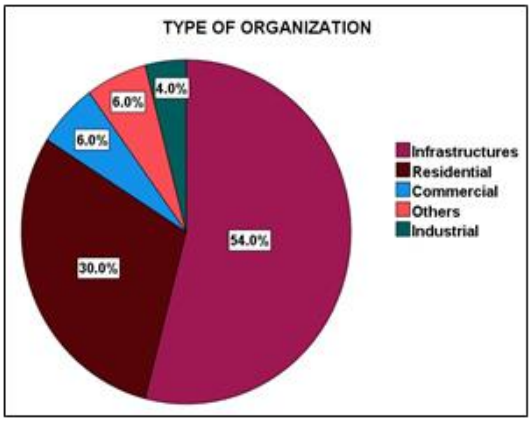

Figure 1: Type of respondent's organization.

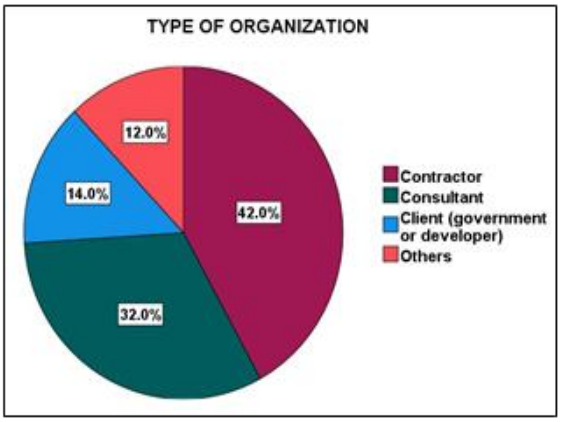

Figure 2: Category of the respondent's organization.

Based on Figure 3, Engineers possesses the highest percentage of responses received with a percentage of 32% (16 of 50) as they are more exposed to hazards due to working at the project sites as per compared to others while the lowest responses with 4% (2 of 50) comes from the Quantity Surveyor. The majority, 44% (22 of 50) of the respondents have less than 5 years working experience while 10% (5 of 50) of the respondents have more than 20 years of experience. This indicates that respondents having 5 years' experience or less have a lack of interest towards safety practices and are highly likely to be exposed to danger at sites.

According to the pie chart in Figure 5, 54% (27 of 50) respondents answered "Yes' ' indicating their experience of encountering workplace accidents while 46% (23 of 50) had not experienced any occurrence of accidents at the workplace. Accident incidents may occur due to few factors such as the availability of a safety plan, worksite conditions, and level of knowledge of workers. Figure 6 implies that 88% (44 of 50) respondents have been exposed to safety programs focusing on training for employees while 6% (3 of 50) have not joined any safety programs implying that they lack knowledge on safety practices for site works. Therefore, this individual must not be given any critical roles as it may affect the employee and also the public.

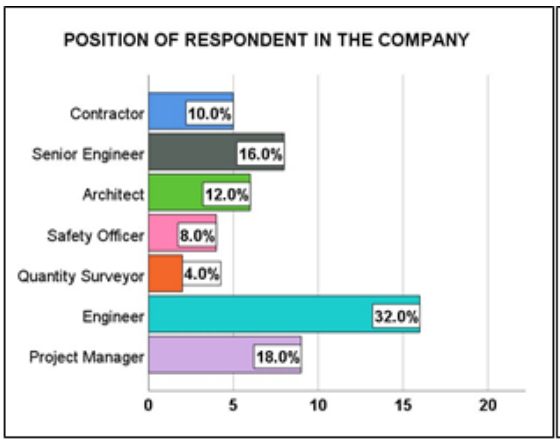

Figure 3: Position of the respondent in the company.

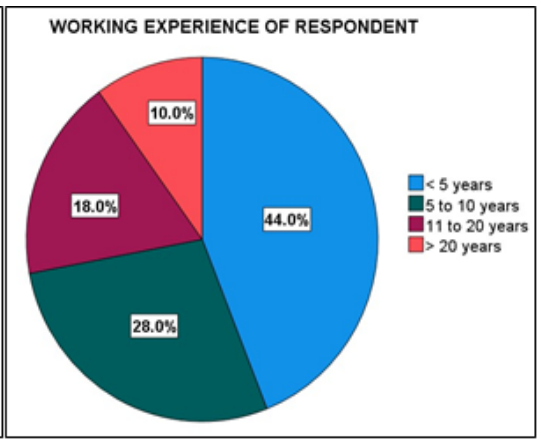

Figure 4: Working experience of respondent.

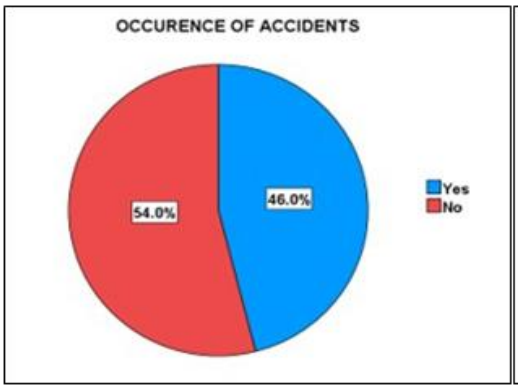

Figure 5: Occurrence of accidents.

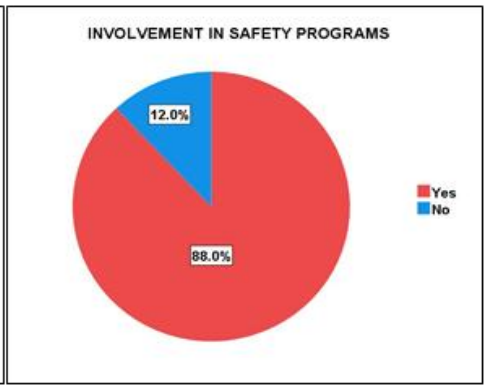

Figure 6: Respondent's involvement in safety programs.

The questions in Section B aids in determining the causes of accidents at the construction site which is also the research's first objective. Based on Figure 7, Education (insufficient safety training and orientation before the project is started) has the highest mean score of 4.18 out of 5.00 and falls under the category of management meanwhile the lowest mean score of 3.06 out of 5.00 is the self-emotion of workers falling under the human element category for the causes of accidents at site. According to Lai et al., (2011), the most effective method to prevent hazards is by providing safety training to employees which is essential because it prohibits them from committing mistakes which might cause accidents, and also to permit employees to execute their particular job obligations with proper safety skills. This is also in line with Birhane et al;(2020): Dorji et al;(2006) and Phawchamnan et al; (2018) on health and safety training and its correct application can reduce the occurrence of accidents on construction projects.

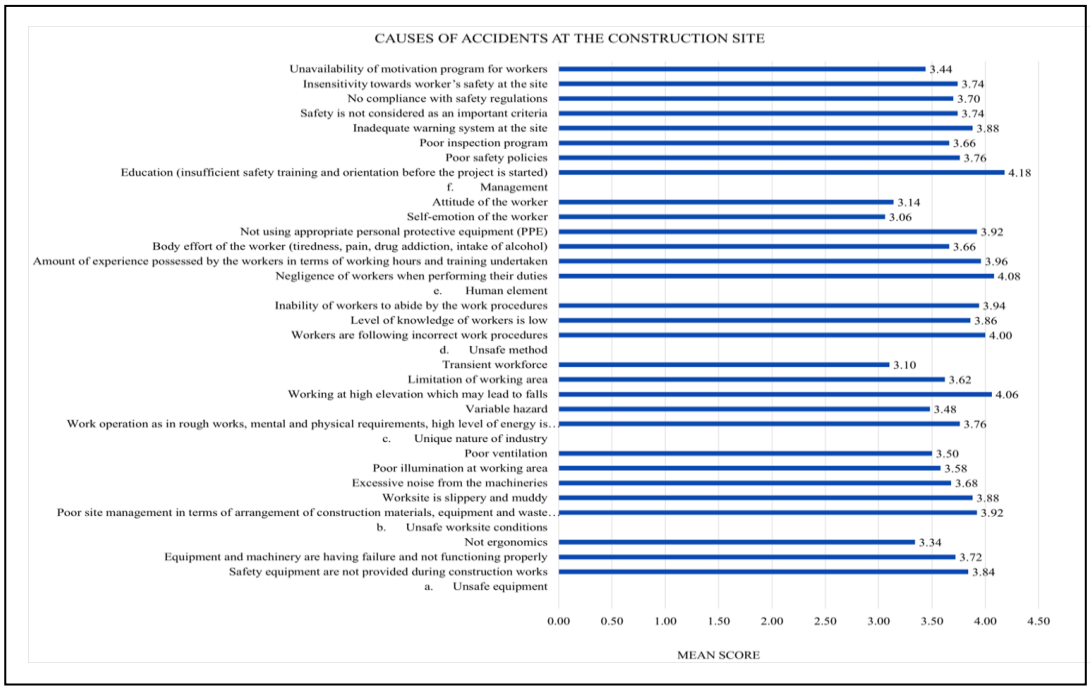

Figure 7: Mean score for causes of accidents at the construction site.

As referred to the designed questions in Section C to achieve the second objective of the study which is to study the effects of accidents at the construction site, leading to a bad reputation. The company is ranked the highest as it has a mean score of 4.34 out of 5.00. while the lowest ranking increases the risk of mental illness in workers by possessing a mean score of 3.44 out of 5.00 as portrayed in Figure 8. Occurrence of accidents can lead to a company's image being tarnished as clients may not be able to build trust on the company and this will highly affect the company since in the long run, the company's production and output will be hindered. Mental illness of workers is not specifically caused by work pressure but can also be caused by various other factors such as genetics, personal financial problems or through ongoing medical conditions.

Economic perspective and condition are the underlying causes of fatal accidents in the construction industry (Hale et al, 2012; Jaafar et al, 2017). This is because aspects of financial and project development are deemed to be more important than OSH management (Jaafar et al, 2017). The social element covers the impact originating from the community and clients in particular. There is a lack of awareness and emphasis by the community on OSH issues in the construction industry (Hale et al, 2012; Jaafar et al, 2017). This is aligned with the finding in Section C.

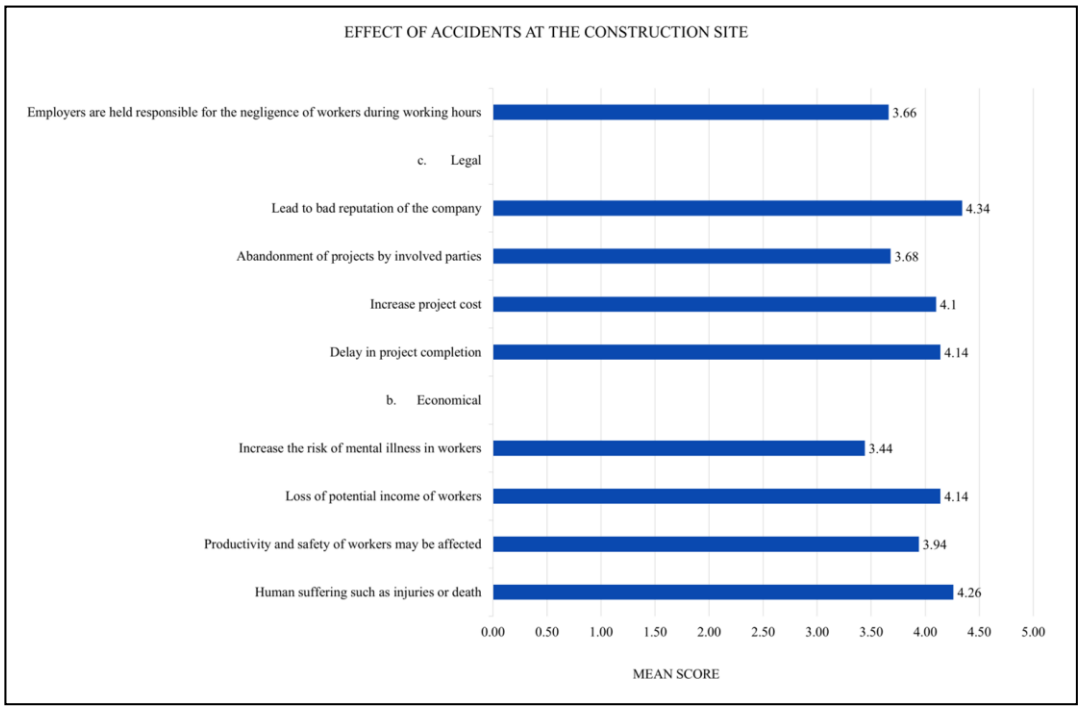

Figure 8: Mean score for effect of accidents at the construction site.

The questions in Section D are designed to achieve the third objective of the study which is to propose suitable preventive measures to reduce accidents rate in the construction site. According to Figure 9, 82% (41 of 50) respondents are satisfied with the safety measures that are implemented in the company where they are working at while 18% (9 of 50) respondents are dissatisfied with the safety measure implemented in the company. The findings signify that worker's safety is not a main priority for certain companies, thus could contribute to a rise of accidents at building sites.

Based on the listed preventive measures to reduce accidents in Figure 10, the highest mean score of 4.38 out of 5.00 lies in implementing a risk assessment plan to identify the possible risks while the lowest mean score of 3.48 out of 5.00 is determined as engaging in communication. The highest ranking

indicates that a risk assessment is very crucial to be carried out as it helps to determine the presence of potential dangers that may arise throughout the project completion in order for the respective authorities to mitigate the hazards. Slightly mean score value is 4.32 which is performing routine inspections of equipment used at the sites. The finding is similar to Xu et al, (2021), in which to prevent the unsafe statuses of objects, the status of safety protection equipment can be regularly checked. Engaging in communication is less effective as difficulties may occur in terms of language barrier between the employer and the employees especially when employing international workers.

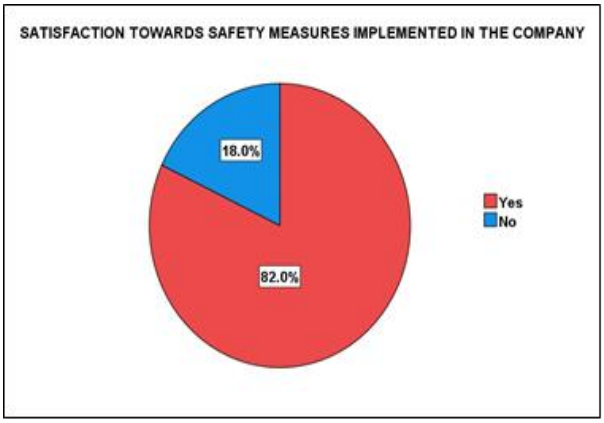

Figure 9: Respondent's satisfaction towards safety measures implemented in the company.

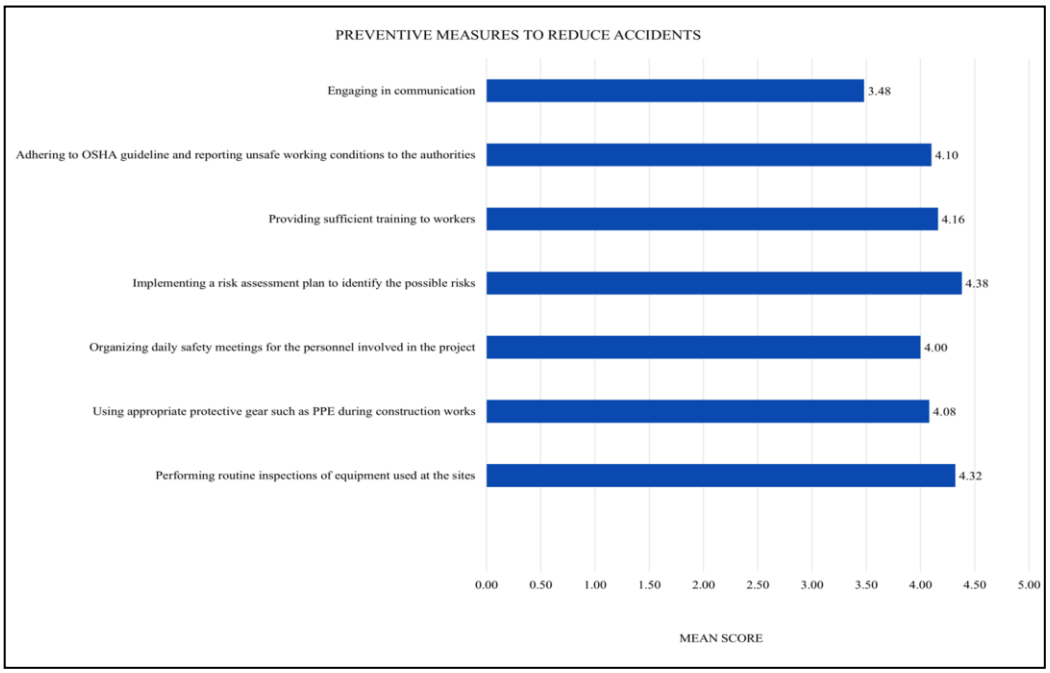

Figure 10: Mean score for preventive measures to reduce construction accidents.

Having two-way communication is also important as miscommunication can lead to major work-related accidents, project rework, and employee concerns in the long period of time.To prevent the unsafe statuses of objects, the following measures can be adopted. For example, safety protection equipment can be used based on operational requirements. The status of safety protection equipment can be regularly checked.

CONCLUSION

When contrasted towards the other causes outlined in the questionnaire survey, a large percentage of the targeted respondents concede with an overall mean of 4.18 out of 5.00 on the statement that education, which is insufficient safety training and orientation programs for employees before the project is started, is the leading cause of accidents. Managers and supervisors should invest time and commitment in delivering effective and beneficial safety training. Employee safety must be optimised by engaging every employee with safety training at varying periods, as well as can be conducted via regular interactions with supervisors, managers, and employees.

Accidents at construction sites lead to bad reputation, according to the large percentage of the respondents, with a mean score of 4.34 out of 5.00 as the main effect of accidents at construction sites. Workers who speak details regarding the inadequate safety management at their workplace may jeopardize a company's image. Having a bad reputation for a firm is correlated with greater hiring and selection costs, worse operating margins, and lower returns. As an outcome of reputational damage, client and stakeholder trust is harmed, and initiatives are impeded. Damage to a company's reputation raises the potential of liquidity, which has an impact on stock prices and, eventually, market capitalization.

Implementing a risk assessment plan is the best preventive measure that can be carried out to reduce the rate of accidents in the construction industry as agreed by the majority of respondents. A firm can use a risk assessment plan to prioritise hazards and formulate a framework to reduce the chances of the hazard to occur. Such an approach not only cuts the organisation time, money, and physical assets, but it also allows employees to focus on business-related activities over extended periods of time.

RECOMMENDATION OF STUDY

Based on data of the research in analysis and discussion, the research is mainly attentive on the way of determining the causes of accidents, how it affects in terms of humanitarian, economical and legal as well as the proposed preventive measures to reduce the accidents at construction sites. The International Labour Organization (ILO) also recommends that organizations must manage occupational safety and health to provide a safe and healthy workplace (Park et al., 2016; Rahman, N.H., & Mohd Kamil, N.L., 2022). Hence, listed below are the recommendations that can be proposed for the usage of future research. Future researchers may conduct detailed research to identify the possible causes of construction accidents as in the current modern world, hazards can be present everywhere. There should be more study on the effects of construction accidents as there is limited research carried out regarding this issue. The importance of identifying and proposing better preventive measures which are more efficient in mitigating the high accidents rate in the construction field. Attempting to increase the number of targeted respondents in order to acquire adequate data for comparable purposes.

AUTHORS BIOGRAPHY

Ashleenjet Kaur, is a graduated Bachelor of Civil Engineering (Hons) in the Faculty of Engineering Science and Technology, Infrastructure of Infrastructure University Kuala Lumpur. *Email: ashleenchaterine@gmail.com*

Haslina Mohamed is a Senior Lecturer in the Civil Engineering & Construction Department, in the Faculty of Engineering, Science and Technology Infrastructure (FEST), at Infrastructure University Kuala Lumpur (IUKL) since 2001. She holds a Master of Project Management from Open University Malaysia (2017), a Bachelor's degree in Engineering (Civil), and a Diploma in Civil Engineering from Universiti Teknologi Malaysia (UTM). Her area of specialisation is in construction safety and project management. *Email: haslina@iukl.edu.my*

Nurul Huda Mislan (Ir), PEng, is currently working at Ranhill Bersekutu Sdn Bhd as Head of Geotechnical. She has 20 years working experience working in Malaysia and Australia. Email: *nurulhuda@ranhill.com.my*

Hanah Zakariah is a Senior Lecturer at Infrastructure University Kuala Lumpur, with a strong background in geomatics and a focus on the practical applications of field technologies and GIS. She is passionate about creating learning environments that engage students and promote critical thinking, particularly within the field of geospatial sciences. Her research interests include digital twinning, gravity field data, and Geographical Information Science. *Email:hanah@iukl.edu.my*

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STUDY ON THE INFLUENCE OF DIFFERENT TYPES OF POLYPROPYLENE FIBER CONCRETE ON FIRE RESISTANCE

Kong Linjie [1,2] & Norul Wahida Kamaruzaman[1]
[1]*Faculty of Engineering, Science and Technology, Infrastructure University Kuala Lumpur MALAYSIA*
[2]*Zhejiang Construction Vocational and Technical College, Construction Engineering Branch, CHINA*

ABSTRACT
The open flame calcination test method was employed to assess the residual stress of fiber concrete in a study aimed at understanding the fire resistance of fiber concrete mixed with different types of polypropylene fibers, both alone and in combination with steel fibers. The results indicated a significant improvement in the fire resistance of concrete with the incorporation of fibers. Notably, concrete mixed with polypropylene monofilament fiber and steel fiber (PSCF1) exhibited minimal compressive strength loss, highlighting its superior performance under fire exposure. Among the various types of polypropylene fibers tested, polypropylene monofilament fiber (a) demonstrated better fire resistance compared to the other two types of polypropylene fibers. This suggests that the specific type of fiber used in the mix plays a crucial role in enhancing the fire resistance properties of concrete. The study underscores the importance of fiber selection in optimizing the fire-resistant capabilities of concrete structures. By incorporating appropriate fibers, the resilience of concrete in high-temperature conditions can be significantly enhanced, which is crucial for the safety and longevity of structures exposed to fire hazards. The findings of this research provide valuable insights for the construction industry, offering guidance on the use of fiber-reinforced concrete in applications where fire resistance is a critical requirement. Overall, the study contributes to the development of more robust and fire-resistant building materials, potentially leading to safer architectural designs.

Keywords:
Polypropylene fiber; steel fiber; fiber concrete; fire resistance

INTRODUCTION

Under the action of high temperature, the compressive strength of ordinary concrete decreases as the temperature rises. According to recent research, at 600°C, the compressive strength of concrete is reduced to approximately 45%, and at 1000°C, it completely loses its pressure-bearing capacity (Chen et. al., 2023). When the temperature exceeds 500°C, its compressive strength cannot recover, and steel-concrete materials lose their tensile capacity at around 600°C. In actual building fires, concrete completely loses its elastic modulus within 0.5-1 hour. The impact of high temperature on concrete materials is significant and cannot be ignored. Compared with ordinary concrete, high-strength concrete is more prone to explosive damage when exposed to high temperatures or open flame conditions (Nguyen et. al., 2023). This explosive damage endangers the integrity of the component, and the loss of bearing capacity of high-strength concrete at and after high temperatures is significantly greater than that of ordinary concrete (Althoey, 2023). Research shows that there are two main reasons for the explosion of high-strength concrete. One is the principle of vapor pressure. Due to the high density and low permeability of high-strength concrete, the water vapor inside the concrete cannot be discharged normally at high temperatures, causing a large accumulation of water vapor inside the concrete (Hager, I., and Mróz, G. ,2019). Vapor pressure generates expansion pressure. As the temperature increases, the expansion pressure inside the concrete gradually increases, causing bursting. The second is the principle of thermal stress, that is, when a fire occurs, a temperature gradient is generated inside the concrete, and the thermal stress caused by the thermal gradient is eventually causing the concrete to burst

The measures proposed to solve the high-temperature explosion protection of high-strength concrete due to these two reasons mainly include two aspects; increasing the pores of concrete to reduce

vapor pressure and reducing the temperature difference between concrete substrates to reduce thermal stress (Khoury, 2023). Studies have shown that adding polypropylene fibers to concrete can achieve the purpose of reducing vapor pressure. The principle of action is: the melting point of polypropylene fibers is about 200°C. Therefore, the polypropylene fibers scattered inside the concrete structure will be in the concrete during a fire. Since the melting point has been reached during the self-evaporation stage, it melts to form numerous small pores. These pores leave space for water vapor inside the concrete, effectively relieving the vapor pressure of the concrete, thereby reducing concrete bursting; another measure is to mix steel into the concrete. Fiber, because steel fiber is a material with high thermal conductivity, it is helpful to improve the temperature difference between the matrix, thereby reducing the thermal stress of concrete (Zhan Sun et. al., 2024). At present, there is no unified and authoritative standard for the high temperature performance and fire resistance of concrete in China. In general laboratory research, concrete is heated in a high-temperature furnace to conduct research on the high-temperature properties of concrete. However, the temperature field generated by heating in the high-temperature furnace is very different from the actual fire situation. In order to simulate the fire situation of concrete components more closely, this article uses an open flame heating experiment. This article mainly studies the effects of three different types of polypropylene fibers mixed alone or mixed with steel fibers on the fire resistance of high-strength concrete.

TEST RAW MATERIALS

The Ordinary Portland cement produced by Guangzhou Zhujiang Cement Factory whereas the fly ash used is from Dongguan Humen Shajiao Power Plant standard Grade II ash, which complies with the provisions of GB 1596-2005 "Fly Ash Used in Cement and Concrete". The sand used is having fineness modulus of 2.5 and a bulk density of 1500 kg/m^3 whereas the coarse aggregate is within the range of 5-20mm. Coarse aggregate used is granite gravel with a bulk density of 1630kg/m^3. The water reducing agent used is polycarboxylic acid high performance water reducing agent HPC-R The polypropylene fiber is produced by Changzhou Zhuwei Building Materials Co., Ltd. and steel fiber produced by Chongqing Yizhu Trading Co., Ltd. The physical properties of the fibers are shown in Table 1 and Figure 1.

Table 1: Physical properties of fibers

Fiber type	Length/mm	Tensile strength/MPa	Elastic modulus/GPa
Polypropylene monofilament fiber (a)	25	≥500	≥3.5
Polypropylene mesh fiber(b)	25	≥560	≥3.5
Polypropylene crude fiber(c)	25	≥530	≥7.0
steel fiber	25	≥1200	≥200

Polypropylene monofilament fiber (a)

Polypropylene mesh fiber (b)

Polypropylene crude fiber (c)

steel fiber

Figure 1: Polypropylene fiber and steel fiber

MIX RATIO DESIGN

The water-cement ratio of the matrix concrete used in the test is 0.29. Water: cement: fly ash: sand: stone = 160: 440: 110: 703: 1054 per cubic meter of concrete. According to the experimental results of previous studies on the effect of fiber content on the mechanical properties of concrete, the volume ratio of the steel fiber content in this article is 0.9%, that is, the steel fiber content per cubic meter of concrete is 70.2kg, and the polypropylene fiber content is 0.05%. , that is, the polypropylene fiber content per cubic meter of concrete is 0.45kg. The specific mix ratio is shown in Table 2. The test uniformly uses CF to represent benchmark concrete, SCF to represent steel fiber concrete alone, PCF to represent polypropylene fiber concrete alone, and PSFC to represent steel fiber and polypropylene fiber hybrid fiber concrete.

Table 2: Concrete mix ratio /(kg/m3)

Mix	Cement	Fly ash	Sand	Gravel	Steel fiber	Polypropylene fibers	Water	Water reducing agent HPC-R
CF	440	110	703	1054	—	—	160	6.6
PCF1	440	110	703	1054	—	0.45(a)	160	6.6
PCF2	440	110	703	1054	—	0.45(b)	160	6.6
PCF3	440	110	703	1054	—	0.45(c)	160	6.6
PSFC1	440	110	703	1054	70.2	0.45(a)	160	6.6
PSFC2	440	110	703	1054	70.2	0.45(b)	160	6.6
PSFC3	440	110	703	1054	70.2	0.45(c)	160	6.6

TEST METHODS

The test uses the water mixing method as the mixing process, that is, first put the gravel, sand, cement, and fly ash into the mixer and stir, and at the same time, sprinkles the steel fibers evenly into the mixing mixture to ensure that the process is completed within 1 minute. Stir for another 1 minute, add the polypropylene fiber to the water, and stir gently with a glass rod until completely dispersed. Finally, pour the water, polypropylene fiber, and water-reducing agent into the mixer and stir for 3 minutes before ending. The test was carried out in strict accordance with the national standards "Standard for Test Methods of Mechanical Properties of Ordinary Concrete" (GB/T 50081-2019) and "Standard for Test Methods of Fiber Concrete CECS 13: 2009" for specimen preparation and strength experiments. The test used 100 mm × 1 Compressive strength and splitting tensile strength tests were carried out before conducted an open flame test after curing for 28 days using SBI single combustion test equipment provided by Guangdong Jianke Construction Engineering Quality Inspection Center (Figure 2). The medium-scale combustion test was developed based on GB/T 20284-2006 "Single Combustion Test of Building Materials or Products" Test device. It is mainly composed of combustion chamber system, burner, propane mass flow controller, propane and standard gas supply system, smoke exhaust system, comprehensive measurement system, flue gas measurement system, and data acquisition and processing system.

Figure 2: SBI monomer combustion experimental equipment

Taking into account the melting point of polypropylene fiber and the temperature changes during actual fires, the test uses a fire temperature of 800°C, a heating rate of 50°C/min, and the maximum fire temperature is reached within 20 minutes. The specimen continues to be exposed to fire for 60 minutes and is closed after 60 minutes. The air supply valve allows the specimen to cool naturally (Figure 3). Take out the concrete cube test block from the single combustion experimental equipment, and after leaving it at room temperature for 24 hours, strictly follow the national standards "Standard for Test Methods of Mechanical Properties of Ordinary Concrete" (GB/T 50081-2019) and "Standard for Test Methods of Fiber Concrete" CECS 13 : 2009 to carry out the residual strength test of the test block.

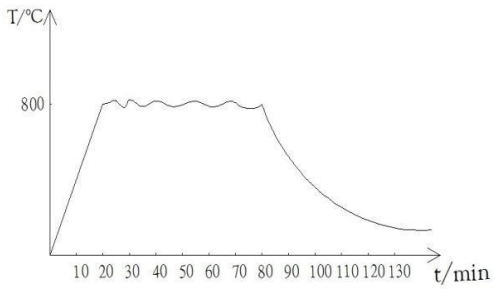

Figure 3: Temperature-time curve of fire resistance test

TEST RESULTS AND ANALYSIS

Appearance changes of concrete specimens after fire

After the fire resistance test, the fire surface of the specimen was basically milky yellow, and there was no obvious difference between the unfired surface and the unfired surface before calcination. The transition surface between them gradually changed from milky yellow to off-white to dark red and then to natural color; the fire surface of the specimen. There are obvious cracks on the surface, and some specimens even have peeling, missing corners, looseness, etc. However, the unfired surface shows good integrity and even no cracks. Since the flame temperature is around 800 °C, there is no strong explosion phenomenon in the specimen.

Table 3: Appearance of concrete with different proportions after fire

Serial Number	Color	Crack	Peeling Off Skin	Missing Corner	Loose	Burst
CF	Creamy yellow, light gray	interpenetrating, dense, wider	serious	have	Seriously, it will fall off if you hit it	none
PCF1	Same as above	Interpenetrating and dense	Slightly less	none	more serious	none
PCF2	Same as above	Interpenetrating and dense	Slightly less	none	more serious	none
PCF3	Same as above	interpenetrating, dense, wider	Slightly less	have	more serious	none
PSFC1	Same as above	Dense	less	none	none	none
PSFC2	Same as above	Dense	less	none	none	none
PSFC3	Same as above	Dense	less	none	none	none

Figure 4: Appearance of the concrete test block after being exposed to fire

RESIDUAL STRENGTH AND ANALYSIS OF CONCRETE AFTER HIGH TEMPERATURE

Residual compressive strength of concrete

The compressive strength of concrete after a fire determines the integrity, stability and post-disaster load-bearing capacity of the entire concrete component. It is an important evaluation basis for structural damage and an important guarantee for casualties and property losses in fires (Sifat *et. al*., 2024).

(1) Comparison of concrete residual compression test results

Since the experiment uses open flame heating, the specimen is subjected to non-uniform high temperatures, which makes the residual compressive capacity of each part of the specimen inconsistent. The fire-receiving surface and the unfired surface are not used as stress-bearing surfaces during loading. Therefore, the damage pattern of the specimen after fire is quite different from that of standard cured concrete. After the specimen was compressed, the corners of the fire surface were seriously damaged, and the damage pattern was different from that of the standard cured specimen. The damage pattern of the middle part was similar to that of the two ends. The damage basically occurs at the aggregate-slurry interface and inside the cement paste, and some aggregates also suffer comminuted damage. The fire surface of the test block was severely damaged, mainly in the form of powder, while the unfired surface had better integrity than the fire surface. The edges and corners did not fall off seriously, but there were obvious cracks. It is difficult to distinguish the difference in residual compressive strength between baseline concrete and fiber concrete simply based on the damage pattern. However, in the hybrid fiber concrete mixed with steel fibers, the sound of steel fibers being compressed was clearly heard in the test. And by observing the damaged test block, it can be seen that after open flame calcination, the bonding degree between the steel fiber and the concrete on the fire surface of the test block decreased significantly, while the polypropylene fiber has disappeared.

Figure 5 Destruction patterns of benchmark concrete, single-polypropylene fiber concrete and hybrid fiber concrete after compression

(2) Test data and analysis

From the analysis of Table 4 and Figure 6, it can be seen that the 28-day compressive strength of concrete mixed with polypropylene fiber alone is slightly smaller than that of the benchmark concrete. However, their residual compressive strength is slightly higher than that of the benchmark concrete. It can be seen that the incorporation of polypropylene fiber has an impact on concrete. The compressive bearing capacity after fire has a positive impact; from the perspective of reinforcement ratio, regardless

of the mixing method, the residual compressive strength of fiber concrete is higher than the benchmark concrete; and the reinforcement effect of polypropylene-steel fiber concrete is very obvious; From the perspective of reinforcement ratio, the residual compressive strength of concrete mixed with polypropylene crude fiber (c) is better than that of the other two types of polypropylene fiber alone, while the residual compressive strength of concrete mixed with polypropylene monofilament fiber (a)-steel fiber Better than any other fiber-incorporated concrete. Combining Table 4 and Figure 7, the compressive strength loss of fiber concrete is significantly less than that of concrete mixed with polypropylene fiber alone; among the three types of concrete mixed with polypropylene fiber alone, the compressive strength loss ratio of polypropylene monofilament fiber concrete is smaller than the other two; Among the three types of mixed polypropylene-steel fiber concrete, the compressive strength loss ratio of the concrete mixed with polypropylene monofilament fiber-steel fiber is significantly better than that of the other two ratios of concrete, and even better than any of the ones studied in this article. It can be seen that whether it is single-mixed or mixed-mixed concrete, the proportion of compressive strength loss is: polypropylene monofilament fiber (a) > polypropylene mesh fiber (b) > polypropylene crude fiber (c).

Table 4: Residual compressive strength and strength loss ratio of concrete after fire

Mix	28d Compressive strength	Enhancement ratio (%)	Residual compressive strength	Enhancement ratio (%)	Strength loss ratio
CF	73.96	-	43.64	-	0.41
PCF1	68.39	-7.54	45.82	5.00	0.33
PCF2	69.79	-5.63	45.37	3.96	0.35
PCF3	74.39	0.58	46.12	5.69	0.38
PSCF1	76.96	4.06	63.88	46.38	0.17
PSCF2	80.32	8.60	60.24	38.06	0.25
PSCF3	82.55	11.62	59.44	36.21	0.28

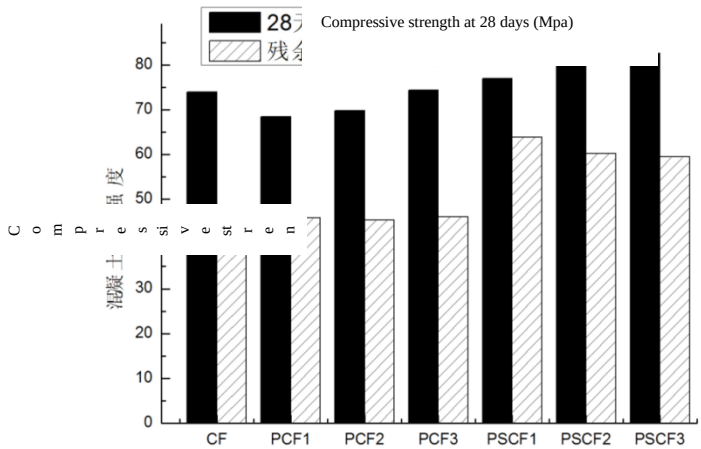

Figure 6: Compressive strength of concrete with different proportions before and after the open fire test

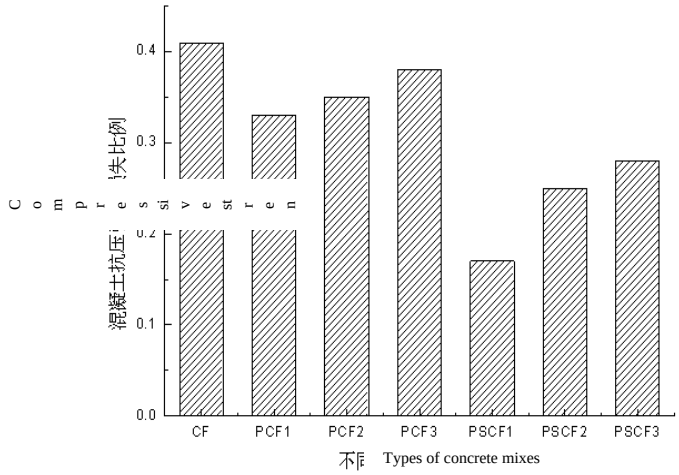

Figure 7: Compressive strength loss ratio of concrete with different proportions after the open fire test

CONCLUSION

After the concrete specimen is calcined by an open fire, the fire surface appears milky yellow and off-white, and the color of the unfired surface has not changed; the cracks in the benchmark concrete are dense and penetrate the specimen, and the skin is loose and loose, and even the corners are peeled off; single The concrete mixed with polypropylene fiber has fewer cracks and the peeling and loosening phenomenon is not obvious; although the concrete mixed with polypropylene-steel fiber has more cracks when exposed to fire, other phenomena are not obvious. It can be seen that from a macro perspective, hybrid fiber concrete is better than single-mixed polypropylene fiber concrete and better than benchmark concrete.

After the open fire test, the compression strength enhancement ratio of the concrete relative to the benchmark concrete is significantly better than that of the concrete aged 28 days. The incorporation of fibers significantly improves the pressure-bearing capacity of concrete after high temperature. In particular, the reinforcement ratio of hybrid fiber concrete after high temperature is about 10 times that of 28 days. Judging from the strength loss of concrete, the loss ratio of fiber concrete is smaller than that of the benchmark concrete. Polypropylene monofilament fiber (a) whether mixed alone or mixed with steel fiber, its compressive strength loss ratio is smaller than that of the other two polypropylene fibers, and the mixture Concrete mixed with polypropylene monofilament fiber and steel fiber (PSCF1) has the smallest compressive strength loss ratio (0.17).

AUTHORS BIOGRAPHY

Kong Linjie is a lecturer at Zhejiang College of Construction, China. She is conducting research and teaching in the construction courses for undergraduates. She is also currently a PhD candidate at Infrastructure University Kuala Lumpur. Her field of expertise are in the construction technology, construction material and concrete technology. *Email: 843913750@qq.com*

Norul Wahida Kamaruzaman is a lecturer at Infrastructure University Kuala Lumpur (IUKL). She is conducting research and teaching in the construction courses for undergraduates and postgraduates. Her field of expertise are in the construction technology, construction material and concrete technology. *Email: wahida@iukl.edu.my*

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OVERVIEW OF WATER LOSSES FROM NON-REVENUE WATER (NRW) IN OMAN

Abdullah Ghanim Al Hazar Al Kathiri, Ts. Dr. Nurazim Ibrahim & Ts. Dr. Nor Azidawati
Infrastructure University Kuala Lumpur, MALAYSIA

ABSTRACT

Water is the most vital and crucial resource for all living things, including humans. Public health, economic prosperity, and the well-being of the country are all impacted by both the availability and the quality of drinking water. Non-Revenue Water (NRW) occurs in many water supply systems around the world that cause the losses of priceless clean water before it reaches consumers. In Oman, the information on water audit, NRW, or water losses are scarce. According to the PAEW, the average of water losses in Oman between 2013 and 2016 is estimated to be around 37%, which exceeds the global benchmark that the Leak Detection and Water Accountability Committee of the American Water Works Association recommends. This paper presents a critical review of the magnitude of non-revenue water (NRW) in Oman and evaluates the effectiveness of mitigation strategies. Previous studies indicate that Oman experiences significant water losses, with NRW reaching approximately 40%, a level considered high by global standards. A critical assessment of the contributing factors reveals that excessive water pressure in certain network segments and inaccuracies in water consumption estimation, primarily due to meter deficiencies, play a significant role in these losses. Moreover, the financial impact of NRW is substantial, accounting for 32% of the total revenue budget. Despite these challenges, the Public Authority for Water (DIAM) reported notable progress in reducing NRW in 2017. While the reported success is attributed to the implementation of advanced strategies, procedures, and technologies, a deeper analysis is required to assess the long-term sustainability and scalability of these measures. This review highlights the gaps in current mitigation efforts and underscores the need for continuous improvements in NRW management to enhance water conservation and economic efficiency in Oman.

Keywords:
Water, NRW, water losses, water distribution system, mitigation plans

INTRODUCTION

The world's water condition has evolved over the last few decades, going from one of relative abundance to one of relative scarcity. This is a result of urbanization, population expansion, food and energy security policies, macroeconomic factors like trade globalization, shifting consumption patterns, and population increase. Particularly, the availability of freshwater resources is put under intensely localized pressure by growing urbanization. One of the major issues for water utilities in underdeveloped countries is managing the notable discrepancy between the amount of water billed to consumers and the amount discharged into the distribution system, sometimes referred to as non-revenue water (Kingdom et al., 2006; Al-Bulushi et al., 2018). The average level of NRW around the globe is 35% of the water that is delivered, or 48.6 billion m^3, annually, with an estimated global cost of US$14 billion (Al-Washali et al., 2019). Non-Revenue Water (NRW) occurs in many water supply systems around the world that cause the losses of priceless clean water before it reaches consumers. Generally, NRW relates to the water wasted from physical accidents including pipe leakage which cause by burst during the transmission from water treatment plant to the consumer, private water-related damages arising from meter error, unmetered public usage and illegal connections (Choi et al., 2006). According to Cassidy et al. (2021), one-third of the water abstracted from metropolitan water distribution systems can be lost through leaks, which could result in substantial financial loss. The lack of information on the sources of NRW in Salalah has resulted in large amount of clean water wastage. Implementing a successful water loss reduction program requires an understanding of the elements influencing water loss and what makes its reduction so challenging. Hence, this research is being conducted to investigate the NRW sources in Salalah area. The data obtained

will be a valuable information to the Salalah water utilities provider to mitigate the problems and increase the water transmission efficiency for long-term water supply reliability and sustainable water management.

LITERATURE REVIEW

Urban water supply systems frequently can't keep up with demand and aren't accessible to everyone. The Commercial Utilities' (CU) inability to develop and expand its water delivery infrastructure is reported to be caused by both technical and economic issues. Failure to control and minimize water losses is one of the delivery bottlenecks, among other problems. Therefore, it is vital to analyse the available literature on the subject in order to have a better knowledge of the problem of Non-Revenue Water (NRW) in Salalah. Cassidy et al. (2021), stated that one-third of the water abstracted from metropolitan water distribution systems can be lost through leaks, which could result in substantial financial loss. Urban regions, where more than 50% of the world's population reside, will experience a worsening water shortage. Over 95% of the projected urban population growth between 2000 and 2030 is predicted to occur in low-income nations, adding 2.12 billion people to the urban population (Jang, 2018). The demand for drinking water has been rising quickly in metropolitan areas of developing countries in tandem with this population expansion.

Water distribution system

Water distribution refers to the procedures by which water is moved or conveyed across a network of interconnected pipes, and it serves as an auxiliary while being continuously pumped and stored to fulfil needs and keep the system's pressures stable (Awe et al., 2019). Water distribution systems, or WDSs, involve an interconnection or network of pipes that deliver water for end use. Pumping stations, reservoirs, water towers, as well as other parts of the system like hydrants, valves, measuring devices, etc., are typically connected together for the system to operate as efficiently as possible. A water supply distribution system's objective is to provide each customer with safe drinking water that is both suitably diluted and has a tolerable odor, flavor and appearance. For ages, communal drinking water distribution has been a major global concern (Geldreich, 2020). Water distribution system (WDS) design has historically relied on experience and trial-and-error to achieve requirements. According to Guo et al. (2021), the optimization of WDS design, operation, etc. has since received a lot of attention due to the numerous design combinations that are available and the necessity to maximize the efficacy of the investments made in water supply infrastructure. Numerous scholars and practitioners have looked into the issue of the best least-cost design of WDSs in the past. In developing nations, government organizations run numerous utilities, including water supply utilities, which must meet both the quantitative and qualitative needs for water (Jabri, 2018). Natural catastrophes can have a significant impact on infrastructure, especially water supply systems. In addition to natural disasters, operational practices that result in the loss of a water service are a key worry because of the potential losses.

Oman's water distribution system

The water supply sector is predicted to face significant problems in the years to come, including maintaining a net increase in population, bridging the coverage and service gap, guaranteeing the sustainability of existing and future services, and enhancing service quality (Naamani et al., 2021). The sustainability of the system to adapt to variations in the amount and quality of water flow in the system owing to population increase, as well as water losses or Non-Revenue Water (NRW) that negatively impact the water utilities, are the two main difficulties facing the water sector in Oman. Figure 1 shows conventional water resources, which comprise both surface and groundwater, make up 87% of the total

amount of water resources in Oman. Non-conventional water resources, on the other hand, make up the remaining 13% (Al-Qurashi, 2019). While groundwater is Oman's most significant source of available water, representing over 94% of that country's conventional water resources and delivering about 1,295 Mm3/year of water, surface water is extremely scarce, accounting for only about 16% of those resources. non-conventional water resources, on the other hand levels decreased and sea water intrusion rose as a result of over use of traditional water resources, notably in coastal regions like Al Batinah and Salalah.

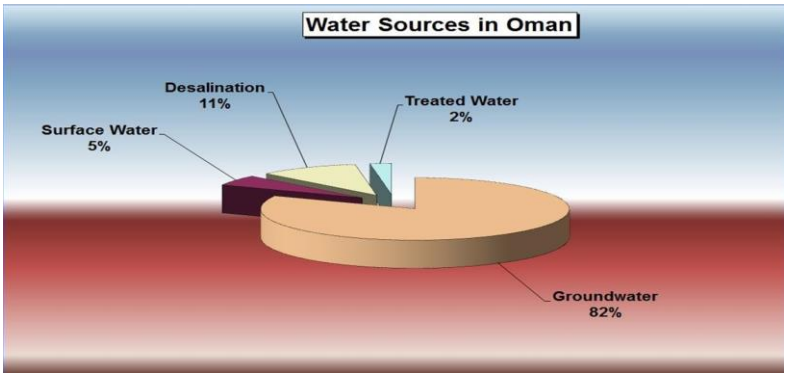


Figure 1: Water sources in Oman (Al-Qurashi, 2019)

According to Al-Siyabi & Expert, (2019) to supplement the residential water supply in the Greater Muscat Area and some other municipalities and villages, desalination facilities were built. The estimated reserve of water is thought to be 5,000 MCM, according on recent findings of fossil water aquifers in the Al-Najd area. According to the Ministry of Water Resources (MWR), an area of about 2,500 feddans can be irrigated with an annual outflow of 100 MCM. Naamani et al., (2021) added that millions of Omanis receive drinkable water from desalination operations, which are essential components of the country's utility infrastructure. In the next seven years, it is anticipated that the Main Interconnected System's (MIS) water consumption will rise from 281 MCM in 2015 to between 390 MCM and 440 MCM in 2022, an increase of 5% to 7% every year. The pumping station, tanker filling stations, transmission lines, networks and reservoirs make up Oman's water supply system. Production sites from desalination plants or wells also form part of it. The creation of 250 district metering areas (DMA) is one of PAW's greatest accomplishments. The SCADA systems continuously monitor the DMAs, so if there is any anomalous water usage in any region, the system will warn the operators and they may take the necessary steps to investigate the problem.

Non-revenue water

The phrase "Non-Revenue Water" (NRW) was initially used as a performance indicator to calculate the amount and percentage of water that is not billed annually (including unreported authorized usage and water loss) compared to the annual system input volume of a water delivery network as shown by the Figure 2. The term "unaccounted-for water" was discontinued because to its inconsistent definition, and it was suggested that "non- revenue water" be used as the major indicator of water loss control. NRW is described as the differential in water volume between the amount that is placed into a water distribution system and the amount that consumers are charged for. The water sector uses a number of indicators to measure NRW in practice (Güngör-Demirci, 2018). An effective water supply system that can sustainably serve customers and make profit for water utilities is one with a low rate of NRW. In contrast, high NRW

raises the possibility of water scarcity and has detrimental effects on people's, economies', and the environment's well-being (Lai, 2020).

<table>
<tr><td rowspan="9">System Input Volume</td><td rowspan="3">Authorised Consumption</td><td rowspan="2">Billed Authorised Consumption</td><td>Billed Metered Consumption (including water exported)</td><td rowspan="2">Revenue Water</td></tr>
<tr><td>Billed Unmetered Consumption</td></tr>
<tr><td rowspan="2">Unbilled Authorised Consumption</td><td>Unbilled Metered Consumption</td><td rowspan="7">Non-Revenue Water (NRW)</td></tr>
<tr><td>Unbilled Unmetered Consumption</td></tr>
<tr><td rowspan="5">Water Losses</td><td rowspan="2">Apparent* Losses</td><td>Unauthorised Consumption</td></tr>
<tr><td>Metering Inaccuracies</td></tr>
<tr><td rowspan="3">Real* Losses</td><td>Leakage on Transmission and/or Distribution Mains</td></tr>
<tr><td>Leakage and Overflows at Utility's Storage Tanks</td></tr>
<tr><td>Leakage on Service Connections up to the measurement point</td></tr>
</table>

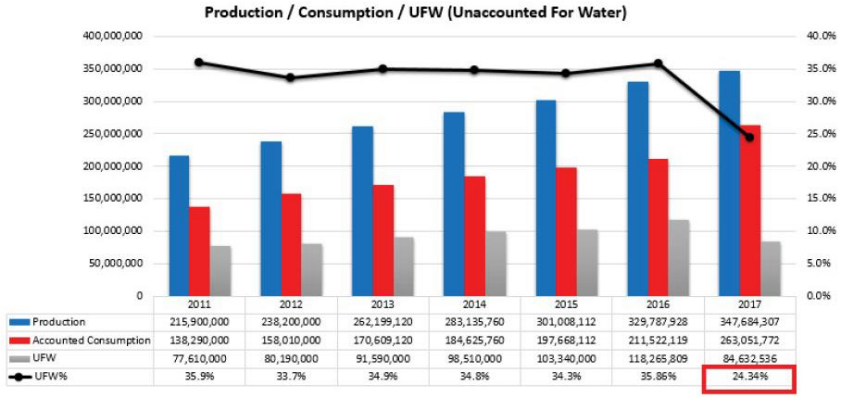
Figure 2: IWA Standard water balance (Gupta & Kulat, 2018)

Managing pressure, replacing pipes, and developing educational initiatives that focus on various NRW causes are just a few of the difficult and complicated tasks involved in reducing NRW (Lai et al., 2020). In light of this, it necessitates modifications to institutional, cultural, and governance frameworks in addition to the participation of numerous departments from various water utilities. For instance, minimizing water theft entails eradicating institutional corruption as well as altering consumer habits. Countries must adapt their water regimes to an integrated framework that can address the complicated human-technology-environment system in order to handle the complex water challenge. Al-Bulushi et al. (2018), investigated the water balance, water losses, uncounted water NRW amounts, and the operational and economic implications to study the performance of the water distribution systems in Muscat. The findings revealed that Oman often has water losses and NRW of around 40%, which is quite high by worldwide standards. Additionally, the findings indicate that excessive water pressure in some network segments and the estimation method of water consumption due to meter inaccuracies were the main contributors to water losses. On the other side, it was discovered that the NRW's financial impact represented 32% of the overall revenue budget.

Non-revenue water in Oman

Water misfortune, which is the true cause of NRW, has been one of the major challenges in managing water utilities around the world, and it is especially challenging and serious in developing countries like Oman (Al-Bulushi et al., 2018). This is made worse by the fact that most water utilities lack the mechanical know-how and equipment necessary to handle water disasters. As a result, it is crucial to improve the management of the water distribution system since it is necessary to evaluate the effectiveness of the nation's urban water supply systems. Prior studies on Oman's water audit, NRW, and water losses is very scarce. Nonetheless, according to the PAEW, Oman's average water losses between 2013 and 2016 are estimated to be around 37%, which is higher than the global standard advised by the American Water Works Association (AWWA) Leak Detection and Water Accountability Committee, which specifies that anything less than 10% is acceptable. Figure 3 summarizes non-revenue water rates in various nations, including Oman. It should be noted that while NRW rates are high in Oman, they are also high in a number of other nations and locations. Public Authority for Water (DIAM) has made excellent progress in lowering NRW in 2017. Water losses decreased by 33.6 Mm^3, going from 118.2 to

84.6 million cubic meters. The drop was 11.5%, taking the percentage from 35.86% to 24%.34. Additionally, despite the yearly growth in the number of customers, there was a decrease in output percentage in 2017 when compared to the years before, indicating that water losses were effectively controlled. These remarkable outcomes were attained by utilizing incredibly efficient strategies, procedures, and tools.



	2011	2012	2013	2014	2015	2016	2017
Production	215,900,000	238,200,000	262,199,120	283,135,760	301,008,112	329,787,928	347,684,307
Accounted Consumption	138,290,000	158,010,000	170,609,120	184,625,760	197,668,112	211,522,119	263,051,772
UFW	77,610,000	80,190,000	91,590,000	98,510,000	103,340,000	118,265,809	84,632,536
UFW%	35.9%	33.7%	34.9%	34.8%	34.3%	35.86%	24.34%

Figure 3: Production, consumption and UFW/NRW in Public Authority of water (DIAM) in Oman (Al-Siyabi & Expert, 2019)

One aspect of demand management is the reduction and control of non-revenue water, where the goal is to reduce user demand for water services and the impact of ongoing water loss on demand reduction initiatives. This translates to more effectively using the resources already available, which becomes a more affordable option to supply augmentation and management (Mubvaruri et al., 2022). As the public sees the results of the efforts, a program for NRW reduction and control should considerably benefit the Authority financially and operationally. The benefits of decreasing NRW include better service, fewer leaks, and expansion of the distribution system. But for such a project to be effective and have long-term benefits, it needs to be adequately conveyed.

CONCLUSION

In Oman, there is a noticeable lack of studies addressing Non-Revenue Water (NRW), water audits, and water losses. Most existing research has focused on water distribution system performance in cities such as Muscat, Alexandria, and Sana'a, primarily examining water losses and unaccounted-for water (NRW). To develop effective strategies for reducing water losses, improving the efficiency of the water supply system, and ensuring sustainable long-term water management in Oman, it is essential to investigate both the sources and the magnitude of NRW in the region. The gap can be address by providing critical insights into Oman water distribution system.

AUTHOR BIOGRAPHY

Al Hazar Al Kathiri Ahmed Ghanim Mohammed, is a Master's degree student in Civil Engineering (by Research) at the Faculty of Engineering and Technology, Infrastructure University Kuala Lumpur. His research examines the issue of non-revenue water in Salalah City, Oman. He is supervised by Dr. Nurazim Ibrahim (Ts., PhD) and co-supervised by Dr. Nor Azidawati Binti Haron (Ts., PhD).

Nurazim Ibrahim, Ts. PhD is a senior lecturer in the Civil Engineering & Construction Department at Infrastructure University Kuala Lumpur. She earned her MSc in Solid Waste Management in 2012 and her PhD in Water Quality in 2018, both from Universiti Sains Malaysia. Dr. Nurazim's research primarily focuses on addressing challenges related to solid waste management and mitigating water pollution. She is also deeply interested in sustainable and green technologies, environmental engineering, and climate change, with a commitment to advancing solutions for a more sustainable future. Additionally, she is a professional member of the Malaysia Board of Technologists (MBOT) and the member of Board of Engineers Malaysia (BEM).

Nor Azidawati Binti Haron, PhD is a senior lecturer at Universiti Teknologi Malaysia (UTM) in the Faculty of Civil Engineering, specialising in hydraulics and hydrology. She has extensive experience in river morphology and water resources management. Dr. Azidawati has contributed significantly to research in these fields, with numerous publications and collaborations with local and international institutions. Her work focuses on sustainable water management practices and the environmental impacts of hydraulic engineering projects. Dr. Azidawati is dedicated to advancing knowledge and solutions for water-related challenges in Malaysia and beyond. She is currently the assistant leader (coordinator) for the CBHE Erasmus grant, an international grant related to green leadership. This role involves coordinating efforts to enhance higher education capacities and promote sustainable practices. Additionally, she is a professional member of the Malaysia Board of Technologists (MBOT), the Board of Engineers Malaysia (BEM), the Malaysian Water Association (MWA), and the Malaysian Society for Engineering & Technology (MySET).

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A REVIEW OF SHRINKAGE AND CRACK RESISTANCE OF INTERNAL CURED CONCRETE USING SAP AS AN INTERNAL CURING AGENT

Li Hongyuan[1,2] & Norul Wahida Kamaruzaman[1]

[1]*Faculty of Engineering, Science and Technology, Infrastructure University Kuala Lumpur, MALAYSIA*
[2] *Faculty of Architectural Engineering, Guangzhou City Construction College, Guangzhou, Guangdong, CHINA*

ABSTRACT

Concrete is the most widely used construction material globally, but its production requires substantial amounts of water for casting and curing. With water scarcity becoming a pressing concern, alternative methods to reduce water consumption while maintaining or enhancing concrete properties are vital. Internal curing using superabsorbent polymers (SAPs) has emerged as a promising solution to address this challenge. This paper explores the mechanisms, benefits, and applications of internal curing concrete, with a particular focus on the role of SAPs. SAPs function by absorbing and retaining water, which is gradually released during the hydration process. This mechanism helps mitigate autogenous shrinkage, a common cause of cracking in concrete, thereby improving the material's crack resistance and overall durability. The review highlights the advantages of SAPs in enhancing the performance and sustainability of concrete, positioning them as a viable alternative to traditional curing methods. However, it also underscores the need for further research to optimize the use of SAPs and validate their long-term benefits across various construction applications. By providing insights into the potential of internal curing with SAPs, this study contributes to the ongoing efforts to develop more sustainable and durable concrete solutions. Future studies should focus on refining the application of SAPs and exploring their effectiveness in diverse environmental and structural conditions.

Keywords:
Internal curing concrete, superabsorbent polymers, shrinkage, crack resistance, construction

INTRODUCTION

Concrete stands as the most extensively utilized building material worldwide, making it an integral component of modern construction practices (Xie et al, 2021). Concrete structures have gained unparalleled prominence in the construction industry, becoming one of the primary choices for various construction projects (Kiran et al., 2021). Water, as a natural resource, holds significant importance in the construction industry and is extensively utilized for casting and curing purposes. Considering the escalating global demand for water and its widespread scarcity, it has become crucial to explore strategies to minimize water consumption in construction processes (Lokeshwari et al, 2021). For the construction of every 1 m^3 of concrete, approximately 3 m^3 of water is needed, with the majority of it allocated to the curing process (A.S. El-Dieb, 2007). Curing of concrete plays a vital role in achieving optimal strength and significantly contributes to enhancing its durability properties. Primarily, curing facilitates the essential hydration process of cement. Several curing methods are available, including water curing, steam curing, self-curing, curing by infrared radiation, electrical curing, among others. However, the extensive use of these methods results in a significant water demand, potentially leading to water scarcity concerns. Exterior and interior curing represent the two fundamental approaches for concrete curing. In the case of conventional concrete, the external curing process takes place after the mixing, placing, and finishing stages. However, in regions facing water scarcity issues, extended curing becomes impractical. When concrete surfaces are exposed to the environment, water within the concrete evaporates, leading to a reduction in the water content used during the concreting process. This, in turn, impacts the cement

hydration process, potentially compromising the quality of the concrete (Kiran et al., 2021). Internal curing concrete, a novel approach to enhancing the curing of high-strength concrete, has been gaining increasing attention in the construction industry. As an innovative maintenance technology, internal curing concrete has significant significance in the context of concrete application and water resource scarcity. It provides strong support for solving the problem of concrete maintenance, improving concrete performance, and promoting sustainable development of the construction industry. Therefore, the research and application of internal curing concrete is worth further exploration and promotion in the field of construction engineering.

MECHANISMS

Philleo pioneering proposal in 1991 utilized lightweight aggregate to supply additional moisture during the curing process (R. Philleo, 1991). Subsequently, the American Concrete Institute (ACI,2001) (Institute AC. Standard Practice for Curing Concrete, 2001) officially defined internal curing in 2001, followed by the International Union of Laboratories and Experts in Construction Materials, Systems, and Structures (RILEM,2012) providing a more comprehensive explanation of the concept (V. Mechtcherine and H. Reinhardt, 2012). The fundamental concept behind self-curing concrete or mortar is to mitigate water evaporation within the concrete and enhance its water retention capacity. To achieve this, water-filled internal curing agents, acting as reservoirs, are introduced into the concrete mixture (Hamzah et al, 2022). The American Concrete Institute, ACI-308 (2013) code states that self-curing is a process where hydration of cement occurs due to avail-ability of the additional internal water which is usually not part of mixing water.

The difference between internal curing and external curing was illustrated in Figure 1 (Bentz ,et al, 2010). The self-curing concrete mechanism was explained. Initially, the conditions between the internal curing agent and the fresh cement paste were uniform, with no movement of absorbed water. As the humidity conditions changed, particularly in a dry environment, the absorbed water in the internal curing agent began to migrate into the hardened cement paste. This migration facilitated the ongoing hydration process around the aggregate's surface. Eventually, the water migration ceased, and the hydration process stopped. The water in the internal curing agent provided a continuous supply for cement hydration (Sampebulu, 2012). Water is transported from the curing agent to the un-hydrated cement through capillary suction, vapor diffusion, and capillary condensation, facilitating continuous hydration. As a result, chemical shrinkage and self-desiccation, caused by low water-to-binder ratio, can be significantly reduced (Namsone et al, 2016).

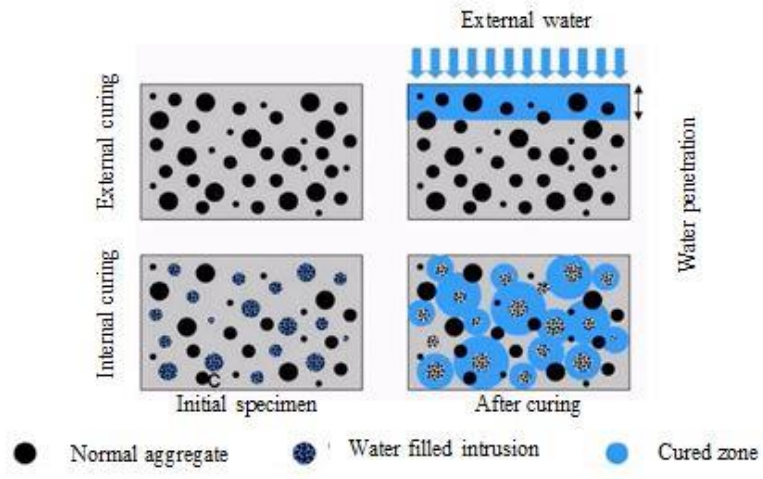

Figure 1 The difference between internal curing and external curing

There are currently two prevailing categories of internal curing materials for concrete: inorganic porous materials and chemical polymers (Ma Xianwei et al, 2015). Porous ceramics and Superabsorbent Polymers (SAP) stand as exemplary representatives of inorganic porous and synthetic polymer internal curing materials, respectively. The excellent water retention property of SAP has spurred numerous studies exploring its application for internal curing of concrete to mitigate early shrinkage (V. Mechtcherine, 2014). SAP with larger particle sizes exhibited a more pronounced effect in mitigating the autogenous shrinkage of early-age concrete (P. Lura et al, 2006), whereas SAP particles of approximately 100 μm in size demonstrated the highest water absorption efficiency (O.M. Jensen, 2001; O.M. Jensen, 2002). In summary, the main mechanism of internal curing agents is to promote the cement hydration reaction in concrete by continuously releasing water, thereby improving the performance and durability of concrete. The application of internal curing agents can effectively solve the problems caused by self-drying and self-shrinkage of concrete, improve the mechanical and overall performance of concrete, and contribute to the sustainable development of construction projects.

BENEFITS AND APPLICATIONS

Internal curing technology, as an innovative concrete curing method, has made significant progress in the field of construction materials. Its unique advantages and wide-ranging applications have made it a highly regarded research direction in the construction industry. Internal curing offers several benefits, including improved hydration, reduced chloride ingress, and minimized early-age cracking, thereby enabling concrete to achieve its maximum potential as a sustainable building material and extending its service life. The utilization of self-curing concrete with the incorporation of Superabsorbent polymers (SAP) as an admixture in different grades of concrete has demonstrated significant positive effects on concrete structures. The key advantages of internal curing are the production of more durable and less permeable concrete. Providing a congenial atmosphere aids in the hydration of cement, making concrete curing essential until a major portion of the hydration process is completed. The proposed research work on self-curing concrete offers several advantages compared to normal concrete, such as enhanced early-stage strength, reduced shrinkage cracks, and a flowable mix without bleeding and segregation. Additionally, incorporating self-curing agents reduces the water content in the concrete, contributing to a healthier and more sustainable environment (Saravanakumar,R. 2023). The addition of SAP reduces early-stage

autogenous shrinkage of concrete, mitigating shrinkage stress during the initial curing period and effectively contributing to the reduction of early-age cracks in concrete (O.M. Jensen and P.F. Hansen, 2002; Saravanakumar et al, 2023; O.M. Jensen et al, 2001; V. Mechtcherine et al, 2008; Kong Xiangmin et al, 2014; X.M. Kong et al, 2015; D. Shen et al, 2016). Internal curing technology holds significant promise in the field of concrete curing, offering advantages in mitigating early-age shrinkage, enhancing concrete strength, improving durability, and conserving water resources. Future research and engineering practices will further drive the development and implementation of internal curing technology.

SHRINKAGE BEHAVIOR AND CRACK RESISTANCE

Cracks in structures can result from various factors, including shrinkage, freeze/thaw cycles, and structural stresses, among others. While several solutions exist, the use of superabsorbent polymers (SAPs) appears to be a promising approach to counteract these problems. The significant concern of cracking in building applications was addressed. During the early stages, SAPs can absorb water, which can effectively mitigate autogenous and plastic shrinkage. Moreover, the formation of macro pores can enhance the freeze/thaw resistance of the concrete. Additionally, when water enters, the swelling of SAPs can seal cracks and prevent the intrusion of fluids, thereby improving overall water-tightness. Furthermore, the absorbed water may facilitate autogenous healing. These various mechanisms make the utilization of superabsorbent polymers highly appealing in addressing the cracking issues in concrete structures (Mignon,A et al, 2017).

High-performance concrete (HPC) is widely used in practical applications. However, due to its low water-to-cement (w/c) ratio, HPC is susceptible to self-desiccation, leading to significant autogenous shrinkage (AS). This high AS increases the risk of early-age cracking, especially when the concrete is restrained from freely shrinking. To address this issue, internal curing (IC) has been extensively employed to reduce AS and mitigate the risk of early-age cracking in HPC. Super absorbent polymers (SAPs) are capable of providing additional internal curing water for concrete hydration, effectively counteracting the effects of self-desiccation. The influence of internal curing (IC) on early-age expansion, autogenous shrinkage (AS) development, AS rate, and IC efficiency of concrete with superabsorbent polymer (SAP) was studied experimentally. Early-age expansion in the internal curing concrete was evident even before the first day, and the maximum expansion increased with higher IC water content. The ultimate AS at 28 days and AS rate in internal curing concrete decreased as the amount of IC water increased. The internal curing (IC) efficiency of SAPs decreased with the increase in IC water content in concrete (Shen,D, 2016).

Past investigations into the restrained shrinkage traits of internal curing concrete centered on SAP incorporation strategies, taking into account the temporal dynamics of water uptake during the mixing phase. Researchers aimed to probe the differential impacts of various SAP integration methods on the ring shrinkage strain of internal curing concrete. It was found that SAP inclusion markedly enhanced concrete's shrinkage performance, notably curtailing shrinkage strain. Notably, concrete amalgamated with pre-absorbed SAP displayed the most pronounced shrinkage strain diminution, with no evidence of cracking surfacing until the conclusion of the testing period. In contrast, the shrinkage-mitigation efficacy of dry SAP was constrained, with cracking persisting in the concrete. Concrete specimens devoid of SAP bore a heightened risk of early-age cracking, fracturing well before reaching the 28-day milestone. To promote sustained hydration, SAPs retained water in the initial stages and progressively discharged it, thereby augmenting concrete's crack resistance and structural integrity. Pre-absorbed SAPs surpassed dry SAPs in terms of shrinkage reduction potency. The pre-water absorption ratio, indicative of SAP's peak water retention capacity, underscored the advisability of the pre-water absorption technique (Huang,X, 2022), highlighting its efficacy in optimizing concrete's performance.

The use of superabsorbent polymers (SAP) for internal curing of ultra-high performance concrete (UHPC) can help reduce autogenous shrinkage and self-desiccation, which can cause early-age

cracking. Testing on the autogenous shrinkage can be successfully decreased while preserving the extremely high strength of UHPC was the primary objective of this work. The pore fluid absorption of SAP was investigated using a novel method based on image analysis on polished cross sections of cement pastes, revealing an approximate value of 16 gpore fluid/g SAP.When a small amount of SAP (＜63 μm in the dry state) was added to a UHPC mixture with a basic w/c of 0.15, autogenous shrinkage could be reduced from over 600 μm/m to approximately 120 μm/m after 30 days. This is most likely because the extra space provided by the SAP allows hydration to continue rather than stopping because there isn't enough free capillary pore space for the precipitation of hydration products (Justs,J, 2015).

The lifecycle crack resistance of internal curing concrete, enriched with superabsorbent polymers (SAPs), underwent scrutiny. Methodically, plate induction tests gauged the plastic stage, ring restraint tests evaluated the curing phase, and three-point fracture tests appraised service life performance—all pinpointing temporal shifts in crack behavior. Plate induction outcomes during the plastic phase revealed that SAP inclusion deferred the emergence of initial cracks and maintained widths between 0.1 and 0.3 mm, with crack propagation largely mitigated within a day. Optimal crack suppression was observed with 40–80 mesh and 100–120 mesh SAP particles, as cracking areas shrank in tandem with augmented water content. Ring restraint trials corroborated extended crack latency periods and diminished steel ring strain. Thermogravimetric analysis (TGA) disclosed that SAPs extended the water release timeline, orchestrating hydration for sustained and homogeneous cementitious material hydration. This investigation underscored the enhancement of concrete's crack resistance through SAP augmentation (Lyu,Z, 2020), encapsulating a comprehensive approach to concrete durability optimization.

The use of low water cement ratio (w/c) in high-strength concrete (HSC) can lead to an increase in autogenous shrinkage caused by self-desiccation, thereby reducing the crack resistance of the concrete. To address this issue, researchers employed internal curing (IC) of superabsorbent polymers (SAP) to reduce autogenous shrinkage and improve the crack resistance of HSCs. The early behavior and tensile creep of ICHSC with different SAPs contents (0%, 0.57%, 0.86%, and 1.14% of cement weight) were studied using a temperature stress testing machine at a constant initial s/s ratio. The mechanical properties of ICHSCs with the same basic w/c ratio decrease with increasing SAPs content. As the content of SAPs increases, the autogenous shrinkage rate of ICHSC decreases. With the increase of SAPs content, the basic tensile creep, basic tensile creep coefficient, and bi tensile creep of ICHSC show a nonlinear increase, which is attributed to the increase of total w/c ratio (Shen,D, 2019).

In recent decades, internal curing has developed into a method of reducing shrinkage in low water cement ratio (w/c) concrete by introducing additional water into the concrete. The restrained ring test was conducted to investigate the crack resistance of concrete containing different amounts of SAP (0%, 0.05%, 0.16%, and 0.26% by weight of cement). The strain in the constrained steel ring decreases with the increase of SAP amount. The residual stress of the concrete ring decreased with the increase of SAPs dosage. The stress rate decreased with the increase of SAPs dosage. After the start of drying, the relaxation stress increased with the increase of SAP content. The cracking time of concrete increased with the increase of SAPs dosage. These findings highlighted the positive impact of SAP in improving the crack resistance of internal curing concrete and provided valuable insights for further understanding the stress relaxation behavior of SAP mixed concrete (Shen,D, 2016).

The effects of SAPs as IC agents on the temperature, autogenous shrinkage, restrained stress, basic tensile creep, and cracking potential of high performance concrete (HPC) were simultaneously studied using the Temperature Stress Test Machine. The adiabatic temperature rise of HPC increased with the amount of SAP, reaching 27.6 °C, 29.3 °C, 31.0 °C, and 34.9 °C, respectively. The restrained tensile stress rates of high-performance concrete decreased with the increase of SAPs content, which are 1.7, 1.5, 1.4, and 1.2 MPa/day, respectively. The specific basic tensile creep of HPC decreased with the increase of SAPs content when the mixed SAP-0 constrained specimen cracks, which are 45, 23, 13, and 7 μ ε/MPa, respectively. According to the comprehensive standard, the cracking potential of HPC decreased with the increase of SAPs content. These findings revealed the beneficial role of SAP as an IC

reagent for HPC, helping to better understand its potential in mitigating cracking and improving the overall performance of HPC structures (Shen,D, 2018).

To explore the impact of superabsorbent polymer (SAP) dosage on the mechanical attributes and tensile creep characteristics of Internal Curing High-Strength Concrete (ICHSC), an experimental study was conducted. Employing a Temperature Stress Test Machine, we scrutinized the performance of ICHSC specimens prepared with SAP contents ranging from 0% to 1.14% by weight of cement, while maintaining a consistent solid-to-solid (s/s) ratio at the outset. The investigation revealed that, under identical baseline water-to-cement (w/c) ratios, the mechanical robustness of ICHSC diminished in response to escalating SAP concentrations. Conversely, there was a noted reduction in autogenous shrinkage with higher SAP content. Intriguingly, both the fundamental tensile creep and its coefficient, alongside the specific tensile creep of ICHSC, displayed a non-linear escalation as the SAP proportion grew. This phenomenon could be ascribed to the augmented effective w/c ratio resulting from the SAPs' water-retaining capability. These outcomes offer significant perspectives on how SAP incorporation affects the mechanical integrity and self-shrinkage dynamics of ICHSC. They contribute to a deeper comprehension of SAPs' potential role in enhancing crack prevention and the comprehensive quality of high-strength concrete formulations (Shen,D, 2020).

The microarchitectural properties of an innovative hybrid concrete were scrutinized, with a focus on the effects of polymer particle dimensions and volume fraction on its mechanical resilience and durability. Complementary insights were gleaned through advanced scanning electron microscopy (SEM) analysis. Findings indicated a negative correlation between the superabsorbent polymer (SAP) content and the extent of concrete shrinkage. Notably, the concrete's volumetric stability showcased a biphasic response to SAP particle size, initially improving before declining. The strategic addition of SAP notably curtailed drying shrinkage by 16.09% and autogenous shrinkage by 30.62%, bolstering the material's overall volumetric consistency (Zheng,X, 2021). Concrete's hydration progression under distinct SAP integration techniques was probed via scanning electron microscopy, elucidating the internal hydration dynamics pertinent to SAP-enhanced internal curing strategies. Our findings underscore that SAP adeptly sequesters moisture in the early hydration phase, subsequently liberating it over time, thus sustaining the hydration process. This continuous hydration fosters a denser microstructure, significantly augmenting the concrete's resilience to cracking. Remarkably, pre-saturated SAP outperforms its dry counterpart in mitigating shrinkage, advocating for a pre-absorption methodology where the saturation ratio aligns with SAP's peak water retention capacity. This revelation underscores the pivotal role of pre-hydration in fine-tuning the performance of SAP-integrated internal curing concrete. SAP-modified cementitious composites have emerged as a focal point in global research due to their exceptional resistance to cracking, robust durability, broad accessibility, and economic viability (Huang,X, 2022), highlighting the transformative potential of SAPs in concrete engineering.

An exhaustive analysis of superabsorbent polymer (SAP)-enhanced cementitious composites was undertaken, zeroing in on fabrication techniques, microstructural evolution (including hydration kinetics and porosity), and the SAP's influence on rheological, mechanical, shrinkage, self-repair, and endurance attributes of these materials. Incorporating SAPs injects supplemental moisture, boosting the blend's fluidity, with a negligible sway on the mechanical robustness relative to SAP-free counterparts. Strikingly, SAPs markedly curb autogenous shrinkage, fortifying crack resistance and elevating longevity, manifested through heightened impermeability, bolstered carbonation defense, and superior frost resilience. It bears emphasis that SAP's precise impact hinges on a constellation of variables encompassing particle dimensions, dosage, and the mode of admixture (He,Z, 2019), underscoring the complexity of optimizing SAP-modified cement-based systems.

CONCLUSIONS AND RECOMMENDATIONS

The use of internal curing (IC) technology addresses water scarcity issues in concrete curing, promoting sustainable construction practices. Internal curing (IC) using SAPs significantly enhances concrete performance by providing sustained hydration, reducing autogenous shrinkage, and improving crack resistance. SAPs effectively mitigate early-age shrinkage and cracking in high-performance and ultra-high performance concrete. Pre-absorbent SAPs are more efficient in reducing shrinkage and enhancing crack resistance compared to dry SAPs. Further research is needed to optimize the use of SAPs in various concrete mixtures, particularly in terms of particle size and pre-water absorption ratios. Standardized guidelines should be developed for the application of IC technology using SAPs in different concrete grades and construction environments.

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AUTHORS BIOGRAPHY

Li Hongyuan is a Doctor of Philosophy In Civil Engineering (by Research) in the Faculty of Engineering And Technology Infrastructure of Infrastructure University Kuala Lumpur, currently work at the Faculty of Architectural Engineering, Guangzhou City Construction College, Guangzhou, Guangdong, China. His doctoral supervisor was Norul Wahida Kamaruzaman, Ts., PhD.

Norul Wahida Kamaruzaman is a lecturer at Infrastructure University Kuala Lumpur (IUKL). She is conducting research and teaching in the construction courses for undergraduates and postgraduates. Her field of expertise are in the construction technology, construction material and concrete technology.

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INFLUENCE OF ORGANIC ALKALI AND CELLULOSE ON THE PROPERTIES OF FLY ASH-BASED GEOPOLYMER

Deng Peng & Zulhazmee Bakri
Infrastructure University Kuala Lumpur, MALAYSIA

ABSTRACT

This study investigates the influence of organic alkali and cellulose on the properties of fly ash-based geopolymer materials. Geopolymers have shown promising applications in various fields, but their performance is significantly affected by the type and dosage of additives. The influence of organic alkali and cellulose on the properties of fly ash-based geopolymer materials has been extensively explored. To reveal the mechanism of these additives in the formation and performance regulation of geopolymers, this study used various characterization methods such as compressive strength testing, XRD analysis, FTIR analysis, and SEM observation. The experimental results show that the dosage of organic alkali has a certain effect on the strength of geopolymer, but the impact is relatively small. When only adding organic alkali, a dosage of twice only increases the strength from 5MPa to 6.3MPa. The addition of sodium silicate significantly improved the compressive strength of geopolymers. At a 5% organic alkali content, the addition of 5.5%, 11.0%, and 16.5% sodium silicate increased the compressive strength by 60%, 186%, and 396%, respectively. At a 10% organic alkali content, increasing by 47%, 256%, and 306% respectively, sodium silicate can promote the formation and expansion of the aluminosilicate network structure. The addition of cellulose exhibits a dual effect of first strengthening and then weakening, and its distribution and dosage have a significant impact on the properties of geopolymer. The cellulose dosages of 0.33%, 0.66%, and 0.1% increase by 0.9MPa, 2.4MPa, and 0.1MPa compared to those without addition. Through comprehensive analysis, this study reveals the correlation between organic alkali and cellulose in the microscopic characteristics and macroscopic performance of geopolymers, providing an experimental basis and theoretical guidance for the preparation of high-performance geopolymer materials.

Keywords:
Organic alkali, Cellulose, Fly ash based geopolymer, Compressive strength, Microscopic characteristics

INTRODUCTION

Concrete, as the main material of most buildings today, has a huge usage. According to statistics, the world's cement production reached 4.4 billion tons in 2021(Garside, 2022). The production of cement requires a large amount of nonrenewable mineral resources such as limestone and clay, as well as a large amount of energy while generating a large amount of CO2, which has adverse effects on the environment. Fly ash geopolymer is a high-performance cementitious material generated from calcium-free or low-calcium aluminosilicate minerals under the action of activators. Its production process is energy-saving and environmentally friendly, and the sources of production materials are extensive (Miasin & Woon, 2020; Salleh & Roslan, 2015; Yang et al., 2023). Fly ash geopolymer has mechanical properties comparable to ordinary concrete, and even exhibits better performance in some aspects, such as high-temperature resistance, corrosion resistance, etc., which has attracted widespread attention from researchers. However, the brittleness of geopolymers greatly limits their development and application (Harmal et al., 2023). Therefore, reducing the brittleness of geopolymers and improving their toughness are important ways to develop high-performance geopolymers and expand their application scope. In addition, as the use of geopolymers becomes increasingly widespread, their consumption is also increasing, and their prices have significantly increased. Reducing the cost of geopolymers has become a focus of researchers' attention.

At present, researchers have conducted extensive research on improving the mechanical properties of geopolymers, consisting of adjusting the active components and content of raw materials

(Sitarz et al., 2022; Xu et al., 2021), selecting appropriate activators and activator ratios (Aiken et al., 2018; Xie et al., 2023), appropriate curing conditions (Sajan et al., 2021; Yılmaz et al., 2023), and adding fibers(Deng et al., 2023; Ganesh & Muthukannan, 2021; Punurai et al., 2018). Chindaprasirt et al. (2007) used Na2SiO3 and NaOH as activators to polymerize with fly ash. The resulting geopolymer sample was cured at 75 ℃ and had a compressive strength of up to 50 MPa after 7 days. Hervé et al. (2017; 2017) studied the effect of the concentration of the H_3PO_4 solution on the properties of geopolymers and found that as the concentration increased, the compressive strength of the polymer increased. Compared with alkali-based geopolymers, phosphate-based geopolymers had higher compressive strength. When the H_3PO_4 concentration was 10 mol/L, the highest compressive strength reached 93.8 MPa, while the compressive strength of alkali-based geopolymers was only 63.8 MPa. Siciliano et al. (2024) investigated the mechanical and microstructural evolution of kaolin-based geopolymers under temperature and pressure curing conditions. The research results showed that a curing temperature of 90 °C was conducive to the formation of regular nanopores, while higher temperatures helped to increase porosity. On the contrary, maintenance pressure can promote or inhibit material recombination, with a pressure of 20 MPa promoting this process and pressures above 40 MPa preventing it.

The above research focuses more on improving the compressive performance of geopolymers. Regarding how to reduce the brittleness of geopolymers, researchers mainly use the method of adding fibers to reduce their brittleness (Johari et al., 2023; Kong & Kamaruzaman, 2023). The disadvantage of the high brittleness of geopolymers greatly limits their application. Adding fibers as a common means to improve the brittleness of geopolymers has been widely studied and applied. Common fibers include nonplant fibers and plant fibers, among which nonplant fibers mainly include inorganic fibers and organic polymer fibers. Khalil et al. (2018) prepared lightweight geopolymer concrete containing steel fibers. The study showed that the addition of steel fibers increased the splitting and bending tensile strength of lightweight geopolymer concrete. When the steel fiber content reached 0.5% of the total volume, its bending strength at 28 days was 1.063 times that of specimens without steel fibers. Sukotasukkul et al. (2018) studied the bending performance of geopolymers under mixed steel fiber and polypropylene fiber conditions. The research results showed that the mixing of steel fibers can improve the bending strength, toughness, and residual strength of polypropylene fiber-reinforced geopolymers to varying degrees. Adding both inorganic fibers and organic polymer fibers can effectively improve the brittleness and mechanical properties of geopolymers, but inorganic fibers have problems such as high cost, difficult degradation, and easy environmental pollution. Organic polymer fibers have disadvantages such as high price and an unfriendly environment (Korniejenko & Łach, 2020; Shaikh, 2020).

Plant fibers in natural fibers have garnered considerable interest among researchers, stemming from their large reserves, renewability, low cost, and environmental friendliness. There have been many reports on adding plant fibers to enhance the mechanical performance of geopolymers during the preparation process. For example, researchers have added fibers such as cotton (Kozub et al., 2023), coir (Ayeni et al., 2022; Narasimha Swamy et al., 2017), pineapple fiber (Linhares et al., 2023; Zulfiati et al., 2019), sugarcane bagasse (Aran et al., 2021; Srinivas et al., 2021), etc. to geopolymers, and the reinforcement effect of geopolymers is excellent. Alomayri et al. (2013) systematically investigated the influence of cotton fiber orientation and content on the mechanical properties of fly ash-based geopolymers. The results indicate that when the orientation of cotton fabric is aligned horizontally with the load, it has greater load-bearing capacity and deformation resistance than when it is aligned vertically. Alshaaer et al. (2017) used 10% loofah fiber reinforced geopolymer to study the physical characteristics and mechanical properties of geopolymer composites. The compressive strength and flexural strength of geopolymer composite materials were found to have increased by 138% and 318%, respectively, with good durability. Huang et al. (2021) compared the effects of untreated and alkali-treated straw on the mechanical properties of slag-based geopolymer composites, and the results showed that the former had significantly lower flexural strength than the latter. Research has found that the compatibility between plant fibers and geopolymers, as well as the particle size and aspect ratio of plant fibers, can be regulated through the selection and adjustment of plant fiber materials to control geopolymer properties. However,

this requires a lot of research work and the enhancement effect is limited. To fully utilize plant fibers, further research can be conducted on the mechanical properties of geopolymers reinforced by plant fibers, especially to improve their toughness. By improving the interaction between plant fibers and geopolymers, geopolymer properties can be improved. Sanfilippo et al.(2024) used alkali pretreatment to damage the wax layer on the surface of jute fibers, enhancing their hydrophilicity and increasing the interaction force between jute fibers and geopolymers. It found that the bending strength of jute fiber geopolymers increased by 53%. Ye et al.(2018) studied the effect of natural cellulose on metakaolin-based geopolymer. It found that the presence of an appropriate amount of cellulose had an internal curing effect on the geopolymer-based material, improving its microstructure and enhancing its flexural and compressive strength. However, excessive cellulose increased the porosity of the material and reduced its mechanical strength due to its increased water absorption rate.

The preparation of traditional geopolymers usually relies on inorganic bases (such as NaOH, and KOH) as activators. These inorganic bases not only pose safety hazards during production, storage, and transportation, such as strong corrosiveness, flammability, and explosiveness, but their high cost also limits the large-scale application of geopolymer materials. Exploring safer, more economical, and environmentally friendly activators has become the key to promoting the development of fly ash-based geopolymers. Organic bases, as a class of compounds with unique chemical properties and wide application potential, have gradually entered the field of research. The molecular structures of organic bases are diverse, and different organic bases have different functional groups and reaction activities, which provides the possibility for precise regulation of geopolymer properties. By selecting appropriate types and amounts of organic bases, precise control of geopolymer reaction kinetics, microstructure, and macroscopic properties can be achieved, thereby meeting the special requirements of different engineering fields for material properties. Lu et al. (Lu et al., 2022) used organic strong alkali sodium tert butoxide as an activator to prepare fly ash geopolymers and characterized the microstructure of fly ash geopolymers through various methods. The results indicate that C-OH in sodium tert butoxide can form C-O-Si bonds after hydrolysis with Si-OH in sodium tert butoxide and geopolymer, resulting in an intricately interlaced 3D network structure.

Based on this, this study intends to investigate the effects of organic alkali and cellulose on the properties of fly ash-based geopolymers. By systematically exploring the effects of different types and amounts of organic alkali and cellulose on the preparation process, microstructure, physical and mechanical properties, and durability of geopolymer, the aim is to reveal their mechanisms and laws of action and provide scientific basis and technical support for the efficient utilization of fly ash and the green development of geopolymer materials. For this purpose, we investigated how the concentrations of Si/Al, organic bases, and cellulose affect the geological polymerization pore structure, hydration products, and strength. The effects of organic alkali and cellulose on the chemical bonding, mineralogy, and mechanics of kaolin-based geopolymers were determined by FTIR, XRD, and SEM, respectively.

EXPERIMENTAL

1. MATERIALS

The activators are reagent-grade sodium tert butoxide (STB), sodium silicate (SS), and a mixture of STB and SS. The modulus of SS is 2.0, and the cellulose is purchased from Aladdin Reagent Co., Ltd. The fly ash is taken from the Laibin thermal power station in Guangxi, China. Si and Al are the main elemental components in the fly ash, as shown in Table 1. The total amount of oxides SiO2 and Al_2O_3 is close to 90% (wt), and the CaO content is 2.61%. It is a low calcium F-type fly ash with a particle size of about 14 μm.

Table 1: Main chemical composition (wt/%) of fly ash

Material	SiO_2	Al_2O_3	CaO	MgO	SO_3	Fe_2O_3	K_2O
Fly ash	58.80	30.76	2.61	0.64	0.33	1.87	1.03

2. SAMPLE PREPARATION

Firstly, through literature analysis and comparison, a composite design experiment was conducted on fly ash, STB, and SS. Set the dosage of STB to 5%~10% of the fly ash dosage, and the dosage of sodium silicate to 0~16.48% of the alkali activator dosage, while maintaining a constant water/binder ratio of 0.33, to prepare geopolymer by compounding with fly ash. The specific mix proportion is shown in Table 2.

According to the experimental requirements, water, STB, and SS are used to prepare the corresponding alkali activator. Then, a mortar mixer is used to mix it with a certain amount of fly ash at 1200r/min for 15 minutes to make the whole mixture uniform. The mixed slurry is placed on a vibration table for 5 minutes to remove the bubbles generated by high-speed mixing. Then, it is poured into a 40 × 40 × 40mm mold and covered with plastic wrap. After curing at 75 °C for 1 day, it is demolded and cured at room temperature and pressure for 28 days. The average of at least 3 parallel experimental results with the same physical and chemical properties is taken as the final data. Analyze the effect of adding different amounts of STB and SS on the compressive strength of geopolymers.

Then the optimal dosage of STB and SS is based on the results of compressive strength, and they are compounded into cellulose, STB, SS, and fly ash in different proportions to prepare fly ash-based geopolymers, with a cellulose dosage of 1-3g.

Table 2: Mix proportions for geopolymer.

Samples	Si/Al	H_2O	Fly ash	SS	STB	Cellulose
SA6-1	1.62	100	300	0.00	15	-
SA7-1	1.72	105	300	16.48	15	-
SA8-1	1.82	110	300	32.96	15	-
SA9-1	1.92	115	300	49.45	15	-
SA6-2	1.62	100	300	0.00	30	-
SA7-2	1.72	105	300	16.48	30	-
SA8-2	1.82	110	300	32.96	30	-
SA9-2	1.92	115	300	49.45	30	-
SA9-1C1	1.92	115	300	49.45	15	1
SA9-1C2	1.92	115	300	49.45	15	2
SA9-1C3	1.92	115	300	49.45	15	3

3. MEASUREMENT METHODS AND MICROSTRUCTURE CHARACTERIZATION

The geopolymer slurry is mixed using a mortar mixer, and after curing in an oven, it is subjected to unconfined compressive strength testing on a cement automatic constant stress testing machine. After the strength test, the sample is crushed and ground to a powder that passes through a 200 mesh sieve. Conduct microscopic characteristic testing on the powder.

2θ is between 10 and 70°, an X-ray diffractometer (Rigaku, SmartLab SE, Japan) was used to examine the crystal structure of fly ash geopolymer in increments of $0.02°\ ^{-1}$. The scanning speed was 5 seconds/step. The fly ash geopolymer was characterized using FTIR (Thermo Fisher Scientific Nicolet iS5, USA). The microstructure of fly ash geopolymer was observed by SEM (ZEISS, Sigma 300, Germany).

RESULTS AND DISCUSSION

1. COMPRESSIVE STRENGTH

The 28-day compressive strength results of geopolymer samples prepared by compounding organic alkali activators with fly ash in different proportions are shown in Figure 1. The compressive strength increases with the increase of the silicon-aluminum ratio under two different dosages of STB. When only adding STB, 5% and 10% alkali influence strength is somewhat increased, but not significant. This should be because the provided alkalinity can indirectly promote the polymerization reaction of geopolymer to form compressive strength to a certain extent, and fly ash itself does not have enough silicate to provide a geopolymer reaction. After increasing the dosage of SS, the strength gradually improved. When the mixed activator was 10% STB and 16.5% SS, the peak compressive strength of the geopolymer could reach 25.6MPa.

Considering that the addition of 16.5% sodium silicate has little effect on the strength, 5%, and 10% STB were ultimately chosen as activators for cellulose-based geopolymers to save costs in application. After adding cellulose, the strength is enhanced to a certain extent, but not significantly. After adding cellulose to the geopolymer, the compressive strength exhibits an initial upward trend, followed by a subsequent decline. From existing literature, on the one hand, a moderate amount of cellulose has an internal curing effect that can improve the internal structure of geopolymers, thereby increasing their strength; On the other hand, the strong polarity of cellulose and the high-density hydrogen bonds between molecules and their internal structures result in a diminished reactivity within the matrix (Rana et al., 2021), and the interfacial tension between cellulose and matrix reduces the density of composite materials(Azlina Ramlee et al., 2021). An excessive quantity may induce detrimental alterations to the internal micropores, such as increased porosity or fiber aggregation, thereby weakening compressive strength.

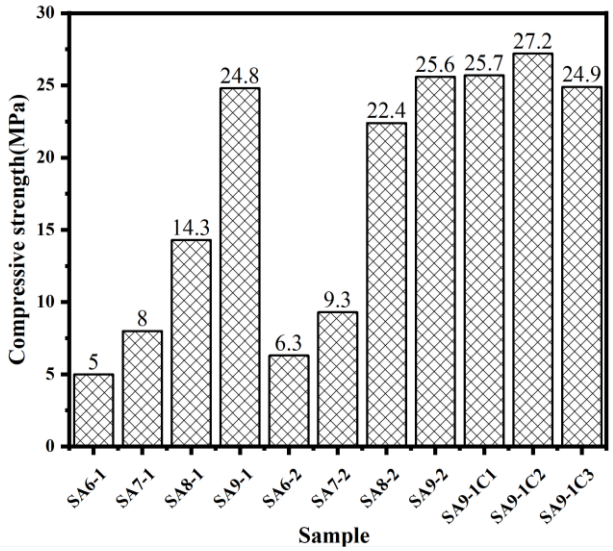

Figure 1: Compressive strength of geopolymers with different mix proportions at 28 days

2. XRD ANALYSIS

To further investigate the effects of STB, SS, and cellulose on the microstructure of geopolymers, we conducted an XRD analysis. The XRD pattern reveals the changes in mineral phase composition and crystallinity in geopolymers, providing important evidence for understanding the changes in macroscopic properties. Figure 2 shows the XRD pattern, and the characteristic peak intensities of each sample phase are relatively close. Compared with the existing research on fly ash XRD, the characteristic peak intensity between 20° and 40° in the fly ash XRD spectrum is significantly weakened, indicating that the glass phase of fly ash is destroyed due to activation reactions (Kaze et al., 2018; Lemougna et al., 2014).

At different STB dosages, there were no significant signs of new phase formation or disappearance of the original phase in the XRD pattern of the geopolymer, indicating that STB mainly participates in the formation process of the geopolymer through amorphous or low crystallinity forms, and has little effect on the overall crystallinity. The observed phenomenon in the compressive strength test aligns with the notion that a rise in STB content results in a marginal enhancement of strength, without significant augmentation.

The primary reaction product of geopolymers, aluminum silicate (N-A-S-H), exhibits feeble diffraction peaks. The primary factor lies in the presence of silicon aluminate (N-A-S-H) primarily in an amorphous state within the reaction products of fly ash geopolymers.(Palomo et al., 2007; Phoo-ngernkham et al., 2014). With the increase of sodium silicate content, more obvious characteristic peaks of aluminosilicate appeared in the XRD pattern, and the peak intensity gradually increased, indicating that the increase of sodium silicate promoted the formation of aluminosilicate network structure and the improvement of crystallinity. The small peaks of SA8-1 and SA9-1 between 30° and 40° are more pronounced than others, indicating that there are more products of aluminosilicate (N-A-S-H).

After adding cellulose, the XRD pattern of the geopolymer sample doped with cellulose did not show significant changes at low cellulose content, and the XRD was almost consistent with SA9-1, indicating that it did not affect the types of geopolymer reaction products and no new substances were generated.

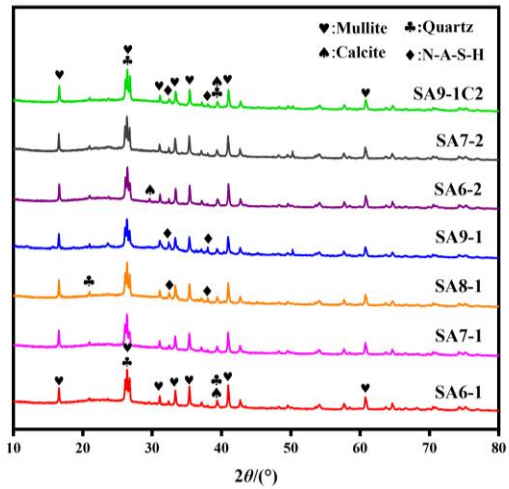

Figure 2: XRD patterns of geopolymers with different mix proportions

4. IR ANALYSIS

The infrared spectra of fly ash-based geopolymers, ranging from 4000 to 400 cm^{-1} are presented in Figure 3. The situation of different groups of polymers is similar. Separately, the vicinity of 3446 cm^{-1} displays a broad absorption peak, indicative of the stretching vibration associated with H_2O molecules., and 1645 cm^{-1} is the -OH bending vibration peak of water in geopolymer. The signal appearing at 1488 cm^{-1} is due to the presence of carbonate groups in the geopolymer. The broad absorption peak at 1050 cm^{-1} is the asymmetric vibration peak of the Si-O-T bond (T can be Si or Al), which is widely accepted for studying the changes in the reaction products of alkaline aluminosilicate gel(Liu et al., 2020). The signal appearing at 460~480 cm^{-1} corresponds to the stretching vibration of Si-O-Si, which is very sharp.

With the increase in STB content, no new characteristic peaks appeared in the FTIR spectrum, but the intensity and position of some peaks changed slightly. These changes may reflect the interaction between STB and geopolymer matrices, such as promoting the formation of geopolymer structures or regulating their surface properties through acid-base reactions. However, these changes did not directly lead to a significant increase in compressive strength, which may be related to the specific mechanism of action of organic bases in geopolymers.

After the addition of SS, the infrared absorption peak shifted around the wavenumber 1080 cm^{-1}, indicating that the active substance in the fly ash reacted with the STB. It can be observed that SA9-1 has the highest offset, indicating that with the increase of silicon content, the geopolymer reaction was complete, leading to an increase in Si-O-T bond aggregation. This also explains why the fly ash geopolymer synthesized with 5% STB and 16.5% SS as activators has the highest compressive strength.

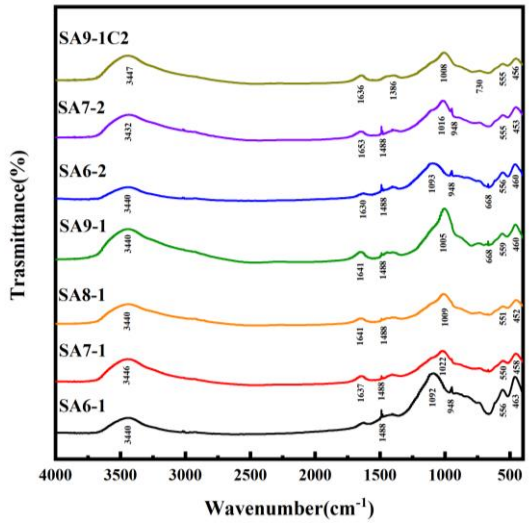

Figure 3: FTIR analysis of polymers with different mix proportions

5. MICROSTRUCTURE ANALYSIS

To visually observe the microscopic appearance of the geopolymer and the effects of STB, SS, and cellulose on its structure, we conducted SEM analysis. SEM images display the microscopic appearance and pore structure of geopolymers, providing an important microscopic perspective for understanding their macroscopic properties. The sample was magnified 10000 times for observation. Figure 4 presents the outcomes of the SEM analysis conducted on the samples. We found many unreacted fly ash glass beads in SA6-1 and SA7-1. After doubling the alkali content, SA6-1 and SA7-1 glass beads were dissolved and reacted in large quantities. There are obvious cracks and pores in the SA8-1 sample. When the SS content is increased to 16.5%, the number of cracks decreases significantly and the slurry matrix becomes denser. When cellulose is added, the basic cracks and pores in the net slurry matrix are greatly reduced, and the density is higher than that of the SA9-1 sample. This fully indicates that when the amount of cellulose is reasonable, the internal curing effect is beneficial for its density and compressive strength. Cellulose can also serve as a nanofiller in the geopolymer matrix, increasing its density and enhancing its mechanical properties.

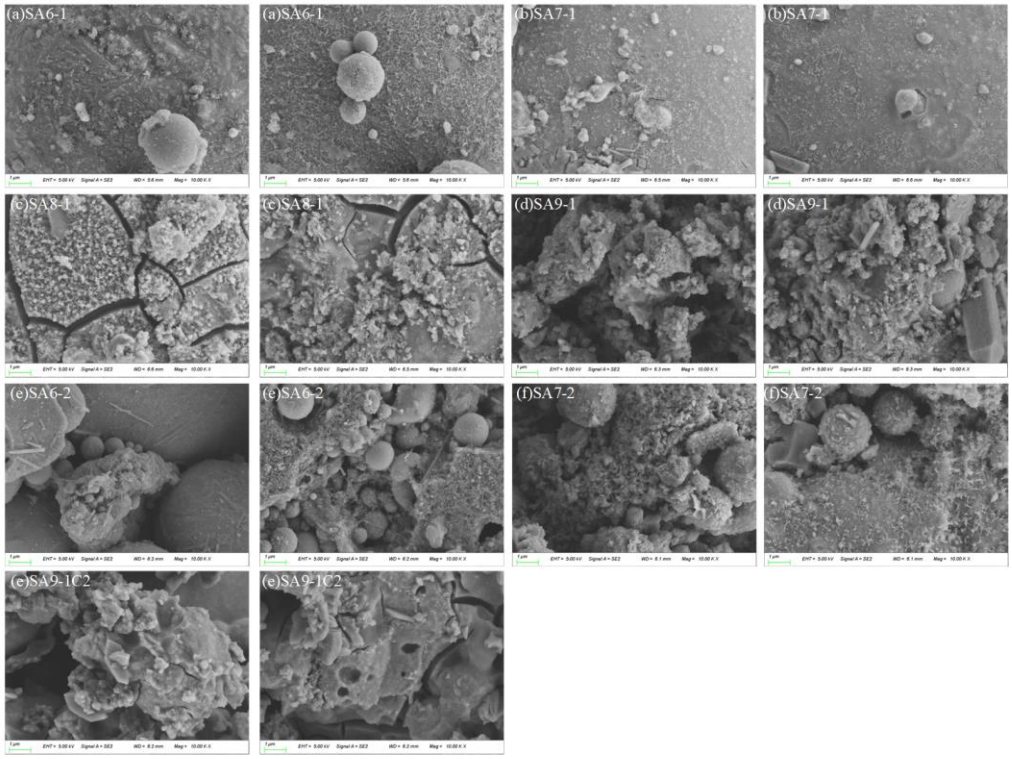

Figure 4: SEM images of geopolymers with different mix proportions

CONCLUSION

This study systematically probed into the influence of STB, SS, and cellulose on the characteristics of geopolymers. Through various characterization methods such as compressive strength tests, XRD analysis, FTIR spectroscopy, and SEM observation, the different mechanisms of these additives in the formation and performance regulation of geopolymers were revealed.

Due to the low quality and low activity of the fly ash used, the effectiveness of STB as a single activator is limited. Therefore, the selection and dosage of organic alkali need to be further optimized in the preparation of high-performance geopolymers. The amount of SS has a notable influence on the compressive strength exhibited by geopolymers, and its increase promotes the formation and expansion of the aluminosilicate network structure, thereby significantly enhancing the strength of geopolymers. When the contents of STB and SS are 10% and 16.5%, respectively, the strength of the geopolymer reaches its maximum at 28 days. However, compared to the contents of 5% and 16.5% STB and SS, the increase is not significant. In practical applications, the content of STB can be adjusted appropriately to save costs. The addition of cellulose did not affect the types of geopolymer reaction products. At low dosages, cellulose enhances the compressive strength of geopolymers through physical reinforcement; However, at high dosages, negative effects such as fiber agglomeration lead to a decrease in strength. Therefore, it is crucial to reasonably control the dosage and dispersion state of cellulose to optimize the properties of geopolymers.

The contribution of this research is to reveal the effect mechanism of different additives on the properties of geopolymer and provide an experimental basis and theoretical guidance for the preparation of high-performance geopolymer. However, this research also has certain limitations, such as a limited selection range of additive types and dosages, and incomplete optimization of preparation process

conditions. Future research can further explore more types of additives, optimize preparation process conditions, and conduct in-depth studies on the interaction mechanism between additives and geopolymer matrices to promote the application of geopolymer in a wider variety of fields.

AUTHOR BIOGRAPHY

Deng Peng, PhD student in Civil Engineering at Infrastructure University Kuala Lumpur. His research focuses on new cementitious materials and high-performance concrete.

Zulhazmee Bin Bakri, PhD, doctoral supervisor, his research focuses on building materials and fire-resistant materials.

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APPLYING GIS AND PRIMAVERA P6 FOR MONITORING CONSTRUCTION PROJECTS IN MALAYSIA

Nur Hazimi Mahbob[1], Hanah Zakariah[1], Nur Khairul Faizah Mustafa[1], Naimah Yusof[1] & Mohd Ashraf Mohd Fateh[2]
[1]*Faculty of Engineering, Science and Technology, Infrastructure University Kuala Lumpur, MALAYSIA*
[2]*School of Construction & Quantity Surveying, College Built Environment, Universiti Teknologi MARA, MALAYSIA*

ABSTRACT
In the field of construction, a wide range of complex tasks must be completed on schedule. Project managers often rely on software like PRIMAVERA and Microsoft Project (MSP) to plan and manage projects efficiently. However, these tools lack the ability to incorporate spatial information into project schedules. To address this limitation, advanced technology known as 4D Geographic Information Systems (4D GIS) has emerged as a promising solution. This technology allows for the integration of AutoCAD drawings with PRIMAVERA project schedules, providing a spatial and temporal dimension to project management. This thesis aims to investigate whether integrating ArcGIS with Primavera P6 enhances the success rate of construction projects and assesses the benefits of this integration. Additionally, the study examines the prevalence of ArcGIS usage in project management within the construction industry, with a specific focus on the types and sizes of companies that commonly utilize ArcGIS as a management tool. The research approach involves distributing questionnaires to 26 respondents, including engineers, project managers, educators, and engineering students. Through an analysis of the data collected and discussions with relevant stakeholders, this research seeks to clarify the potential advantages of incorporating 4D GIS technology into construction project management. Ultimately, this study contributes to our understanding of what makes a project management strategy successful and provides insights into how ArcGIS can be a valuable tool in the construction sector.

Keywords:
PRIMAVERA, Geographic Information Science (GIS), Project Management, ArcGIS

INTRODUCTION

One of the global industries with the fastest rate of growth is construction. At both the international and domestic levels, the construction industry is a significant industry branch. Numerous investment opportunities are presented by construction projects in a variety of associated industries. Therefore, for growing nations like Malaysia, the construction sector is a crucial economic indicator. Construction sector is essential to the nation's economic development and the creation of job opportunities (Annappa and Jamadar, 2017).

The construction project needs a proper scheduling, planning and monitoring of the work activities in order to be successful. Most construction projects face time and cost overruns due to a large number of uncertainties in the construction industry (Vyas and Birajdar, 2016). It is project manager's main duty to keep the expenditures connected with the work packages under control. Project managers can prevent schedule and cost overruns by employing an efficient project monitoring and management technique (Meng and Boyd, 2017).

Traditionally, just two factors are used to evaluate the planned cost of construction projects which is Planned expenditure and Actual expenditure. Although these components help the manager evaluate anticipated and actual spending, they do not provide information on the project's success. This

information is not sufficient because it offers no indication of the completed task (Tomar and Bansal, 2019).

In the construction industry, it is crucial for project managers to control and monitor the progress at each stage of the building job to prevent project cost and time overruns. It is possible with the right project management methodology (Radujković and Sjekavica, 2017). The development of tools and equipment, instruments for communication, approaches for effective management are all priorities for the construction sector. Construction project from government of Malaysia nowadays prefer construction company that implementing GIS as one of their monitoring tools. Malaysia has a small number of construction firms that practise GIS technology as their main application to manage and monitoring the construction project.

Therefore, it is crucial to study the advantages and subjecting the use of advances construction management tools such as ArcGIS. The main objectives of this paper are to identify whether the use of ArcGIS will increase the success rate of the construction project and to determine the advantages of using ArcGIS with Primavera P6 software.

Currently, the proposed construction work for typical building projects is communicated with the civil contractor through 2D CAD working drawings in a paper-based format. The contractor must be able to comprehend the working drawing, and it is his role to decide how and when to implement this plan according to the schedules with his planning team. The planner not only focuses on the work that needs to be done, but also considers needs such as equipment, plants, and other facilities that are necessary to finish the work in the time given. To enable the planning team to move forward with the time line scheduling for working drawings and all plans, a time frame is prepared (Kumar and Reshma, 2017).

Project managers employ conventional methods for scheduling processes, such as Critical Path Method (CPM), Program Evaluation and Review Technique (PERT), bar charts and more. These are utilised for planning, which makes it difficult to make decisions because they do not provide the necessary spatial information and data. In the event that proper monitoring is not carried out, project managers will be under pressure to speed up project completion and cut costs without compromising project quality or timeliness (Vinayakumar et al., 2019).

Nowadays, there are advances software and systems to help project managers manage and monitor the construction project with more details and accurate results such as Geographic Information System (GIS) & Primavera P6 software. The Primavera P6 project management tool is made to help project managers create plans, allocate resources to tasks, monitor work progress, analyse workload, and manage budgets (Suvarna et al., 2018). Primavera allows for the creation of budgets based on resource rates and job allocation. The distribution of resources among projects and the assignment of work is the rate of each volume up to the level of tasks, which rolls up to the task level, then to the numerous summary tasks, and eventually for the project level, determines the estimated, planned expenses calculated labour hours. Primavera P6 was also used to generate WBS, timetables, and allocate costs to each activity. The programme assisted in assessing the Earned Value Method (EVM) and creating the project's CPM schedule (Nalawade et al., 2019).

The aforementioned management tools cannot provide precise visual information, such as drawings, for working operations. Hence, GIS software are the better management tool as it gives useful details about building construction by generating 4D output for a better visualisation. Four-dimensional demonstrating is what 4D modelling is all about, it includes three dimensions for the working project model and one dimension for the work schedule. 4D planner is a tool for visualising, imitating, and communicating that provides simultaneous access to drawing and schedule data (Kumar and Reshma, 2017).

Construction management focuses on the efficient organisation, planning, monitoring, control, and the marketing, production, accounting, and finance departments' fundamental business processes are reported to ensure that construction facilities are profitable. When compared to construction project management, which focuses more on working with stakeholders to produce a specific solution who combine the indicative subprocesses such as project planning, design coordination, management structure

establishment, estimating and tendering, project scoping, and budgeting for a particular project (Harris et al., 2021).

When discussing projects, the terms "project success" and "project management success" are most frequently used. These two project success factors are related but also different from one another. The main difference is the connection of project success with the overall result of project goals achievement, while project management success relates to traditional measurements such as time, cost and performance (Radujković and Sjekavica, 2017).

The large part of economic growth for every country depends on construction projects. However, a survey of the project documents reveals that, in the majority of cases, the projects are not completed on budget as planned, thus they normally lose their operational budget and simply fail (Shahhosseini et al., 2018). Despite the fact that there is no universal definition of what defines a successful project, researchers concur that a project manager's effective actions can lead to the success of the project. Success of construction projects is a big priority for most governments, users, and communities (Radujković and Sjekavica, 2017).

Construction projects often consume significant amounts of capital asset investment from the state budget, and Malaysia's construction industry is no exception (Shahhosseini et al., 2018). Therefore, it is crucial to always seek out innovative approaches to help improve the success of construction management, particularly by enhancing organisational and human resource capabilities (Radujković and Sjekavica, 2017).

In project-based industry sectors, particularly in construction, the value of project managers has been universally recognised (Meng and Boyd, 2017). The role of the project manager includes not just time, budget, and quality management, but also human resource, scope, communication, integration, procurement, and risk management. Thus, they bear the primary responsibility for the project's success (Radujković and Sjekavica, 2017). The project manager should therefore keep an eye on activities to be completed in time for the fulfilment of the plan as a planner, organiser, and overall project controller (Rwelamila, 1994).

The following is the result of a recent survey and analysis by the Economist Intelligence Unit, which was funded by Oracle, of 213 senior executives and project managers worldwide. The survey also included in-depth interviews with nine executives and project management experts.

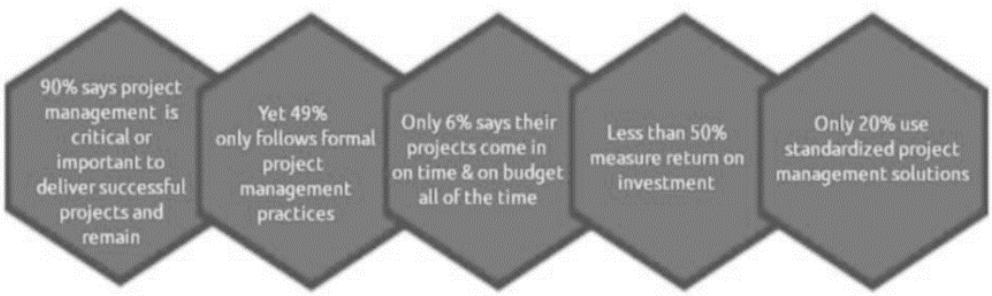

Figure 1: Outcome of the survey

Due to a construction project's varied and dynamic design, risk and opportunities are typically linked. Risk is defined as an unforeseen event that can happen over the course of a construction project (Smith et al., 2006). The generated Web-based GIS monitoring application gives data that helps the project managers or monitoring team to decide on a variety of options, as detailed in the next section (Thekulla et al., 2021). Moreover, to achieve the objective of on-time material delivery at the lowest supply chain cost, project managers can employ 4D BIM-GIS as a decision support base that serves as a

tool to determine the most advantageous site for a consolidation centre by providing the establishment costs of a consolidation centre in different locations (Deng et al., 2019).

A large variety of risks, including those related to finances and design that have a direct impact on overall performance and the achievement of the desired goals, are faced by the construction industry. Practical managerial abilities are absolutely necessary to deal with the unexpected and risky environment, which is seen as a constraint for project accomplishment due to the task's complexity (Sharma, 2011; Philbin, 2008; Hillson and Murray-Webster, 2007; Zwikael, 2011).

As a result of the unsatisfactory risk management techniques in the majority of Malaysia's construction industries, project managers view risk management as a proactive strategy for effective risk minimization and management. The risk propensity and risk management of Malaysian construction industry project managers are affected by organizational elements such communication, economic status, policy, and market status (Noor and Shaista, 2021).

For every project-based firm, choosing the ideal project manager is a difficult task. It is general knowledge that using effective leadership is a strategic move to create competitive advantages for project management (Meng and Boyd,2017). The top ten selection criteria for project managers included communication, technical proficiency, stakeholder management, budgeting, time management, educational background, planning, leadership, team building, and professional certification (Ahsan et al.,2013). To become competent, a project manager must be wise and perform honest constructive actions (Noor and Shaista, 2021).

Developed by Esri (Environmental Systems Research Institute), ArcGIS is a geographic information system (GIS) software used to create, organise, analyse, and visualise geospatial data. ArcGIS is created by Esri for mapping on desktop, mobile, and the web. "Science of Where" is their motto. ArcGIS's expertise thus is on location intelligence and analytics. The company's headquarters is in Redlands, California. The company was initially established in 1969 with a focus on land use development.

The interactive maps and 3D sceneries in ArcGIS Online enables the entire organisation to view, comprehend, and analyse the geographic data. It is simple to share content both inside and outside of an organisation. Companies can create private, invitation-only, or public groups that are accessible to everyone. Other than that, user can access 'ArcGIS Living Atlas of the World' which is a collection of dynamic data layers, analytics, maps, imagery and scenes from the ArcGIS community.

ArcGIS users come from a diverse range of backgrounds and industries. For example, ArcGIS is used by the government, schools, and businesses. However, the environmental, military, and land planning sectors have the most users. ArcGIS is also used in the construction industry especially in leading country, to manage and analyse data related to construction projects, such as land use, zoning, and site planning. Additionally, it can be applied to manage and examine data related to infrastructure projects, such as those involving roads, bridges, and utilities. It can also be used to manage digital maps and 3D models of construction sites and to monitor on the status of ongoing construction projects.

In order to get over the software's limitations, advanced technology like 4D GIS is important. Combination of schedules prepared in PRIMAVERA software and 2D drawings from AutoCAD can be applied in 4D GIS technology. Correlation between scheduled activities and accurate drawings in GIS can enhanced the identification of construction sequences and the detection of logical problems in project schedules. The produced 4D view improves the monitoring of a project's construction process (Chaitanya and Reshma, 2017).

For a more efficient evaluation and sharing of construction project schedule information, advanced visualisation techniques like 4D (3D geospatial + time component) and virtual reality should be used (Chaitanya and Reshma, 2017). This 4D GIS view makes it easier to grasp the planning process and execution of a construction project by improving visualisation of the project's progress and helps a planner to anticipate the construction process that would be carried out (Koo and Fischer, 2000). As a result, scheduling issues can be easily identified and smaller tasks can be done efficiently.

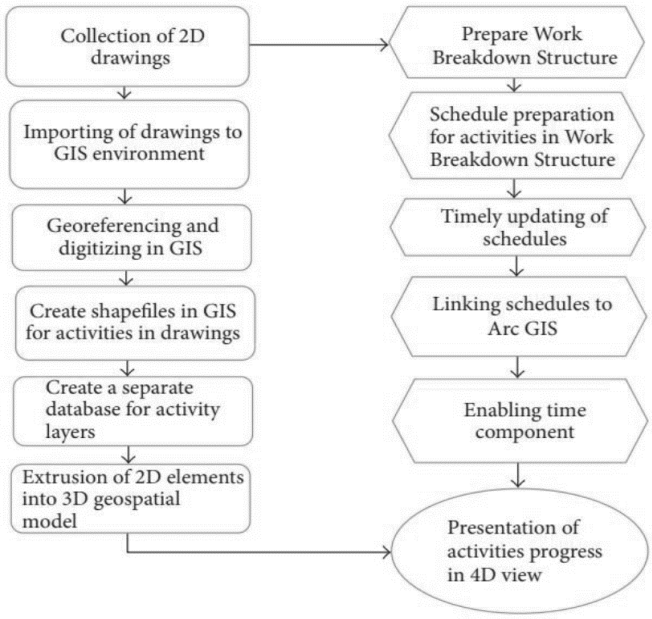

Figure 2: A flowchart for creating a 4D GIS model

The planning development tools are used to create schedules, such as start and end dates which are needed to be updated on a regular basis. Shapefiles prepared by the digitization process should have their own database with information about each activity stored in it. Linking of Schedules. GIS software must be linked to schedules that are updated after being created in planning software. Drawings and schedules must be tied together, meaning activity names and IDs should be the same for those activities. Creation of 3D Geospatial Model. ARCSCENE transforms the created activity layers into 3D layers. The created 3D file will have the same resource information as specified. Preparation of Final 4D Output. The displayed time line slider and the final outcome can both be seen in the produced 3D simulation. The created GIS-based planning and scheduling tool can be utilised for repetitive job tasks. The final product is known as a 4D drawing, which combines a 3D image with a time component (Chaitanya and Reshma, 2017).

This 4D system includes everyone involved in the project for better decision-making by enhancing knowledge of collaborative construction frameworks, analyses, and providing a means for graphically visualising the total construction process. Moreover, this 4D planning tool assist planners to reduces cost overruns of the projects by analysing limits, avoiding scheduling conflicts, and assessing various construction methods. Project planners can view the development of construction operations at any level of a project with 4D visualisation (Chaitanya and Reshma, 2017). As the project progresses, this 4D output assists the project manager in keeping track of the time estimates involved and speeds up decision-making because all relevant project information is contained in a single environment (Vinayakumar et al., 2019).

Primavera software was founded in 1983 by Joel Koppleman and Dick Faris in Philedalphia, USA. Over 75,000 businesses around the world rely on Primavera as their primary project management tool to successfully manage their projects, programmes, and portfolios. Project scheduling has always been Primavera's strongest suit, but as methods and techniques have evolved over time, Primavera has successfully transformed its core functionality from a planning tool to a better project portfolio management solution used by the entire project team and executives.

Using the Primavera system, notable iconic projects in Malaysia like KLCC, KLIA, Putrajaya, Cyberjaya, and LRT were successfully completed. Primavera has also been used by Petronas in Malaysia's oil and gas industry, in addition to the construction sector, as their preferred method of managing capital projects and maintenance/shutdown projects.

The main feature from Oracle Primavera is called Oracle Primavera P6. Primavera P6 is a construction project management software. Large-scale construction projects are scheduled and planned using it, and activities are scheduled, resources are allocated, progress is monitored, and project data is analysed. It is a tool that assist construction managers to efficiently managing and controlling the numerous parts of a construction project from beginning to end. For managing large-scale construction projects, Primavera P6 is known as one of the industry standards.

Primavera software scheduling is a process that includes estimating, sequencing the activities, allocating resources, and time. The idea of the construction scheduling is to finish the project on schedule and coordinate the resources with the given timeframe. Using Primavera software for scheduling provides effective control (E. Suresh Kumar, 2015).

Following are procedures to create schedule using Primavera P6. The first step in creating an efficient schedule for any project is obtaining the project's available information then create the full organisational structure of the company that is working out the project in Primavera P6. This is known as Enterprise project structure (EPS) (Anurag and Amitkumar, 2018).

Next is creating new project. The project is a strategy for developing a service or product and includes a number of different activity and related data, which were managed by their respective EPS divisions. By given dates for the beginning and end of the construction that is achievable, the project determines which global, resource, or project calendar to use. After that, project manager needs to do the work breakdown structure (WBS) which is work of identifying and categorizing each of the project's components. WBS is an organization of all the project work that needs to be done to execute a construction project. This will help to clearly identify deliverables, analysing and summarising project schedule and anticipated cost data at various level of detail (Anurag and Amitkumar, 2018).

The essential and critical work aspects of a project are segmented into the smallest subdivisions, which make up the WBS's top to bottom level. The detail of the activities that can be seen are such as ID, activity name, start and end times, calendar, activity codes, type of activity, limitations, costs, links between predecessor and successor, resources, and roles. The activities should be scheduled in a network by assigned succeeding activities that have a substantial relevance to the overall project activities (Anurag and Amitkumar, 2018).

After that, the calendar may be made and assigned to each activity. These calendars establish the number of hours that must be work during each day that also includes national holidays, project-specific workdays, non-workdays, and resource-vocation days (Anurag and Amitkumar, 2018).

The project duration is set in the original duration field during task planning. Only the project activities that have been finished can have their real duration entered. Then the Actual Start, Planned Start, Actual Finish, and Planned finish dates for project activities are all available in Primavera (Anurag and Amitkumar, 2018).

Primavera P6 software is highly beneficial for efficiently and effectively planning and scheduling projects. It recognises the floats that are available and figures out all potential critical pathways for the project. In order to explore different options, it can generate numbers of possible situations. This software can also split down any activities into smaller and clearly defined parts so the progress and completed task can be monitor and calculate the activity's completion percentage. Additionally, it evaluates risk, presents risk exposure values, and estimates how these risks will affect a project's schedule, duration, and budget (Vishal and Balasaheb,2017).

METHODOLOGY

This section presents the parts that were assessed along with the application of methods in order to collect the data and obtain the information that were need. The research method section describes the techniques used for data gathering or collecting as well as the analytical strategies used. The main assessment process determines whether the use of ArcGIS with Primavera P6 in monitoring and managing construction project in Malaysia, will enhance the probability of success of the project versus using the Primavera P6 software by itself. A survey on several articles and journals related to the implementation of ArcGIS in monitoring and managing construction project proves that the use of ArcGIS will give more advantages towards the project manager, construction company and client. The second stage of the process involves identifying with the study that has been included to make a more in analysis of writing. At this stage, a third procedure were applied to review the pilot study information and identify the factors of how and why ArcGIS software is used to monitor building projects. The fourth step were carried out with a focus on approach adjustments for all of the input information and sources from the pilot's ideas. The primary purpose and aim of this pilot study were to gather information and, in addition, to ensure that the chosen responder could clearly and effectively understand the element in the content. By doing this, the guarantee of the data gathered can be enhanced in achieving the aims. The fifth step are doing more extensive research in the area that is focused on obtaining data sources and information necessary to achieve the objectives. The sixth and last step are analysing the information that was gathered, hold a discussion, and research through the information.

Research Plan

Starting with the research title “Applying GIS And Primavera P6 For Monitoring Construction Projects in Malaysia”, everything falls together. Then, as part of the regular procedure for information gathering and analysis, a set of questionnaires was created and used in conjunction with the literature review, study of the info, and poll surveys. This assessment concentrate on the factors required to accomplishing the objectives along with the reliability and shortcomings of it.

Study Area

The study primarily focuses on universities and construction companies in Kuala Lumpur. This is because Kuala Lumpur hosts construction companies that use ArcGIS software for managing and monitoring construction projects, making it an ideal location for this topic: Applying ArcGIS and Primavera P6 in Monitoring Construction Projects.

Pilot Study

A pilot study is a small-scale exploratory investigation that is carried out in order to assess the viability, duration, potential risks, and study design before the completion of a larger research project. This will enhance data collection before the questionnaire's form and questions are applied and distributed to relevant respondents.

Data Collection

In order to gather data and information for the study, there will be two different types of data collection which is interview surveys and the distribution of questionnaires to appropriate respondents. To get the anticipated viewpoints and outcomes from the relevant respondents, it is important to collect as much information as possible relating to the topic.

Questionnaires

A questionnaire is a research tool used to collect data from respondents through a set of questions, which can be distributed via email, phone, computer, or face-to-face. The questions are designed for either qualitative or quantitative analysis, and respondents must have sufficient knowledge of ArcGIS and

Primavera P6 software. Before distribution, the questionnaire will be reviewed with the supervisor to ensure its relevance and clarity. Drawing on previous examples of similar surveys, the questionnaire will be divided into three main sections: the first will assess the success rate of construction projects using ArcGIS, the second will compare the advantages of ArcGIS over Primavera P6 for monitoring construction projects, and the third will explore the use of ArcGIS by companies of different sizes in Malaysia. This approach ensures that the research objectives are effectively addressed.

Data Analysis

The data were processed and placed into a pattern, group, and unit basis after being gathered through questionnaires and interviews. In order to complete this study, the data collected through questionnaires and interviews will be compiled and formatted into sources using Microsoft Word to ensure that the findings are clearer and more acceptable to the readers. The data from the questionnaire were gathered and evaluated using the percentage calculation.

RESULT AND CONCLUSION

With a total number of 26 respondent, 6 of them are reported being very familiar with ArcGIS, 9 respondents indicated that they are somewhat familiar with ArcGIS and 11 respondents are not familiar at all with ArcGIS. Which then make up a total 42.3% who are very familiar, 34.6% are somewhat familiar and 23.1% are not familiar at all. From the result obtain, we can see that people are getting aware about ArcGIS as a project management tools and more people might start using it in the future to improve their projects.

These percentages reveal that a significant portion of respondents (57.7%) have not used ArcGIS in construction projects. Among those who have used it, a combined 42.4% (19.2% significantly increased, 23.1% somewhat in-creased) reported positive impacts on the success rates. No respondents reported that ArcGIS had no impact. These findings offer valuable insights into the perceived effects of ArcGIS on construction project success rates among those who have experience with the software.

The recommendations for the use of ArcGIS in construction project management were diverse. None of the respondents recommended ArcGIS for small companies, while 8% favoured its use for medium-sized companies. 60%, recommended ArcGIS for large companies. None of the respondents opposed recommending ArcGIS for any company size. How-ever, a considerable percentage, 32%, expressed un-certainty about whether to make such recommendations. These various comments give an understanding of the various points of view regarding the suitability of ArcGIS for construction project management across different company sizes in Malaysia.

In the pursuit of enhancing construction project management practices in Malaysia, this study followed three main objectives to guide its research. Objective 1 sought to evaluate the potential impact of ArcGIS on project success rates. Objective 2 explored the advantages of combining ArcGIS with Primavera P6 software. Objective 3 delved into recommendations for ArcGIS usage across companies of varying sizes. The survey responses provided a mosaic of perspectives from lecturers, engineers, project managers, and students within the Malaysian construction industry.

First objective revealed that while 76.9% of respondents had not yet incorporated ArcGIS into their project management strategies, those who had experience with it acknowledged its potential to influence project success rates. The study emphasized the critical need for further exploration of ArcGIS adoption in construction projects, given its potential to enhance outcomes.

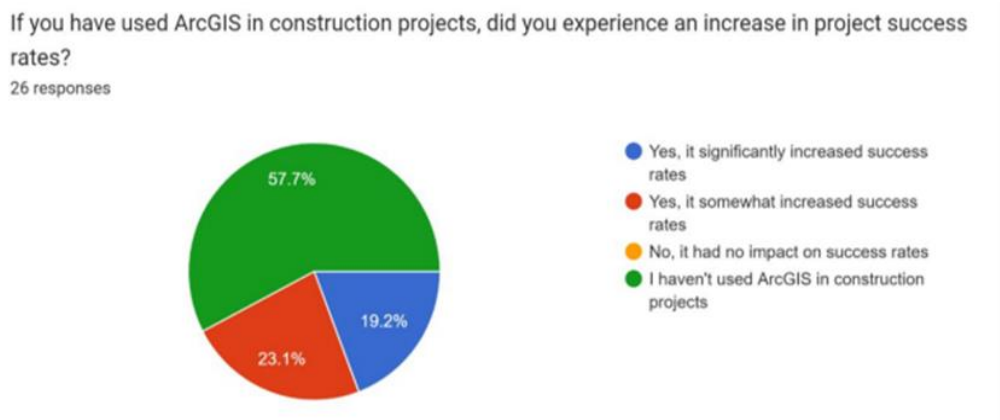

Figure 3: Usage of ArcGIS in constructions projects

For the second objective, it underlines the complexity of technology adoption decisions in construction project management. They provide a valuable foundation for further exploration of how these tools can be effectively utilized in diverse construction project contexts, offering construction professionals and decision-makers insights into the diverse perspectives surrounding the integration of ArcGIS and Primavera P6 in their project management practices.

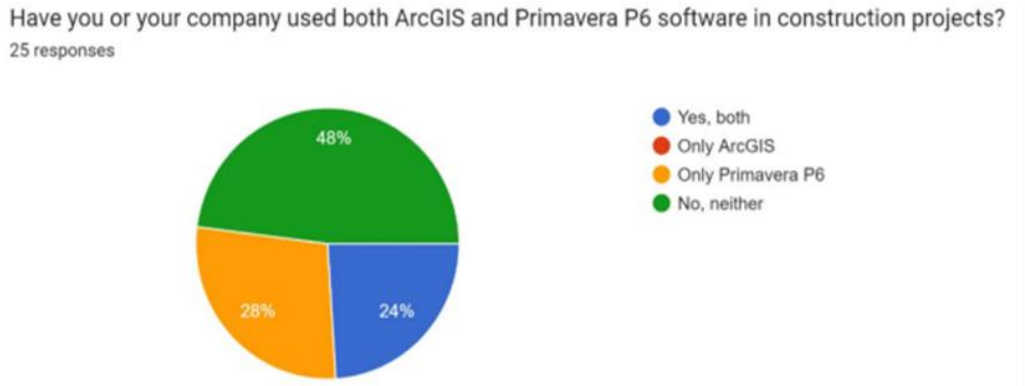

Figure 4: Usage of ArcGIS and Primavera P6 in construction projects

Meanwhile the third objective provided valuable insights into technology recommendations across varying company sizes. The mixed views on company size, coupled with factors like user-friendliness and cost influencing recommendations, underscored the multifaceted nature of technology adoption decisions. These findings offer guidance for construction firms in Malaysia as they make informed choices regarding the integration of technology, particularly ArcGIS, into their project management practices.

This study shows the complex structure of technology adoption in the Malaysian construction industry. The potential of ArcGIS to enhance project success rates, its perceived advantages when combined with Primavera P6, and the varied recommendations based on company size provide a comprehensive understanding of the intricate interplay of technology and construction project management. These insights are instrumental for practitioners and decision-makers in making informed choices that drive efficiency and success in construction projects in Malaysia.

RECOMMENDATIONS

To improve construction project management practices in Malaysia, companies should consider adopting ArcGIS due to its potential to enhance project success rates and its recognized benefits. Those with experience using the software have acknowledged its positive impact, suggesting that further research and case studies are necessary to assess its effectiveness across different construction contexts. Such studies can offer valuable insights to guide informed decision-making on its integration. Collaboration between construction companies, software providers, and government agencies is essential to develop tailored ArcGIS solutions that meet the specific needs of the Malaysian construction industry. Beyond adopting the technology, construction firms must also create clear integration strategies, carefully assessing organizational needs, evaluating the user-friendliness of the technology, and considering cost factors. Change management plans are also crucial for a smooth transition. Additionally, ongoing education and training programs are essential to equip construction professionals with the necessary skills to use ArcGIS and Primavera P6 effectively. These programs should highlight the advantages and practical applications of these tools in construction project management. Finally, fostering platforms for knowledge sharing through industry conferences, forums, and online communities will allow practitioners to exchange best practices and experiences, supporting informed decision-making and successful technology integration in construction projects across Malaysia.

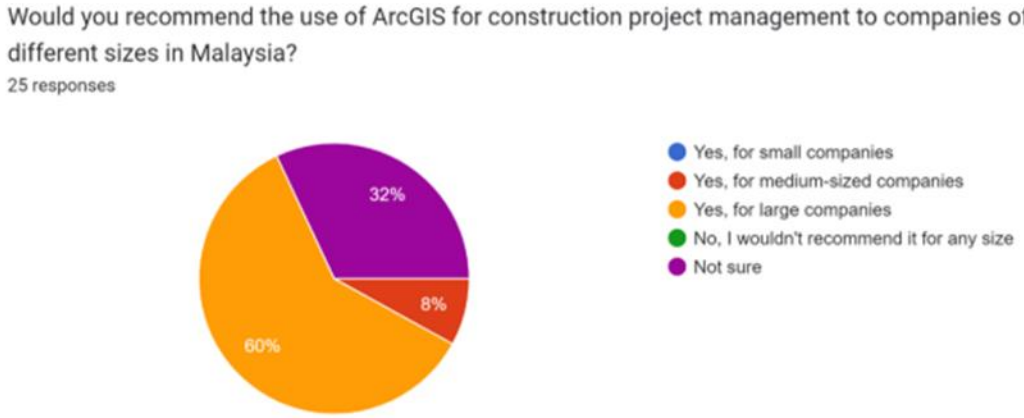

Figure 5: Recommendation from respondents

AUTHOR BIOGRAPHY

Nur Hazimi Mahbob is a graduated Bachelor of Civil Engineering (Hons) from Infrastructure University Kuala Lumpur. His research interest also includes project management, constructions and structures.

Hanah Zakariah is a Senior Lecturer at Infrastructure University Kuala Lumpur, with a strong background in geomatics and a focus on the practical applications of field technologies and GIS. She is passionate about creating learning environments that engage students and promote critical thinking, particularly within the field of geospatial sciences. Her research interests include digital twinning, gravity field data, and Geographical Information Science.

Nur Khairul Faizah Mustafa has been in academia for more than 20 years and also a member of the Royal Institution of Surveyors Malaysia (MRISM). Her consultancy work primarily focuses on building conditions surveys and inspections and specializing in building performance and compliance.

Naimah Yusof is a senior lecturer at Infrastructure University Kuala Lumpur (IUKL). She is involved in various research projects, particularly related to geotechnical and environmental engineering. Her work includes significant contributions to studies on erosion, ecohydrology and water security.

Mohd Ashraf Mohd Fateh is a Senior Lecturer at Universiti Teknologi MARA Shah Alam, with a research focus on the intersection of engineering, government, and linguistics. He has previously held positions at Infrastructure University Kuala Lumpur and Heriot-Watt University. His work contributes to the advancement of knowledge in these diverse areas.

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A REVIEW OF THE IMPACT OF CLIMATE CHANGE AND URBANISATION ON DRAINAGE SYSTEM IN OMAN

Ahmad Ghanim Al Hazar Al Kathiri, Nurazim Ibrahim & Ts. Dr. Nor Azidawati
Infrastructure University Kuala Lumpur, MALAYSIA

ABSTRACT

The impacts of climate change have become increasingly evident, significantly altering the environment in unpredictable ways. One of the most affected infrastructures is drainage systems, which are struggling to cope with the rising frequency and intensity of extreme weather events. Rapid urbanization further exacerbates the issue, as expanding paved surfaces increase runoff, placing additional strain on drainage networks. Oman has witnessed a notable rise in extreme rainfall, resulting in frequent flash floods with severe economic, social, and environmental consequences. This paper examines the combined effects of climate change and urbanization on Oman's drainage systems, highlighting key challenges and vulnerabilities. The findings indicate a sharp increase in catastrophic events between 2009 and 2014 compared to 2000–2008, primarily due to climate change. These events have resulted in numerous fatalities, extensive infrastructure damage, and substantial economic losses. More pavement areas and poor drainage infrastructure and inadequate management in many Omani cities further exacerbate the problem, leading to widespread flooding during extreme rainfall events. Given the rising occurrence of flash floods, it is crucial to reassess Oman's urban development and infrastructure planning to enhance resilience against future climate challenges.

Keywords:
Drainage systems, climate change, urbanization, rainfall, flash flood

INTRODUCTION

The effects of climate change have been more clearly visible in recent years, changing the environment around us in significant and frequently unpredictable ways. Drainage systems is one of the infrastructures that face a noticeable impact. Extreme weather events are occurring increasingly frequently and intensely, and as a result, the demands for drainage systems improvement are growing (Zhou et al. 2018). Generally, cities and towns have been maintained by a sophisticated network of pipes, canals, and basins, but it is now having difficulty adjusting to the shifting climatic trends. Numerous locations across the globe are affected by climate change, which disturbs ecosystems, water cycles, and societies. Increased rainfall trends have been observed globally in a number of places. Oman's Salalah region is among those places most affected by climate change (Andreou et al., 2020). Changes in weather patterns have resulted in more rain and flooding in this area, which have severely damaged the infrastructure and affected daily life for the locals. Major extreme rainfall events have increased in frequency in Oman over the past few years, leading to frequent flash floods and significant economic, social, and environmental losses (Gunawardhana et al., 2018). The Salalah region's current drainage infrastructure is unable to handle the increased rainfall and flooding brought on by climate change. A better drainage system is now required in order to handle the extra water and lessen the effects of flooding. To preserve the security and wellbeing of local citizens as well as to maintain the region's economic activity, an upgraded drainage system is essential. The study will concentrate on the impact of climate change to the current drainage system in Oman. The finding will offer insightful information on the difficulties brought on by climate change and can be helpful to decision-makers, planners of infrastructure, and local citizens.

LITERATURE REVIEW

Urban drainage is an important aspect of city infrastructure that is meant to transfer excess water away from urban areas in order to keep floods to a manageable level (Zhou et al., 2019). Climate variability has contributed to precipitation unpredictability throughout the world in numerous locations, as well as frequent urban flooding. According to Thanvisitthpon et al. (2018), climate change and urbanization have the potential to affect not only surface floods, but also the planning and construction of drainage systems. Conceptually, climate change and urbanization cause as changes in stormwater flow (higher volumes and faster runoff), overloading of drainage systems due to increased surface water and rising frequency and severity of floods, which expose the limitations of current infrastructure. The drainage system demand reflects the need for expanded, upgraded, or new systems to manage increased water flow effectively. The demand encompasses enhanced drainage capacity, improved designs, and the adoption of sustainable solutions like green infrastructure and retention basins to mitigate flooding risks.

Urbanization

Urbanization is the process of population movement from rural to urban areas, increasing the percentage of people living in cities and towns. Kumar et al. (2020), stated that the already depleted natural resources are under severe strain as a result of urbanization. The phenomenon of urbanization is on the rise, with more than 75% of the world's population anticipated to live in cities by 2020. Urban areas have grown in recent decades as a result of population expansion. Water scarcity promoted migration from rural to urban areas in arid and semi-arid countries. Surface runoff is a significant component of the hydrological cycle in these areas (Mahmoud & Gan, 2018). The rapid urbanization of the world has been attributed to a variety of socioeconomic issues, with cities producing between 70% and 80% of the gross domestic product (GDP) of several nations [World Bank, 2020]. While urbanization and economic growth are anticipated to grow in the upcoming years, it is possible that more money will be required to deal with natural disasters because of how frequently they occur (Gu, 2019). Even Nevertheless, these rapidly expanding metropolitan areas will keep growing in accordance with regional differences.

The speed of urbanization in most cities has outpaced the infrastructure development rate in emerging nations. A lack of sewage facilities, increased water demand, insufficient wastewater treatment facilities, and increased impermeable surface all have a negative impact on water resources, as well as congestion in urban drainage networks has been increased by urbanization. According to Abd-Elhamid et al. (2020), One of the key factors contributing to the poor performance of drainage systems is urbanization. Construction areas and impervious surfaces are two features of urban form change that contribute to higher flooding volumes. Mahmoud & Gan (2018), stated that even in desert areas with little yearly rainfall, the risk of flooding has increased recently as a result of urbanization. Numerous flood risk studies have documented how urbanization affects surface runoff.

Alves et al. (2020) point out that water management will have to deal with more extreme weather occurrences, such as heavier rainfalls that will cause more urban flooding and water pollution. Due to these changes, it is also anticipated that other issues, such as heat waves, droughts, and air pollution, will worsen in urban areas around the world (EEA, 2016). Therefore, it's crucial to take into account a variety of benefits while building urban infrastructure in order to create sustainable solutions that can make cities more resistant to deteriorating future conditions.

Urban Drainage System

All around the world, cities have installed urban drainage systems for more than a century to swiftly drain metropolitan regions of runoff and minimize the annoyance of flooding. In several regions of the world, combined storm water and wastewater drainage systems have been developed with a similar goal. In the 1850s, urban drainage systems were created with the goals of ensuring public hygiene and preventing flooding. In order to reduce the flow of pollutants to natural water bodies, WWTPs were modified and extended starting in the 1960s as pollution loads and environmental implications came into focus (Lund et al., 2018). In developed metropolitan areas, drainage systems are necessary due to the interaction between human activities and the natural water cycle. This interaction happens mostly when water is extracted from the natural cycle to meet human needs and when impermeable surfaces are used to redirect rainfall from the nearby natural drainage system. (Butler, 2018).

City expansion can affect runoff patterns, including peak flow volumes and runoff speeds, as well as changes in urban intensity and distribution that can increase or decrease a region's vulnerability to flooding. According to Guptha et al. (2021), rapid urbanization alters land cover, transforming vegetative surfaces and barren plains into impermeable pavements and infrastructure. This would have immediate ramifications for the system's hydrology, and as a result, a significant volume of storm water runoff generation would put the city's existing drainage system to the test. In most cases, these drainage systems are unable to cope with rising urban runoff, resulting in the occurrence of urban flooding in numerous cities across the world. As stated by Gimenez-Maranges et al. (2020), the current urban drainage systems struggle to meet both present-day and foreseeable future issues.

Urban Drainage System in Oman

The perils of floods pose a threat to the urban population, and in Oman many communities have sprung up in flood-prone areas. This is mostly because water is readily available close to Wadi drainage basins. Nevertheless, it is altering as a result of wise land planning and actions made by the government. According to Al-Charaabi & Al-Yahyai, (2019) rains were not anticipated in Oman when the country was being built. But over the past few years, several storms and extremely heavy rainfall have been brought on by the effects and consequences of global warming. It is important to remember that the nation concentrated on creating drainage systems during the construction of metropolitan infrastructure since there were few places for heavy rains to escape, which created a platform for flooding during the rainy season. In urban regions, urban floods submerge streets, basements, ground floors of buildings, etc. The majority of them are caused by riverine, flash, and coastal floods, but some of them are also a result of the drainage system's inadequacy, which is especially prevalent in metropolitan areas. The excess runoff flows onto roadways and urban areas when the drainage system is overloaded or unable to drain effectively into an outfall due to high river levels (Al-Barwani, 2018) The traditional drainage systems have also implemented a combined sewer system, in which rainwater flows into sewers carrying unclean water and both are sent to sewage treatment facilities. Such drainage systems' capacity is dependent on the treatment facilities', and is frequently insufficient for even comparatively light rainfalls. In many Omani cities, the drainage infrastructure is either non-existent or poorly maintained. Therefore, many cities are flooded when flash floods happen. A prime example occurred when Muscat, Quryat, and Sur were severely inundated during Cyclone Gonu in June 2007 as shown in Figure 1.

Figure 1: Floods in one of the Oman coastal areas after the Guno cyclone in 2007 (Al-Barwani, 2017)

Because Oman had less rain in the past, the drainage system did not receive much attention. However, the previous three years of climate change have seen greater rain, which, combined with a lack of or inadequate drainage systems, causes sporadic flooding. According to Al-Charaabi & Al-Yahyai (2019), floods are a factor in major traffic congestion, fatalities, casualties, poverty, and car damage, which costs the government and insurance firms millions of Rials. The local government is working on incorporating rapid actions to solve the issue in order to prevent more difficulties of troubles brought on by the rains. This is accomplished by making use of practical and efficient methods for both the renovation of existing drainage systems and the building of brand-new drainage systems.

Climate Change

Variations in the global temperatures of the air and ocean have confirmed climate change, extensive snow and ice melting, and an increase in average sea levels. In many places of the world, unpredictable precipitation and frequent urban flooding are both caused by climate variability. According to Salimi & Al-Ghamdi (2020), climate change's far-reaching consequences on human and ecological systems are well documented, and continued emissions of greenhouse gases induce more warming and will have long-term repercussions on every element of the climate system on Earth. Changes in climate and urbanization are two of the most prominent elements that affect existing and future urban flood management systems. Zhou et al. (2018), stated that climate change has a substantial impact on the water cycle and patterns of precipitation extremes, which can have a direct impact on surface runoff as well as the frequency and amplitude of floods. Some case studies done by (Chang et al., 2009; Sun et al., 2021; Yang et al., 2021) have documented the effects of climate change on excessive precipitation and urban flooding.

Due to the predicted effects of climate change on urban water systems, such as changes in water runoff and urban flooding, it has been widely identified as a global issue. According to studies by many academics, depending on the region, the anticipated rise in new drainage system design due to climate change can range from 20% to 80%. The current drainage system, which was designed based on a specific return period, has been faced with a significant difficulty as a result (Zhou et al., 2019). Climate change, urbanization, and the growth of population are predicted to increase pressure on the environment and human infrastructure, as well as test the sustainability of water resources (Kourtis & Tsihrintzis, 2021). As a result, climate change is expected to impact the water cycle by influencing precipitation patterns, leading to an increase in design intensities. Flood danger is expected to rise in the future as a result of a combination of meteorological and socioeconomic changes, particularly in urban areas.

Salimi and Al-Ghamdi (2020) conducted research on how climate change is affecting the Middle East and found that temperature increase, wet-bulb temperature increase (which will call into question the population's ability to work and survive), sea level rise and altered precipitation patterns are climate change's key effects in the Middle East. The key infrastructure in the area, particularly water production and electricity, built-up areas (leading to an increase in energy demand), transport and telecommunication systems, in addition to human health and welfare, will be under pressure as a result of these climate phenomena. Similarly, Babovic and Mijic (2019) discuss the necessity to modify urban drainage systems so that cities can manage the growing hazards of flooding brought on by further urbanization and climate change. Thus, it is crucial to adapt to climate change because doing so reduces the likelihood of urban floods. Additionally, Babovic and Mijic (2019) note that there is significant uncertainty around knowledge of future conditions, which makes it difficult to develop effective adaptation techniques.

Climate Change in Oman

Oman's climate ranges primarily from semi-arid to hyper-arid, and it receives less than 100 millimetres of annual rainfall on average, compared to the 1123 millimetres received worldwide on average (Al-Charaabi & Al-Yahyai, 2019). Numerous locations of the world exhibit increasing rainfall trends, according to global-scale studies. Recent years have seen a rise in big extreme rainfall events in Oman, which frequently cause flash floods and cause significant economic, social, and environmental consequences. Oman is particularly sensitive to the effects of extreme climate events due to the country's aridity and semi-aridity, as well as the persistent conditions of chronic water stress, catastrophic flooding, and protracted drought. The rainfall values recorded by meteorological stations in Oman between 2000 and 2014 provide conclusive evidence of a change in the intensity of extreme rainfall occurrences (Müller et al., 2020). The frequency of these potentially harmful events rose in Oman between 2009 and 2014 compared to 2000 to 2008. According to the report by Müller et al., (2020), a significant increase in extreme rainfall occurrences on Masirah island to the east and Thumrait to the south of Oman.

The average amount of precipitation in Oman over the previous ten years has either declined or fluctuated continuously, according to Trading Economics (2023). Based on the data in Figure 2, 2014 had the highest average precipitation, with 83.49 mm. However, Oman's precipitation fell off in the years that followed, reaching a low of 31.94mm in 2021. To date, several water management facilities in Oman, including storm water collection systems, recharge dams and flood protection structures, have been designed using historical climatic data and the stationary assumption (the idea that rainfall variation features remain constant over time). Therefore, a more thorough evaluation that takes into account the potential effects of climate change is needed in order to prevent or, at the very least, lower the risks of flooding and infrastructure damage. (Gunawardhana et al., 2018)

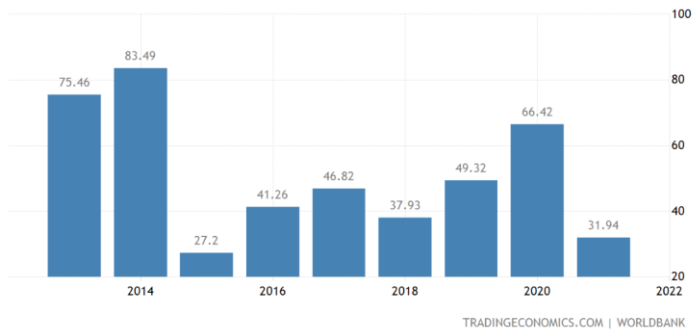

Figure 2: Oman average precipitation (Source: Trading Economics, 2023)

The recent experience of the cyclones Gonu in 2007, Phet in 2010, and Mekunu in 2018 in Oman illustrates the potential impact of an extreme meteorological event on metropolitan areas by the large number of fatalities, the damage to infrastructure, and the economic harm (Al-Awadhi et al., 2019). Due to flash floods and decreased aquifer recharge, severe weather harmed metropolitan areas. The frequency of these potentially catastrophic events rose in Oman between 2009 and 2014 compared to 2000 to 2008, according to a recent study that used data for one-hour and one-day high rainfall events. Some of these tendencies are anticipated to persist, posing a serious risk to the populace as well as the infrastructure (Gunawardhana et al., 2018).

Additionally, due to the combined effects of sea level rise and storm surges brought on by extreme weather events, Oman's low-lying coastal metropolitan centers will be more susceptible to flooding because of climate change (Al-Awadhi et al. 2016). Furthermore, future heavy rainfall events might result in an increase in the size and frequency of flash flooding (Al-Awadhi et al. 2018). Reevaluating Oman's growth plans for urban areas and infrastructure is necessary to take these dangers into account. Although Oman faces numerous threats related to climate change, no initiatives or policies have been created expressly to increase climate resilience in Omani cities. Building resilience will be crucial for urban regions in the future decades to respond to shocks and pressures from climate change, according to a number of studies (Leichenko 2011; Bahadur & Tanner 2014; Meerow et al., 2016; Zhang & Li 2018).

CONCLUSION

Existing studies clearly indicate that climate change and urbanization have significantly impacted Oman’s drainage systems. The current infrastructure, designed based on historical rainfall patterns, is now inadequate due to the increasing variability in rainfall intensity and frequency caused by climate change. Additionally, the expansion of paved surfaces has exacerbated the issue, leading to more frequent and severe flooding, particularly in urban areas. To mitigate these risks, it is crucial to conduct updated assessments of the drainage system and implement necessary improvements to enhance its capacity and resilience. Proactive planning and adaptation measures are essential to minimize future flood-related losses and ensure sustainable urban development in Oman.

AUTHOR BIOGRAPHY

Al Hazar Al Kathiri Ahmed Ghanim Mohammed, is a Master’s degree student in Civil Engineering (by Research) at the Faculty of Engineering and Technology, Infrastructure University Kuala Lumpur. His research examines the issue of non-revenue water in Salalah City, Oman. He is supervised by Dr. Nurazim Ibrahim (Ts., PhD) and co-supervised by Dr. Nor Azidawati Binti Haron (Ts., PhD).

Nurazim Ibrahim, Ts. PhD is a senior lecturer in the Civil Engineering & Construction Department at Infrastructure University Kuala Lumpur. She earned her MSc in Solid Waste Management in 2012 and her PhD in Water Quality in 2018, both from Universiti Sains Malaysia. Dr. Nurazim’s research primarily focuses on addressing challenges related to solid waste management and mitigating water pollution. She is also deeply interested in sustainable and green technologies, environmental engineering, and climate change, with a commitment to advancing solutions for a more sustainable future. Additionally, she is a professional member of the Malaysia Board of Technologists (MBOT) and the member of Board of Engineers Malaysia (BEM).

Nor Azidawati Binti Haron Ts. PhD, is a senior lecturer at Universiti Teknologi Malaysia (UTM) in the Faculty of Civil Engineering, specialising in hydraulics and hydrology. She has extensive experience

in river morphology and water resources management. Dr. Azidawati has contributed significantly to research in these fields, with numerous publications and collaborations with local and international institutions. Her work focuses on sustainable water management practices and the environmental impacts of hydraulic engineering projects. Dr. Azidawati is dedicated to advancing knowledge and solutions for water-related challenges in Malaysia and beyond. She is currently the assistant leader (coordinator) for the CBHE Erasmus grant, an international grant related to green leadership. This role involves coordinating efforts to enhance higher education capacities and promote sustainable practices. Additionally, she is a professional member of the Malaysia Board of Technologists (MBOT), the Board of Engineers Malaysia (BEM), the Malaysian Water Association (MWA), and the Malaysian Society for Engineering & Technology (MySET).

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Infrastructure University Kuala Lumpur

Infrastructure University Kuala Lumpur
Corporate Block, Unipark Suria,
Jalan Ikram-Uniten, 43000 Kajang,
Selangor Darul Ehsan.
Tel : (603) 8926 6993
Fax : (603) 87341021

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