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A Letter from Jordan Engineers Association

Engineering, as the essence of human progress, is no longer merely a professional practice but rather a comprehensive intellectual system founded on the principles of science and technology to anticipate the future. Amidst the profound transformations the world is witnessing—from the Fourth Industrial Revolution to artificial intelligence and advanced materials engineering—the role of engineers is no longer confined to design and execution. Instead, they have become partners in knowledge production, developing innovative solutions that reshape economies and societies.

Digital transformation, the integration of big data with high-performance computing, and the rise of artificial intelligence compel us to redefine the concept of engineering within academic and professional spheres. We are at a stage that necessitates adaptive engineering with an integrative, cross-disciplinary character, where applied mathematics, data science, bioengineering, and intelligent systems form the foundation for the infrastructure of the forthcoming scientific revolution. Today, engineering is not isolated from space sciences, quantum physics, or clean energy; rather, it serves as the driving force connecting these fields and integrating them into a more efficient and sustainable production model.

The real challenge lies in moving beyond traditional models of engineering education toward more dynamic environments that encourage applied scientific research and cultivate a generation of scientists and engineers capable of developing technologies that transcend today's limitations. We cannot confront climate challenges, infrastructure gaps, or the complexities of urban transitions without engineering rooted in systemic thinking and cross-disciplinary innovation.

In this context, the responsibility of scientific and engineering institutions is to foster interactive research environments, push the boundaries of experimentation and application in renewable energy, smart building materials, adaptive cybernetic systems, and quantum mechanics in engineering applications. The interaction between engineering and fundamental sciences will define the contours of the coming scientific revolution and reshape the concept of sustainability—not only environmentally but also economically, socially, and technologically.

We stand at a pivotal moment that demands an engineering response that goes beyond incremental solutions to introduce radical transformations in thought patterns and application methods. From programmable materials engineering to the development of autonomous smart cities, from ultra-high-speed transportation systems to neural engineering, it has become imperative for engineering to redefine the future rather than merely adapt to it.

Therefore, we call upon researchers and academic practitioners worldwide to reconsider traditional engineering frameworks and work toward integrating multidisciplinary knowledge into a new engineering paradigm capable of addressing the growing complexity of the world. Engineering is not merely a tool for problem-solving; it is a proactive science that redefines reality and establishes an era where innovation is the norm, not the exception.

Eng. Ahmad Samara Al-Zoubi

President of the Jordan Engineers Association

A Letter from the Editor

Dear Colleagues, Scholars, and Readers,

It is with great enthusiasm and pride that I introduce the inaugural issue of Jordan Engineer Jornal-Academic Section, a peer-reviewed journal dedicated to advancing knowledge in all engineering and related fields. Launching this journal represents a milestone in our commitment to fostering rigorous scholarly dialogue, promoting innovative research, and bridging gaps between theory and practice in all engineering fields.

The launch of Jordan Engineer Journal-Academic Section stems from a recognized need for a platform that prioritizes interdisciplinary collaboration, open-access scholarship, and emerging technologies. Our mission is to publish high-quality, original research that undergoes a stringent yet fair peer-review process, ensuring credibility, relevance, and impact. This first issue reflects the dedication of authors, reviewers, and editorial teams worldwide who share our vision of advancing Engineering for the benefit of academia, industry, and society.

This debut edition features articles that exemplify the journal's scope and ambition. Each contribution underwent meticulous evaluation by our expert editorial board and reviewers, and I extend my deepest gratitude to all who participated in this collaborative effort.

A journal's success hinges on its community. I thank our esteemed editorial board for their guidance, our reviewers for their time and expertise, and our authors for entrusting us with their work. Special recognition goes to Eng. Ruqaia Kanaan and Mrs. Majd Abdulhamid for their relentless efforts in bringing this vision to life.

As we embark on this journey, we invite researchers, practitioners, and policymakers to contribute to future issues. We aim to amplify underrepresented voices, address global challenges, and foster inclusivity in scholarly discourse. Our commitment to open access ensures that knowledge reaches diverse audiences without barriers.

Finally, to our readers: your engagement will shape this journal's trajectory. We welcome feedback, ideas, and collaboration as we strive to make Jordan Engineer Journal-Academic Section a cornerstone of excellence in Engineering.

With gratitude and anticipation,

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A Novel Method of the Evaluation of the Dynamic Response of Pressure Biosensors with Boss-Stiffened Diaphragms

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Abstract

The aim of this work was to study the dynamic behavior of boss stiffened clamped circular diaphragms, subjected to a dynamic function pressure, and adopted to constitute pressure biomedical sensors.

The main objective was to find optimum dimensions, thickness ratio (TR) and radios ratio (RR), thus obtaining minimum stresses and minimum response time. The theoretical study was achieved both analytically and numerically. The theoretical solution was obtained by treating the diaphragm as a thin plate with variable thickness at the boss stiffener location, which leads to a Bessel type equation of fractional order. The finite element method was used for modeling such a case, hence obtaining an optimum solution. The verification of the suitability of this sensor to medical application for measuring the blood pressure was performed by subjecting the boss stiffened diaphragm to a blood pressure pulse wave (BPPW) recording and interpreting its response.

Keywords

Pressure biosensors, dynamic response, Boss-stiffened diaphragms, MEMS, finite element method, modeling.

Introduction

Understanding the behavior of boss-stiffened diaphragms is necessary for designing microelectromechanical systems (MEMS), such as miniature pressure sensors, micro-actuators and micro-valves. Considering the emerging importance of MEMS, it is instructive to review the evolution process and to examine new developments of pressure sensors starting from metal diaphragm sensors with bonded silicon strain gauges and moving to present developments of surface-micromachined smart pressure sensors with boss-stiffened diaphragms. Zhang (2022) has focused on the wide use of sensors in medical instrumentation and other acoustic devices [1]. By Kumari (2024), MEMS devices are driving innovation and revolutionizing patient care across various medical sectors. MEMS-based sensors embedded in wearable devices enable continuous monitoring of vital signs such as heart rate, blood pressure, and temperature. These devices empower individuals to track their health in real time, facilitating early detection of abnormalities and proactive management of chronic conditions [2].

Yang (1996) and Saini (2000) presented a comprehensive model of a circular diaphragm of a piezoresistive microphone [3, 4]. Kim (1999) investigated a large deformation behavior of a rubber diaphragm, which was a critical element of accumulators [5]. Gibbons (2000) designed a miniature silicon condenser microphone diaphragm that exhibits good, predicted directionality, sensitivity, and reliability [6].

Diaphragm design and features play a leading role when employing them in different types of sensors. Diaphragms usually come in different designs: uniform-thickness diaphragms, non-uniforms, and bossed diaphragms. One method for achieving a linear response is to use bossed diaphragms. The thicker center portion (or boss) is much stiffer than the thinner tether portion on the outside. The center boss contributes most of the capacitance of the structure and its shape does not distort appreciably under applied load. Hence the capacitance–pressure characteristics will be more linear [7].

To understand diaphragm's behavior under different conditions, several researchers perform deep studies and suggest designs and forms that meet needed applications [8]. Their work showed that classic flat diaphragm structure exhibits poor linearity at very low pressure and requires a large collection surface to achieve reasonable outputs, which is not reasonable in many medical applications as the pressure is reduced further and further. An alternative is to fabricate a "bossed" structure with a suspended thicker diaphragm in the center of the diaphragm. The moveable surface then deflects more like a piston deformable plate. This allows force concentration and improved linearity. Because of both the complexities in forming the double-boss structure and in connecting optimally to the measuring circuit, the double-boss was proved to be not the most preferred structure [8].

In the other hand, high-sensitivity pressure sensors with bosses of reduced thicknesses were designed to reduce the unavoidable nonlinearity increase with sensitivity by using structured membranes. These devices exhibit performances impossible to achieve with classical designs based on flat diaphragms. An example of such designs is the high-performance piezoresistive pressure sensors for biomedical applications using very thin structured membranes, [9].

Pressure sensors using different types of diaphragms as their sensing elements can be modified to be used as biosensors. For example, pressure sensors using stress detection can be employed to measure proteins in solutions [10]. In this case, antibodies are covalently attached to the surface of the membrane in such a way that the stresses induced in the antibody when it reacted with its antigen were detected. Detection of biological warfare agents or bacteria and viruses in the hospital laboratory should be expedited with this stressed antibody technique. Because of the small size and versatility of this biosensor, arrays of sensors can be fabricated on a single chip [11].

The variety of designs of pressure sensors requires deep attention to the analysis and testing of their features. In this paper, the theoretical analysis was carried out both numerically and analytically. The numerical solution was carried out based on the finite element method in which ***ANSYS*** package was used. The diaphragm was discritized using shell elements. The analytical part comprises a new uncommonly built stiffening-boss model in which the diaphragm was treated as a thin plate with variable thickness at the boss stiffener location. The solution of this model was obtained in the form of Bessel function.

Theoretical Analysis

The suggested theoretical model of the mechanical behavior of boss diaphragms is presented in this paragraph. The knowledge of natural frequencies and modes of vibration is not only important from a design viewpoint (to avoid resonance conditions, for instance), but it is also the basis for forced response calculations. Hence both parameters were taken into consideration.

The operator form of the equation of motion for free vibration of thin plates is:

$$D\nabla^4\eta_3 + \rho h\frac{\partial^2\eta_3}{\partial t^2} = 0 \tag{1}$$

Where η_3, ρ, and h are the response, density, and thickness of the plate respectively.

Assuming separation of variables, the response will be

$$\eta_3(r,\theta,t) = U_3(r,\theta)e^{j\omega t} \tag{2}$$

Substituting equation (2) into equation (1), and using the procedure introduced by Al-Dawoodi [12], the following matrix-form equation (3) is obtained. This equation is true in a meaningful way only if the determinant is zero, giving the frequency equation. Its solution gives then the natural frequencies of the boss stiffened diaphragm, shown in figure (1),

$$\left[\begin{array}{cccccccccc}
J_n(\lambda a_1) & I_n(\lambda a_1) & -J_n(\lambda_2 a_1) & -I_n(\lambda_2 a_1) & & & 0 & 0 & 0 & 0 \\
J_n'''(\lambda a_1) & I_n'''(\lambda a_1) & J_n'''(\lambda_2 a_1) & I_n'''(\lambda_2 a_1) & & & 0 & 0 & 0 & 0 \\
J_n'(\lambda a_1) & I_n'(\lambda a_1) & J_n'(\lambda_2 a_1) & I_n'(\lambda_2 a_1) & & & 0 & 0 & 0 & 0 \\
J_n''(\lambda a_1) & I_n''(\lambda a_1) & J_n''(\lambda_2 a_1) & I_n''(\lambda_2 a_1) & & & 0 & 0 & 0 & 0 \\
0 & 0 & J_n(\lambda_2 a_2) & I_n(\lambda_2 a_2) & & & & & & -K_n(\lambda a_2) \\
0 & 0 & J_n'(\lambda_2 a_2) & I_n'(\lambda_2 a_2) & & & & & & K_n'(\lambda a_2) \\
0 & 0 & J_n''(\lambda_2 a_2) & I_n''(\lambda_2 a_2) & & & & & & K_n''(\lambda a_2) \\
0 & 0 & J_n'''(\lambda_2 a_2) & I_n'''(\lambda_2 a_2) & & & & & & K_n'''(\lambda a_2) \\
0 & 0 & 0 & 0 & 0 & 0 & & & & K_n(\lambda a) \\
0 & 0 & 0 & 0 & 0 & 0 & & & & K_n'(\lambda a)
\end{array}\right]
\begin{Bmatrix} C_1 \\ D_1 \\ C_2 \\ D_2 \\ E_2 \\ F_2 \\ C_3 \\ D_3 \\ E_3 \\ F_3 \end{Bmatrix}
=
\begin{Bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{Bmatrix} \tag{3}$$

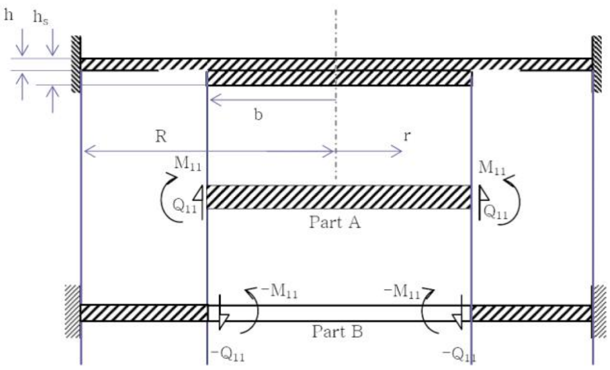

Figure (1). Boss Stiffened Diaphragm

Knowing the eigenvalues makes it possible to obtain the forced vibration in terms of these eigenvalues. This approach is called spectral representation or modal expansion.

In a mathematical sense, the natural modes of a shell structure represent orthogonal vectors that satisfy the boundary conditions of the structure. This vector space can be used to represent any response of the structure. In the case of finite degree of freedom systems, the vector space is of finite dimension and the number of vectors or natural modes is equal to the number of degrees of freedom. For continuous systems, such as plates, the degree of freedom is infinite. This means that the general solution will be an infinite series written as follows

$$u_i(\alpha_1,\alpha_2,\alpha_3)=\sum_{k=1}^{\infty}\eta_k(t)U_{ik}(\alpha_1,\alpha_2) \tag{4}$$

where i = 1, 2, 3. The U_{ik} are the natural mode components in the three principal directions. The modal participation factors η_k are unknown and can be determined by using Love equations.

It is well known that Love equations are of the form

$$L_i(u_1,u_2,u_3)-\lambda\dot{u}_i-\rho h\ddot{u}_i=-q_i \tag{5}$$

Where λ is the equivalent viscous damping factor.

Substituting equation (4) into equation (5) gives the following differential equations:

$$\sum_{k=1}^{\infty}[\eta_k L_i(U_{1k},U_{2k},U_{3k})-\lambda\dot{\eta}_k U_{ik}-\rho h\ddot{\eta}_k U_{ik}]=-q_i \tag{6}$$

However, from eigenvalues analysis, it is known that:

$$\omega_k^2=\frac{-L_i(U_{1k},U_{2k},U_{3k})}{\rho\, hU_{ik}} \tag{7}$$

Substituting expression (7) into equation (6), we obtain:

$$\sum_{k=1}^{\infty}(\rho h\ddot{\eta}_k+\lambda\dot{\eta}_k+\rho h\omega_k^2\eta_k)U_{ik}=q_i \tag{8}$$

From the fact that natural modes U_{ik} are orthogonal, the modal participation factor equation can be written as

$$\ddot{\eta}_k+2\zeta_k\,\omega_k\dot{\eta}_k+\omega_k^2\eta_k=F_k(t) \tag{9}$$

Where ζ_k is called the modal damping coefficient.

Numerical Solution

The numerical solution of this investigation has been achieved by using the finite element software package ***ANSYS*** with fine meshes of quadrilateral shell element. Elastic shell elements have bending and membrane capability both in plane and normal loads are permitted. The elements have six degrees of freedom at each node. Stress stiffening and large deflection capabilities are included.

Results and Discussion

The results obtained from this theoretical study concentrate on the effect of the normalized boss dimensions, namely b/R and h_s/h, on the induced maximum Von Mises stresses and on the time of response during the application of a known step function. Figure (2) shows the response of the stiffened-boss diaphragm on a pressure of the step function form.

In order to have a non-dimensional representation of the Von-Mises stresses and the time of response, the following terms were adopted, t_s/t_f and s_s/s_f, where t_s, t_f represent the time of response of stiffened and flat diaphragm respectively, and s_s, s_f represent the maximum Von-Mises stresses induced in stiffened and flat diaphragms respectively.

The effect of h_s/h is presented in figure (3), which shows that the induced stress tends to decrease until reaching almost a constant value as h_s/h increases, while the time of response fluctuates as h_s/h increases. Based on minimizing both stress and time of response, an optimum value of h_s/h can be obtained. This optimum value happens to be in the range of (1.6 – 1.8).

Regarding the effect of b/R, both stress and time of response fluctuate as b/R increases, yielding an optimum b/R value in the range of (0.2-0.4) as shown in figure (4).

From the results obtained for all cases, Von-Mises stress and time of response were reduced for boss-stiffened diaphragms as compared to flat and non-stiffened diaphragms, hence obtaining better performance.

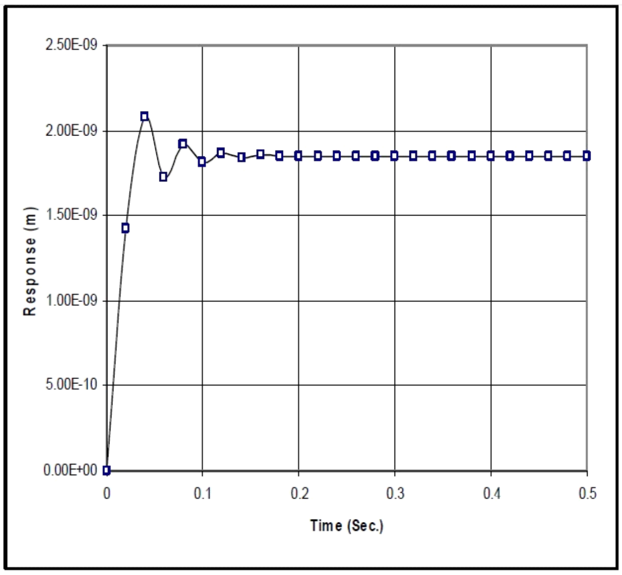

Figure (2). Response of step function

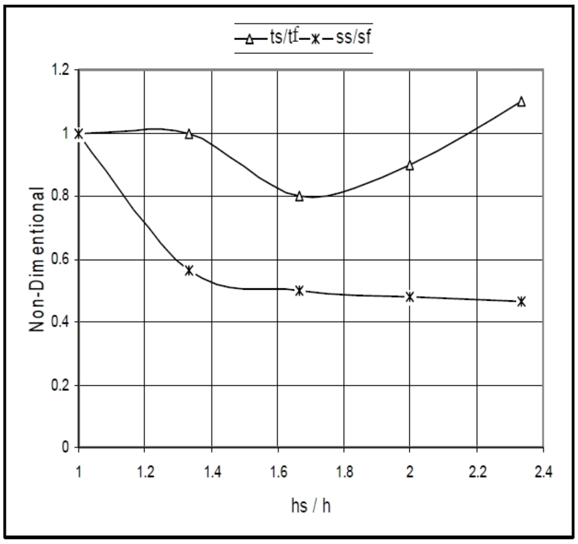

Figure (3). Effect of h_s/h

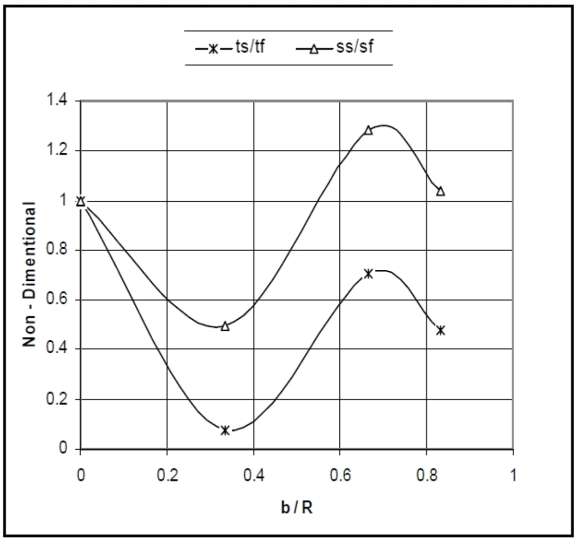

Figure (4). Effect of b/R

Testing the suitability of Boss Stiffened Pressure Sensor for Blood Pressure Measurement

To justify the suitability of the pressure sensor with stiffened-boss diaphragm for medical application, we test its response to pressure pulse wave by the same methodology used in the case of the step function. For that pressure pulse wave is generated through presenting it by three piecewise continuous functions over the cardiac cycle period T [13]. This will look like

$$x(t)=\begin{cases} A_1 \sin 2\pi f_1 (t-0.00), & for\ 0.00 < t \le t_1 \\ S_1(t-t_1)+A_2, & for\ t_1 < t \le t_2 \\ A_3 \exp[-h(t-t_2)], & for\ t_2 < t \le T \end{cases} \qquad (10)$$

Where:

A_1 – the value of the BP pulse scaled maximal amplitude (mmHg),

A_2 – the BP pulse scaled value at the beginning of the dicrotic notch (mmHg),

A_3 – the BP pulse scaled value at the end of the dicrotic notch (mmHg),

h – the time constant (s^{-1}),

S_1 – the slope (mmHg/s),

f_1 – the frequency of the pulse wave (Hz), and

t_i – the time intervals of the pulse components (s)

These estimated values of the parameters of different parts of the simulated pulse wave signal are calculated empirically for a normal person (Table 1).

A_1	B_1	B_2	h	S_1	f_1	t_1	t_2	t_3	T
1	0.57	0.66	6.1	2.0	1.5	0.000	0.265	0.310	0.900

Table (1). The estimated values of the parameters of the simulated pulse wave signal

The values of the input and the response of the pressure sensor are shown in table (2).

Time, sec	0.000	0.050	0.100	0.150	0.200	0.250	0.265
Input Pressure	0.000	0.454	0.809	0.988	0.951	0.707155916	0.580000
Response	0.000	0.460	0.819	1.000	0.963	0.716	0.587
Time, sec	0.300	0.310	0.350	0.400	0.450	0.500	0.550
Input Pressure	0.634	0.663	0.530	0.372	0.276	0.205	0.153
Response	0.642	0.672	0.537	0.376	0.280	0.208	0.154
Time, sec	0.600	0.650	0.700	0.750	0.800	0.850	0.900
Input Pressure	0.113	0.084	0.063	0.044	0.033	0.024	0.018
Response	0.115	0.085	0.063	0.044	0.033	0.025	0.018

Table (2). The input and the response of the pressure sensor

It is seen from the values in the table that a pressure sensor with stiffened-boss diaphragm working in the low-pressure range gives response of the same shape as the applied input. This clearly demonstrates the suitability of this type of sensors for measuring blood pressure with high accuracy.

Conclusions and Future Work

The following conclusions can be drawn:

- An optimum h_s/h value is in the range (1.6 - 1.8) at which the time of response is reduced by 20% and the maximum Von-Mises stress is reduced by almost 50% as compared to flat diaphragms.
- An optimum b/R value is in the range (0.2 – 0.4) at which the time of response is reduced by almost 90% and the maximum Von-Mises stress is reduced by almost 50% as compared to flat diaphragm.
- One of the advantages of the discussed sensor is that it can be adapted to detect physical, chemical, or biological activity which will be the future work of this paper.

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Investigating the Entrepreneurial Implications of Self-Healing Concrete Technology

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Abstract: The concept of self-healing materials has captivated researchers across various fields, holding immense potential for both medical and industrial applications. In the construction industry, self-healing concrete paves the way for a revolutionary advancement. This innovative material actively repairs cracks as they appear, significantly enhancing structural integrity. This feature has the potential to safeguard lives during earthquakes or landslides where cracked buildings pose a major threat. Notably, the application of self-healing within concrete mirrors the protective nature of the human skeletal system, guarding against frequent cracks and the corrosion of iron. This technology extends its protective capabilities to shield humanity from both natural and human-induced disasters. The self-healing attributes inherent in concrete, coupled with advancements in nanotechnology and bacterial involvement, confer regenerative abilities to buildings across diverse conditions and environments. Moreover, self-healing technology contributes to the prolonged life of structures. This paper explores the integration of self-healing technology within the cement industry. It examines the potential of this innovation to bolster building safety and analyzes its impact on the future of the cement sector.

Keywords: Self-healing concrete, Cement industry, Investment, Concrete Technology, Entrepreneurial

1-Introduction

In the contemporary milieu of sustainable infrastructure development, the convergence of groundbreaking materials science with enterprising initiatives has emerged as a pivotal force in addressing the critical challenges of structural maintenance and longevity. Positioned at the vanguard of this convergence is the groundbreaking domain of self-healing concrete technology, lauded as a transformative innovation poised to redefine construction practices on a global scale.[1] Within this paradigm-shifting investigation, we undertake a meticulous examination of the entrepreneurial ramifications intricately interwoven within the fabric of self-healing concrete technology. With an unwavering dedication to scholarly rigor and forward-looking insight, we embark upon a comprehensive exploration of this cutting-edge field, scrutinizing its multifaceted dimensions and unveiling its profound implications for entrepreneurial endeavors. Through a synthesis of empirical data, theoretical frameworks, and strategic analyses, our study aims to unravel the intricate interplay between technological innovation and entrepreneurial dynamism, thereby illuminating novel pathways toward sustainable growth and resilience in the built environment. This study delves into the depths of this intellectual odyssey of the entrepreneurial implications discovery, charting a trajectory toward a future where self-healing concrete is a testament to human ingenuity and enterprise. Concrete, as one of the most ubiquitous construction materials globally, demands continual enhancement of its properties and materials. The integration of self-healing technology is poised to significantly bolster the efficacy of buildings, fortifying their structural integrity and safeguarding against deterioration. This pioneering technology operates by addressing small cracks that imperil the structural integrity of buildings through the utilization of specialized bacteria endowed with a unique capacity for self-repair. Environmentally friendly and engineered to prevent structural collapse, self-healing concrete effectively seals cracks, thereby enhancing building stability. Furthermore, its application extends to the realm of nanotechnology, where the integration of bacteria with cement components promises to prolong the lifespan of structures and fortify them against seismic events and other external stressors. The advent of self-healing concrete heralds a transformative future for the construction industry, offering a proactive solution to mitigate the deleterious effects of earthquakes and potentially save countless lives. This technology represents a paradigm shift in construction methodologies, underscoring its pivotal role in fostering resilience and sustainability within the built environment. This study aims to analyze self-healing concrete technologies by exploring and understanding their functionalities and practical applications in the construction industry. Additionally, it seeks to examine the environmental impacts, assessing the benefits of using self-healing concrete. The research will also delve into the entrepreneurial dimensions, analyzing aspects related to the development and commercialization of this technology, and identifying opportunities and challenges for entrepreneurs. Finally, the study will evaluate the economic effectiveness of implementing self-healing concrete technology in major construction projects, focusing on its potential to reduce long-term costs. [2, 3, 4]

2. Research Methodology

This research delves into the transformative impact of self-healing concrete technology, marking a significant shift in the cement industry. It underscores the economic implications, market analysis, and groundbreaking development of this scientific innovation, which has spurred growth in the concrete market by reducing costs, enhancing purchasing power, and attracting investors. Additionally, it examines the positive effects on leadership and technological advancements in existing buildings, particularly in the repair and maintenance of cracks. The study reviews prior research conducted by earlier scholars, highlighting the challenges encountered with different research methodologies. This review aids in presenting their experiences, fostering scientific discussions, and contributing to the technological advancement of self-healing concrete. It also examines the overall growth of the cement sector, emphasizing the substantial improvements in the self-healing technology market. This research links and synthesizes critical information about the impact of self-healing concrete on the cement industry, which is continually evolving and bolstering the economic development of the cement industry within the construction market. Furthermore, the study interprets previous research on the development of self-healing properties and provides a comprehensive resource for researchers seeking to enhance the benefits and growth of the cement technology sector. [5, 6, 7, 8, 9].

2.2 Research Design

The research methodology of this study is grounded in analyses of self-healing concrete, entrepreneurial development, and technological advancements in the cement sector. It aims to align research objectives with the detailed presentation of topics discussed in the analysis, ultimately achieving positive outcomes related to self-healing technology. This technology enhances the development and capacity of cement products while positively influencing purchasing power and investment in the cement sector, as evidenced by literature reviews. The approach taken in this research is both interpretive and deductive, focusing on previous literature to highlight research progress and present the latest advancements in cement technology and the cement industry market. It also explores economic and creative development and their impacts on entrepreneurial companies. The study systematically examines the effects of entrepreneurship in the self-healing concrete technology sector, incorporating systematic reviews from various databases and sources. [9, 11, 12].

2.3 Research Protocol of Data

This research involves a detailed analysis of studies and data obtained from various databases, focusing on investigating the entrepreneurial implications of self-healing concrete technology and its market impact. Initially, numerous research findings were identified, but refining the objectives, topics, keywords, and research period enhanced the accuracy and precision of the methodology. The chosen keywords “self-healing concrete,” “investment,” “cement industry,” “investigating,” “construction market,” “entrepreneurial,” and “concrete technology” proved effective in accurately retrieving relevant results from the databases. The research period spans from 2004 to 2024, ensuring comprehensive coverage and ensured precise search results within the databases, aligning well with the research goals.

3. Literature Review

3.1 Mechanisms of Self-Healing in Concrete

3.1.1 Investigating the role of specialized bacteria in the self-healing process

The emergence of self-healing concrete technology stands as a promising solution to combat the prevalent issue of cracks and degradation in conventional concrete structures. A key element of this self-healing process involves the incorporation of specialized bacteria within the concrete matrix, actively contributing to the repair process when cracks occur. [3] This section aims to delve into the role of these bacteria and their potential implications for entrepreneurial ventures in the construction industry. Specialized bacteria, such as Bacillus subtilis or Sporosarcina pasteurii, play a crucial role in the self-repair process of concrete. These bacteria possess the capability to generate calcium carbonate ($CaCO_3$) through microbial-induced calcite precipitation (MICP) when exposed to calcium ions and a source of carbon dioxide (CO_2). In concrete mixes, these bacteria remain dormant until cracks form, triggering their activation. Self-healing Mechanism, upon detection of cracks, the bacteria within the concrete matrix become activated and commence the breakdown of nutrients available in the surrounding environment. As a result of their metabolic activity, the bacteria produce urea, which acts as a source of carbon dioxide upon hydrolysis. The combination of leached calcium ions from the cementitious matrix and carbon dioxide leads to the creation of calcium carbonate, effectively filling the cracks and restoring the structural integrity of the concrete. [12, 13]

3.1.2 Self-Healing Concrete Technology

The properties of concrete are influenced by various factors, and recent technological advancements have introduced vital systems that mimic natural biological processes, enabling concrete to self-heal. This self-healing concrete technology enhances the durability and repair ability of cement materials, mitigating external influences and interventions. It provides a robust, sustainable, and superior infrastructure. For instance, in the United Kingdom, self-healing concrete technology has been tested to focus on the expansion and spread of cracks, triggering the self-healing process. This concrete contains bacterial microcapsules embedded in the cement mix, which activate upon the formation of cracks, facilitating the self-repair process. This development significantly advances the cement industry and concrete technology, bridging gaps in the concrete market and driving innovation. [14, 15, 16].

3.1.3 Biological Cementation Technology

Recent advancements in building materials science have led to the development of techniques for addressing fissures in concrete. The self-healing of cement materials has been enhanced through the integration of biological processes, specifically by incorporating a consortium of bacteria and limestone. This method leverages calcium lactate to nourish the bacteria, which helps address issues related to the chemical reactions occurring during the initial mixing of cement. Self-healing concrete is composed of limestone powder, which serves as a nutrient source for the bacteria (Bacillus subtilis), along with calcium lactate and cement components. When cracks develop, the presence of moisture and carbon dioxide creates an environment that activates the bacteria. These bacteria then facilitate the formation of a robust layer that seals the cracks and protects the concrete from external factors, thus enabling self-restoration and enhancing the material's strength and durability. [17, 18].

3.2 Market Perspectives on Emerging Concrete Technologies

Ongoing advancements in the cement industry are fostering growth in concrete products and innovations, highlighting the sector's significant economic impact. Self-healing concrete, in particular, represents a pivotal development, enhancing market dynamics by boosting purchasing power and exchanges. This advancement is poised to substantially increase financial returns within the cement industry. The evolution of concrete products, driven by the introduction of self-healing technology, plays a critical role in strengthening purchasing power and achieving growth in the concrete sector. [19, 20].

3.2.1 Internationalization of Innovative Concrete Technology for Global Markets

The technological advancements in the cement industry, particularly in the development of self-healing concrete and its introduction to the global market, have significantly affected other products within the cement sector. These advancements have led to cost reductions and savings in the construction and infrastructure sectors, fueling growth and prosperity in the self-healing concrete market. This positive effect on purchasing power has spurred global investment in the cement industry, creating new opportunities and addressing market gaps. Consequently, this innovative technology has played a crucial role in meeting market demands and driving investment growth by developing technology that aligns with evolving market needs. [21, 22].

3.3 Evaluating the ecological implications of self-healing concrete technology

One of the primary ecological advantages of self-healing concrete technology resides in its capacity to extend the lifespan of concrete structures. Through autonomously addressing cracks and curbing deterioration, self-healing concrete diminishes the necessity for frequent repairs and replacements. As a result, this technology holds the potential to decrease material consumption and waste generation associated with conventional concrete maintenance practices. This decline in resource utilization not only lessens environmental impact but also fosters sustainability in construction projects. The potential of self-healing concrete to contribute to energy savings and carbon emissions mitigation is noteworthy across its lifecycle. By elongating the service life of concrete structures, this technology diminishes the frequency of maintenance activities, such as patching and sealing, which typically involve energy-intensive processes and emit greenhouse gases. Additionally, the integration of self-healing mechanisms into concrete mixes can augment durability, leading to structures demanding less energy for heating, cooling, and lighting throughout their lifespan. These cumulative reductions in energy consumption and emissions contribute significantly to the overall environmental sustainability of self-healing concrete technology. To optimize the ecological benefits of self-healing concrete technology, it is imperative to infuse sustainable practices throughout its lifecycle. This involves securing environmentally friendly raw materials, refining production processes to minimize energy consumption and emissions, and implementing efficient transportation and logistics strategies. Such comprehensive integration of sustainable practices ensures that the positive environmental impact of self-healing concrete technology is maximized at every stage of its development and application. [23, 24]

3.4 Innovative Marketing and Branding Strategies

3.4.1 Industrial Analysis of Construction Market for New Concrete

Self-healing concrete has emerged in the global cement industry as a pioneering technology in engineering, construction, and restoration. This innovation represents a significant advancement in the cement sector, creating new opportunities for market expansion. It allows for a comprehensive analysis of the cement industry’s market dynamics and the impact of self-healing concrete, particularly in the growing fields of building maintenance and restoration. This development is poised to significantly influence and enhance the industrial landscape. [25].

3.4.2 Market Analysis

The market for self-healing concrete represents a pivotal area of innovation within the construction industry, particularly given the centrality of cement in construction practices and the industry’s crucial role in global development. As humanity relies heavily on the cement sector, concrete emerges as a prime focus for advancements that promise enhanced durability, sustainability, and cost-effectiveness. Notably, the demand for self-healing concrete is underscored by its potential to address the current market needs, with ready-mix concrete sales alone accounting for a significant portion of the industry. This technology offers superior quality, reduced costs, and a prolonged lifespan, aligning perfectly with the evolving requirements of modern construction projects. As such, the market is primed for the adoption of improved concrete products, given the imperative for more efficient and economically viable solutions to meet the demands of both ongoing and future development endeavors. Self-healing concrete has gained substantial attention and traction due to its potential to revolutionize traditional construction practices. The market is primarily driven by the increasing demand for durable and sustainable infrastructure solutions. As urbanization continues to accelerate globally, there is a growing need for construction materials that can enhance the lifespan of structures while minimizing the environmental impact. Market drivers for self-healing concrete include long-term cost savings, regulatory support, and urbanization and population growth. Firstly, the technology offers potential long-term cost savings by minimizing the need for frequent repairs and maintenance, appealing to construction entities aiming to optimize project budgets and lifecycle costs. Secondly, stringent environmental regulations and sustainability mandates drive the adoption of eco-friendly building materials like self-healing concrete, fostering market growth. Lastly, rapid urbanization and population growth worldwide necessitate durable and resilient construction materials, positioning self-healing concrete as a solution for urban environments prone to structural damage and deterioration. [26, 27]

3.4.3 Sales Assumption

Biology plays a pivotal role in the advancement of self-healing technologies, show casing remarkable progress in the utilization of self-healing compounds across various sectors beyond traditional cement applications. These innovations extend into diverse fields such as medicine and aerospace industries, underscoring the multifaceted potential of self-healing materials.
The global market for self-healing materials is poised for significant expansion, with an anticipated annual growth rate of 59% between 2018 and 2026, as reported by Polaris Market Research. This rapid growth can be attributed to the intrinsic properties of self-healing materials, characterized by their high-quality composition and inherent ability to repair. Often referred to as “smart” or “intelligent” products, these materials are poised to experience robust sales across a spectrum of industries vital to human existence.

As self-healing materials continue to penetrate diverse sectors, ranging from healthcare to aerospace, their adoption is anticipated to drive innovation and efficiency, thereby enhancing the overall sustainability and resilience of critical infrastructure worldwide. [27]

3.4.4 Investment in Self-Healing Concrete around the World

Investment in self-healing concrete technology is gaining momentum worldwide, fueled by a convergence of factors that underscore its transformative potential in the construction industry. With advancements in materials science and engineering, coupled with growing awareness of sustainability, there is a notable surge in funding and investment directed towards the development and implementation of self-healing concrete solutions. The global market for self-healing materials, including self-healing concrete, is experiencing rapid growth, with projections indicating a robust annual growth rate of 59% between 2018 and 2026 (source: Polaris Market Research). [10] This upward trajectory reflects the increasing recognition of self-healing technologies as a viable solution to address the challenges of aging infrastructure, minimize maintenance costs, and enhance the longevity of concrete structures. Investment in self-healing concrete extends beyond traditional construction applications, with diverse industries recognizing its value proposition. From transportation infrastructure to commercial and residential buildings, the demand for durable and resilient concrete solutions is driving investment in research, development, and commercialization of self-healing technologies. Moreover, the integration of self-healing concrete into sustainable building practices aligns with global initiatives aimed at reducing carbon emissions and mitigating environmental impact. This alignment with broader sustainability goals further incentivizes investment in self-healing concrete technology, as stakeholders seek innovative solutions to promote eco-friendly construction practices. [28]

4. Entrepreneurial Strategies for Self-Healing Concrete Businesses

4.1 Entrepreneurial Opportunities in Self-Healing Concrete Technology

The incorporation of specialized bacteria into self-repairing concrete opens up novel entrepreneurial prospects within the construction industry. Entrepreneurs have the opportunity to delve into the development and marketing of tailored bacterial additives designed for specific applications and environmental conditions. Furthermore, there exists potential for the innovation of construction materials and methodologies that leverage self-repairing attributes, enhancing both durability and sustainability. Moreover, entrepreneurs can capitalize on the growing demand for eco-friendly building solutions by offering self-repairing concrete products that alleviate the necessity for expensive repairs and reduce environmental impact. Collaborative efforts with researchers, engineers, and industry stakeholders can facilitate the translation of scientific breakthroughs into marketable offerings, thereby fostering innovation and bolstering competitiveness in the construction industry. [3, 27]

4.2 Industrial Analysis (SWOT)

Strength	Weaknesses	Opportunities	Threats
o Innovative Technology o Sustainability: The eco-friendly o Cost Savings o Research and Development	o Initial Costs o Dependency on Environmental Factors o Longevity of Research	o Market Growth o Global Infrastructure Development o Emerging Technologies	o Supply Chain Disruptions o Economic Uncertainty o Competition

[Table 1: SWOT Analysis [4, 27, 29

4.3 Critical Risk and Safety Production

Addressing critical risks and ensuring safety in production processes is paramount within the self-healing concrete industry. Given the innovative nature of this technology and its potential applications in construction, identifying and mitigating risks associated with production is essential to safeguarding both product integrity and worker safety. Factors such as handling specialized bacteria, managing chemical reactions, and maintaining quality control protocols present inherent risks that must be carefully managed throughout the production lifecycle. Moreover, ensuring adherence to industry standards and regulatory requirements is imperative to minimize potential hazards and promote a safe working environment. By implementing robust risk management strategies and prioritizing safety measures, stakeholders can mitigate risks effectively while fostering a culture of safety and accountability within the self-healing concrete production industry. [2, 24]

5. Analysis Data in Research

The analysis aims to clarify the research methods and objectives. Additionally, the studies included in this research are recognized within literary circles for their contribution to research quality. This analysis ensures the quality of selected studies from databases and references high- caliber scientific literature that supports the research's development. Consequently, it enhances and refines the analytical components of the research objectives and literary references.

5.1 Research Data Analysis

The analysis of research studies hinges on several critical factors, particularly the methodological framework and specific methodologies employed in developing literature reviews. This study investigates the entrepreneurial implications of self-healing concrete technology and its market impact, with a particular focus on economic and creative development and their effects on entrepreneurial companies. The initial phase involves navigating databases using predefined protocols to identify pertinent studies, with search criteria including parameters such as period and subject specificity. This systematic approach ensures the retrieval of comprehensive research results aligned with the study's objectives. Key terms like "self-healing concrete," "investment," "cement industry," "investigating," "construction market," "entrepreneurial," and "concrete technology" are systematically deployed, complemented by secondary and specific data searches. The search scope remains broad to encompass diverse regions, enabling a thorough exploration of relevant data. Leveraging advanced search functionalities within platforms such as Ebsco facilitates meticulous examination and comprehensive data extraction, as evidenced by findings from the Emerald database. The study utilizes databases such as Emerald, Science Direct, Ebsco, Research Gate, and Google Scholar, relying on qualitative methods and secondary data through a systematic review methodology.

5. Conclusion

In conclusion, the integration of biological factors, such as bacteria, in the production of self-healing concrete marks a significant advancement in construction materials technology. Through our analysis, we have observed that self-healing concrete offers a compelling solution that addresses multiple challenges faced by traditional concrete, including environmental impact, quality assurance, and structural durability. This innovative material not only contributes to the sustainability of construction practices but also enhances the protection of infrastructure and reduces maintenance costs over time. Self-healing concrete demonstrates remarkable potential in preserving the integrity of reinforced steel and prolonging the lifespan of structures by effectively sealing large cracks and addressing internal damage. Furthermore, its positive impact on the environment by minimizing the need for harmful maintenance materials aligns with global efforts to promote eco-friendly construction practices and mitigate carbon emissions.

6. Recommendations

The recommendations for advancing self-healing concrete technology encompass various aspects crucial for its successful integration into the construction industry. These recommendations include continued investment in research and development to enhance performance and versatility, promoting education and awareness among stakeholders, collaborating with regulatory bodies to establish standards and guidelines, implementing strategic market penetration strategies, and fostering a culture of continuous improvement. By following these recommendations, stakeholders can unlock the full potential of self-healing concrete, realizing its promise as a sustainable, durable, and cost-effective solution for infrastructure development.

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Rework in Residential Building Projects: Causes and Effects

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Abstract: This article aims at investigating rework factors and effects in residential building projects in the West Bank – Palestine. Questionnaire survey is used to collect and rank the main factors and effects of rework from consultants and constructors view. Respondents show that more than 80% of the projects completed with rework cost of value greater than 5% of the total project cost. Overall respondents view concludes that the top rework factors include: mistakes in design, unskilled labors, unqualified subcontractors, non-conformance with required specifications, and bid awarding policy. Respondents indicate that the main effects of rework are cost overrun, project time extension, material waste excess and profit reduction. The results of this study would be helpful for researchers and professionals to guide their efforts should to minimize rework in construction projects and to improve projects outcomes in term of cost, time and quality.

Keywords: rework, factors, effect, construction, causes.

1. Introduction

Construction sector is one of the most important sectors as it contributes to increasing GDP and absorbing local labors [1]. However, there are many common problems in construction project that should be handled to improve and enhance the outcomes of this sector. One of these problems is rework [2]. Rework is simply defined as extra efforts to redo the same work after completion [3]. Rework is concluded by many studies as a main source of poor performance in construction projects. Many previous articles pointed that rework is a main contributor to cost increase, delay, conflicts, disputes and parties dissatisfaction ([2], [4], [5], and [6]). For instance, [7] found that rework accounts for 5% of cost increase in construction projects. [8] revealed that rework could delay the construction projects by duration = 70% of planned time.

Rework has an adverse effect on project outcomes. Yet, little is done to understand and analyze the root factors and effects of this common and severe problem on construction sites. In Palestine and other neighboring countries, no or very little attention is paid to this area of knowledge. Thus this paper is performed. It aims at 1) investigating the rework cost in residential projects, 2) recognizing the rework-related factors, 3) identifying the rework-related effects, and 4) investigating the relation between rework and cost overrun in some construction activities. The study findings would push professional efforts to understand the problem of rework and help them to minimize it and to enhance project outcomes in construction industry.

2. Previous studies

Rework is simply defined as redoing an activity that is incorrectly implemented [1]. [9] concluded that little attention is paid to rework management in construction projects. They claimed that good rework management can improve the performance in construction projects and increase the profits. [10] reported that rework is a major challenge that leads to project failure in construction industry. [11] concluded that rework leads to schedule delay, material waste excess and cost overrun. In the same vein, [8] found that rework increases project cost and schedule by values reach to 30% and 70%, respectively. [12] revealed that rework cost is about 5% in new building projects. [13] indicated that rework is a main source of cost overrun in construction projects. They pointed that rework cost in residential projects is about 5% of the total project cost. They also concluded that the main contributors to rework cost include: contractors (20.10%), design (18.91%) and client (14.73%).

Previous studies found number of factors lead to rework in construction projects. [8] concluded that the main factors of rework are: unqualified supervisors, unskilled labors and unqualified contractors and subcontractors. He recommended to improve the bidding policy and to select the qualified subcontractors and contractors to execute the project, because unqualified subcontractors suffer from shortage in cash that forcing them to hire unskilled labors (low salary) who can't implement the work correctly which lead to rework. Through a questionnaire survey, [12] found that among the factors affecting rework, the top factors are: poor communication between parties, late changes, design errors, and additions or omissions. They claimed that communication between parties should be improved during early phases to reduce the size of changes and mistakes during construction. [14] investigated the critical rework causes in construction projects using questionnaire survey. The top causes are: poor material specifications, improper project planning and management and inappropriate construction technology.

[2] performed a questionnaire survey to study the main factors of rework in building projects. He found that rework cost is about 15% of original cost. He found that the top contributors include: poor communication between different parties, manipulation in material specifications and variation orders. [15] conducted a field survey in Gaza to understand the main rework causes in construction projects. They found that the top causes are: fraud, poor project security and tight project schedule. Through a questionnaire survey, [1] conducted a study to rank the main factors lead to rework in construction industry. The factors that top the list include: scope change, poor labor skills, variation orders and specifications requirements. [16] concluded that the main effects of rework in construction projects are: loss future business for the firms, reduction in labor motivation and profit reduction.

Rework is concluded as a main source of major obstacles in construction projects such as poor productivity, quality defects, time-extension, claims and disputes, and over budget ([2], [16] and [17]). Through a case study, [1] and [10] indicated that rework has a great impact on change orders and material waste in construction projects. To improve the performance of construction projects, they recommended to reduce rework through conducting training for labors, more communication and cooperation between parties in planning phase, and using proper planning and management techniques. [18] conducted a questionnaire survey to recognize the most frequent factors of rework. 38 factors considered in their study and responses received from 62 participants. They found that the most frequent rework factors are: schedule shortening, delays in payments, bid award strategy, design mistakes, and lack of skilled labors.

3. Research Methods

The objective of this study is to find out the cost, factors and effects of rework in residential buildings. A questionnaire survey is used to investigate that. The questionnaire is divided into 3 divisions. Division A asks for information related to the respondent and the firm (experience, type of works, position...etc.). One of the main questions asked in this division is: What is the average of rework cost in the projects you have experienced? Division B includes the identified rework factors. 26 factors collected from previous studies and opinions of professional experts. Factors put in a table form and the participants asked to rank them according to their severity. A 5-point Likert scale ranging from 1 to 5 is used. The ordinal scale is: 1 = very low severe, 2 = low severe, 3 = moderate severe, 4 = high severe and 5 = very severe. Division 3 includes rework effects. Six (6) effects are considered from previous published researches and experts input. As in division B, the effects arranged in a table form and participants required to rank them using the 5-point Likert scale.

3.1 Pilot study

Before sending the designed questionnaire to the participants, 3 local project managers with experience of more than 30 years in the residential building projects are asked to test its validity for measuring the study objectives. Minor changes are introduced by them. The questionnaire is reviewed according to their remarks.

3.2 Target population

Population of the study are contractors of class 1 and 2, and consultants with valid membership in Engineers Association of Palestine. Target respondents are selected randomly from available list of 190 contractors and 90 consultants in Engineers Association of Palestine. Target respondents assumed to have normal distribution. Sample size is computed according to Eq. 1 [19].

$$SS=[z^2\times P\times(1-P)]/C^2 \qquad \text{Eq. 1}$$

Where;

SS = Size sample
Z = Z-value
P = picking choice %, (0.5 used)
C = confidence interval (0.5 used)

$$\boldsymbol{SS} = (1.96^2 * 0.5 * (1 - 0.5)) / 0.5^2 = 384$$

Finite population correction

$$SS_{new} = \boldsymbol{SS}/ (1 + ((\boldsymbol{SS} - 1)/n)) \qquad \text{Eq .2}$$

Where, n = 190 contractors, 90 consultants.

Using Eq. 2, the calculated sample size is 51 contractors and 29 consultants based on a 95% confidence level. The questionnaire sent, by email, fax, or face to face, to 60 contractors and 50 consultants asked to fill the questionnaire and to rank the related factors and effects from their point of view. Responses received from 87% (52 filled questionnaires) of targeted contractors and 80% of targeted consultants (40 filled questionnaires). Overall response rate is 84%. Most of the responses come from persons with high experience in construction projects (Fig. 1). Regarding the respondent position in their organizations, it includes managers (16%), site engineers (26%), office engineers (22%), project engineers (32%) and others (4%).

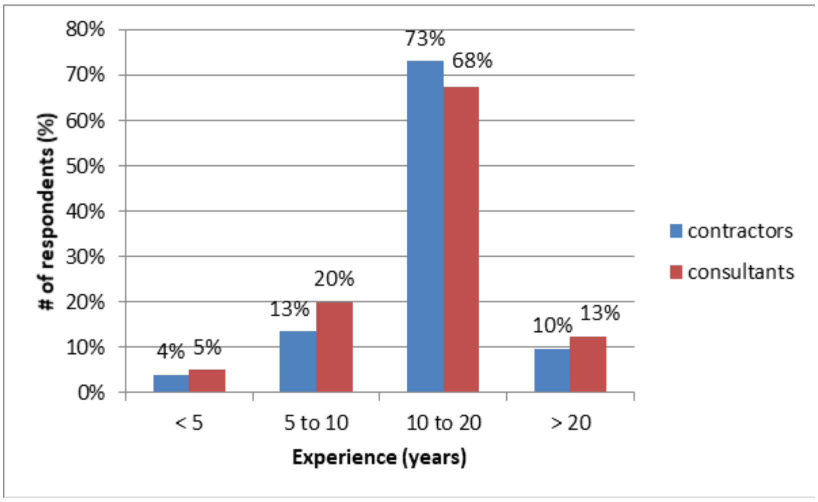

Figure 1: Respondents' experience (Own source)

3.3 Data analysis

The collected data analyzed using SPSS. Average score, standard deviation, correlation are some of stats calculated. Average score is computed as weighted average. Table 1 shows the illustration for the average score results.

Table 1: Illustration of average score results (Own source)

Average score	Severity level
1	very low
1-2	low
2-3	moderate
3-4	high
4-5	very high

3.4 Spearman rank correlation (r_s)

The value of Spearman rank correlation (r_s) is computed to reveal the agreement between the respondents regarding the severing of rework-related factors. If the value of r_s closes to 1, it indicates a good agreement between responses about the severity of the factors and the results are reliable. Otherwise, the data shows scattered responses.

3.5 Case study

Data from 47 building projects are collected. The data include information about the rework cost in steel reinforcement works and the total cos overrun in the projects. Linear regression model built to show the relation between rework cost and cost overrun which helps to conclude the effects of rework on cost overrun in construction projects. More details about the projects, data and regression model are explained in section

4. Results and Discussion

4.1 Rework-related factors

Table 2 indicates the ranking of rework-related factors in residential projects from the view of consultants and contractors. Twenty six (26) factors identified from interview with local experts and review of similar published articles. Contractors rank the following factors as the top five, they are: mistakes in design, unskilled labors, non-conformance with required specifications, unqualified subcontractors, and bid awarding policy. While, the consultants reveal that the top contributors are: unskilled labors, mistakes in design, unqualified subcontractors, bid awarding policy, and non-conformance with required specifications. The least severe factors from contractors view are: use of unsuitable construction methods, poor motivation system for labors and weather. While, the least important factors from consultants view are: poor motivation system for labors, poor site management and weather. Overall rank finds that the top factors include: mistakes in design, unskilled labors, unqualified subcontractors, non-conformance with required specifications, and bid awarding policy.

Mistakes in design could be as a result of unqualified designers, tight schedule for design and review, lack of coordination between designers, improper planning, unclear scope, design copy from previous projects...etc. Design mistakes have adverse impact on project progress in term of rework which interrupts the construction process and plans. The same finding is concluded by [12]. "Unskilled labor" leads to mistakes in works execution which leads to work damage and redoing it. Therefore, construction companies should hire skilled labors to guarantee a good work performance. This result agrees with [1] and [8]. "Unqualified subcontractors" and "bid awarding policy" are two major rework factors. Selection of subcontractors and contractors because of their lowest price is the common bid awarding strategy in Palestine. The lowest bidders are generally unqualified and don't have the needed resources and staff to implement the work as planned. Mistakes, manipulation in materials and specifications, inadequate supervision are some of the problems occurred because of unqualified subcontractors. These all lead to rework on construction sites. [18] concluded the "bidding strategy" as a main rework factor, while no previous study pointed to "unqualified subcontractor" as a main source of rework. "Non-conformance with required specifications" is a major problem in construction projects. This can be justified as some unqualified contractors and subcontractors use materials with poor quality to save cost and make profit. This factor is concluded by [1] as a critical factor leading to rework on construction sites.

Table 2: Ranking of rework-related factors in residential projects (Own source)

Factor	Contractors' view		Consultants' view		Overall view	
	Avg. Score	Rank	Avg. Score	Rank	Avg. Score	Rank
mistakes in design	4.27	1	4.13	2	4.21	1
unskilled labors	4.21	2	4.17	1	4.19	2
unqualified subcontractors	3.96	4	4.08	3	4.02	3
non-conformance with required specifications	4.11	3	3.77	5	3.95	4
bid awarding policy	3.85	5	3.88	4	3.87	5
additions and omissions	3.78	6	3.54	8	3.67	6
incomplete design drawings	3.62	8	3.70	6	3.65	7
mistakes by labors	3.63	7	3.55	7	3.59	8
unclear contract documents	3.61	9	3.46	11	3.54	9
late changes by owner	3.57	10	3.49	10	3.53	10
lack of supervision	3.48	11	3.53	9	3.50	11

change of scope by owner	3.32	14	3.44	12	3.37	12
financial conditions of owner	3.42	12	3.25	13	3.34	13
manipulation by contractor	3.39	13	3.18	16	3.30	14
poor site conditions	3.19	17	3.22	14	3.20	15
reallocation of labors to other projects	3.22	16	3.12	19	3.18	16
frequent design changes	3.26	15	3.04	22	3.16	17
use of old equipment	3.10	19	3.21	15	3.15	18
lack of communication between parties	3.15	18	3.13	18	3.14	19
unskilled supervisors	3.06	21	3.17	17	3.11	20
mistakes in shop drawings	3.05	22	3.10	20	3.07	21
improper planning	3.08	20	3.06	21	3.07	22
use of unsuitable construction methods	2.94	24	3.03	23	2.98	23
poor site management	3.02	23	2.90	25	2.97	24
poor motivation system for labors	2.86	25	2.99	24	2.92	25
weather	2.81	26	2.79	26	2.80	26

4.2 Rework Effects

Table 3 addresses the main effects of rework in residential buildings. Eight (8) rework effects are recognized from experts' opinions and review of similar studies. According to contractors and consultants, cost overrun is the top effect of rework (ranked in position 1), followed by project time extension (ranked in position 2). Contractors identified "profit reduction" in position 3, while consultants identified "material waste excess" in this position. Table 6 indicates that all effects have average score greater than 4 which means that rework has a very high impact on these factors. Redoing the same activity for more than one time, leading to use the project resources more and more which leads to cost overrun and project delay. Material waste could be as a result of damaging the completed work and redoing it. This situation increases the cost of resources used to complete the work which leads to loss in profit. Rework that occurred because of contractors might lead to conflict with other parties that adversely affects their reputation and limit their chances in winning future bids. Results agree with previous studies in identifying cost overrun and time extension as the top effects of rework in construction industry ([2], [16] and [17]). The new findings in this regard are: material waste excess, frequent change orders, and bad reputation of the constructor. They aren't concluded as significant effects of rework in the investigated studies. Efforts should be guided to minimize rework and to reduce its effects on project performance.

Table 3: Rework effects in residential projects (Own source)

Effect	Contractors' view		Consultants' view		Overall view	
	Avg. Score	Rank	Avg. Score	Rank	Avg. Score	Rank
cost overrun	4.55	1	4.62	1	4.58	1
time extension	4.50	2	4.56	2	4.53	2
material waste excess	4.25	4	4.42	3	4.33	3
profit reduction	4.40	3	4.20	7	4.31	4
frequent change orders	4.18	5	4.31	4	4.24	5
loss future business of firm	4.12	6	4.28	5	4.19	6
bad reputation of the constructor	4.07	8	4.22	6	4.14	7
reduction in labor motivation	4.11	7	4.13	8	4.12	8

4.3 Spearman rank correlation (r_s)

The value of Spearman rank correlation (r_s) is computed to reveal the agreement between the respondents regarding the severing of rework-related factors. Results with values of 0.83 for rework factors and 0.88 for rework effects indicate good agreement between respondents.

5. Conclusion

This article aims at investigating rework cost, factors and effects in residential building projects in the West Bank – Palestine. Questionnaire survey is used to rank the main factors and effects of rework from consultants and constructors view. Regarding the ranking of rework factors, consultants indicate that the main rework-related factors are: unskilled labors, mistakes in design, unqualified subcontractors, bid awarding policy, and non-conformance with required specifications. Contractors rank the following factors as the top five rework factors, they are: mistakes in design, unskilled labors, non-conformance with required specifications, unqualified subcontractors, and bid awarding policy. Overall rank concludes that the top rework factors include: mistakes in design, unskilled labors, unqualified subcontractors, non-conformance with required specifications, and bid awarding policy. Both contractors and consultants indicate that the main effects of rework are cost overrun and project time extension. Reduction in profit and material waste excess also concluded among the top effects or rework in construction project. Spearman correlation test concludes a good correlation between contractors and consultants in the ranking of rework factors and effects.

The importance of this study lies in the fact that it is the first detailed study of rework problem in construction projects in Palestine, as it gives us a comprehensive and clear idea of the reality of this problem in the Palestinian construction industry. Thus, this study fills the gap in this field. The results of this study confirm the results concluded by previous studies, with reference to some new findings that were not addressed in previous studies, namely: the conclusion of the "unqualified sub-contractors" as a main reason for the rework, and also the conclusion that "material waste excess", "frequent change orders", and "bad reputation of the constructor" are significant effects of rework in construction industry. This is an important addition to the literature on rework problem in construction projects.

Construction participant should pay their efforts to handle the main rework-related factors to minimize its cost and effects on project performance. They are recommended to: 1) hire qualified designers and give them enough time to prepare and review project designs, (2) hire skilled labors and organize training workshops to improve their skills, (3) motivate labor financially and morally to increase their productivity and efficiency. This will help in reducing mistakes and rework, (4) change bidding policy; qualification of contractors and subcontractors should be taken into consideration during bidding phase. Qualified contractors and subcontractors guarantee proper planning and management, availability of qualified staff and labors, minimizing rework-related factors, and enhancing the performance in construction projects.

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INTEGRATED & SUSTAINABLE WATER RESOURCES MANAGEMENT IN THE ARAB WORLD: CHALLENGES & OPPORTUNITIES

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Abstract

Integrated water resources management (IWRM) has been an effective tool for sustainability in water sector. IWRM can make changes in water management in complex social, economical, environmental and political contexts. The sustainable development goals 2015-2030 in SDG 6 aims to ensure availability and sustainable management of water and sanitation for all. Target 6.5 of SDG6 requested to implement, by 2030, IWRM plans and actions at all levels, including through transboundary cooperation and partnership will all stakeholders as appropriate.

This study assesses the challenges that meet the water sector in the Arab world and assess the progress in implementing the IWRM plan and strategies in the Arab Countries. Investigation carried out by different UN agencies indicated that there is a modest progress in achieving SDG6 in the Arab Region with an average progress from 48% in 2017 to 53% in 2020. The current rate of progress will not achieve the SDG6.5 by 2030. A set of recommendations and cations is proposed to double the rate of progress in the remaining years till 2030 to ensure meeting SDG especially IWRM plans.

1. Introduction

Integrated Water Resources Management (IWRM) is a comprehensive and holistic approach to the sustainable development, allocation, and management of water resources. It recognizes the interconnected nature of water systems and aims to optimize their use while preserving the ecological balance. IWRM emphasizes the integration of various sectors, stakeholders, and disciplines to address the complex challenges associated with water resources.

1.1 Definition of IWRM:

At its core, IWRM is a process that promotes the coordinated development and management of water, land, and related resources. It seeks to balance the social, economic, and environmental dimensions of water use, taking into account the diverse needs of different users and the dynamic nature of water systems. IWRM is not a one-size-fits-all approach; rather, it acknowledges the uniqueness of each watershed or basin, considering local conditions, cultures, and institutional frameworks.

1.2 Key Principles of IWRM:

- Holistic Approach: IWRM considers the entire water cycle, from precipitation to consumption and recycling, and integrates it with land and ecosystem management.

- Stakeholder Involvement: The active participation of various stakeholders, including government agencies, communities, industries, and non-governmental organizations, is crucial in IWRM to ensure inclusive decision-making and sustainable solutions.
- Sustainability: IWRM aims to meet current water needs without compromising the ability of future generations to meet their own needs, emphasizing sustainable and equitable water use.
- Adaptive Management: Given the uncertainties associated with climate change and other dynamic factors, IWRM encourages adaptive management strategies that can be adjusted based on evolving conditions.

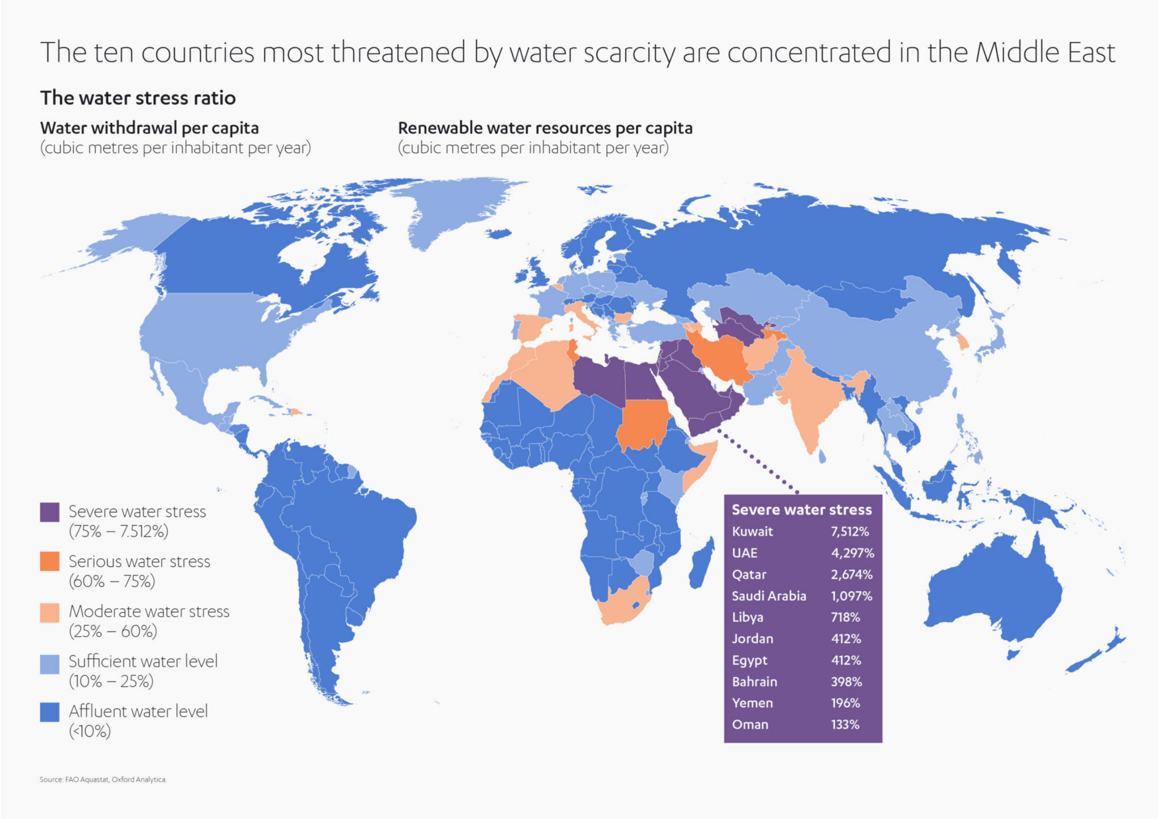
1.3 Tools for Implementing IWRM:

- Water Governance Frameworks: Establishing effective governance structures, policies, and regulations is essential for successful IWRM. This includes the creation of river basin organizations and the development of water laws and policies.
- Data and Information Systems: Accurate and up-to-date data is critical for decision-making in IWRM. Monitoring water quantity and quality, as well as understanding the socio-economic context, enables informed and effective management.
- Decision Support Systems (DSS): These computer-based tools assist in analyzing complex data and scenarios to aid decision-makers in developing and implementing water management strategies.
- Community Engagement and Capacity Building: Empowering local communities through education, awareness programs, and capacity building initiatives fosters a sense of ownership and responsibility in the sustainable management of water resources.
- Economic Instruments: IWRM can benefit from the use of economic tools such as water pricing, market mechanisms, and incentives to encourage efficient and equitable water use.

2. Challenges of IWRM in the Arab World

The status of Integrated Water Resources Management (IWRM) in the Arab world varied across countries due to diverse socio-economic, political, and environmental conditions. However, here are some general challenges that limit the application of IWRM in the Arab World as:

- Water Scarcity Challenges: Many countries in the Arab world face significant water scarcity issues due to arid and semi-arid climates, increasing population, and high rates of water consumption. This has put pressure on the need for effective water management strategies, making IWRM a crucial consideration. Figure 2.1 shows the freshwater availability and water stress in the Arab world.



(Figure 2.1. Water ﬆress index in the world with focus on the Arab World (FAO Aquaﬆat website

- Diversity in Implementation: The implementation of IWRM principles varied among Arab countries. Some nations had made considerable progress in adopting and integrating IWRM into their policies and practices, while others faced challenges in implementation due to issues such as political inﬆability, insufficient infraﬆructure, and limited resources.
- Transboundary Water Issues: Several Arab countries share transboundary water resources, leading to complexities in water management. Cooperation and joint efforts in implementing IWRM principles are essential for addressing these challenges and ensuring suﬆainable water use across borders.
- National Water Strategies: Many Arab countries have developed or revised their national water ﬆrategies, incorporating IWRM principles to address the water challenges. These ﬆrategies often emphasize suﬆainable water use, ﬆakeholder involvement, and the integration of water into broader development goals.
- Technological Innovations: Some countries in the Arab world have embraced technological innovations for water management, including the use of advanced irrigation techniques, desalination technologies, and smart water monitoring syﬆems. These technologies play a role in supporting IWRM objectives.
- Capacity Building and Awareness: Efforts to enhance capacity building and awareness about water-related issues have been observed in some Arab countries. This involves educating ﬆakeholders, including government officials, local communities, and the private sector, about the importance of IWRM and suﬆainable water practices.
- Climate Change Impact: The Arab region is vulnerable to climate change, which can exacerbate water scarcity issues. IWRM ﬆrategies need to incorporate adaptive measures to address the impact of climate change on water resources.
- International Cooperation: Some Arab countries participate in regional and international initia-

tives related to water management and share experiences and best practices. Collaborative efforts are crucial for addressing shared water challenges in the region.

3. The Status of Sustainable Development Gools in the Arab World

Given the arid and semi-arid climates in many Arab countries, sustainable water management (SDG 6) is a critical focus. Efforts have been made to address water scarcity through technological innovations, desalination projects, and integrated water resources management.

Since 2015, SDG 6: Ensure availability and sustainable management of water and sanitation for all. Target 6.5: By 2030, implement IWRM at all levels, including through transboundary cooperation as appropriate.

Access to Safe Drinking Water: While significant progress has been made in improving access to safe drinking water in the Arab world, disparities persist, particularly in rural and marginalized communities. Some countries have achieved high levels of access to improved water sources, but others still struggle to provide safe drinking water to all their citizens.

Sanitation Services: Access to sanitation services remains a challenge in many parts of the Arab world, particularly in rural areas and informal settlements. Lack of proper sanitation infrastructure poses health risks and hinders progress towards achieving SDG 6 targets related to sanitation and hygiene.

Desalination and Water Recycling: Given the water scarcity in the region, desalination and water recycling technologies play a significant role in meeting water demand. Some Arab countries have invested in desalination plants and wastewater treatment facilities to augment their water supply and improve water quality.

Transboundary Water Issues: Many Arab countries share transboundary water resources, leading to complexities in water management and governance. Cooperation and joint management efforts are essential for addressing transboundary water challenges and ensuring equitable access to water resources.

Climate Change Impact: The Arab region is vulnerable to the impacts of climate change, including changes in precipitation patterns, rising temperatures, and increased frequency of droughts and floods. Climate change exacerbates water scarcity and poses challenges to achieving SDG 6 targets.

Urbanization and Infrastructure Development: Rapid urbanization and population growth in many Arab cities require significant investments in water infrastructure and services and exacerbates water scarcity and poses challenges to achieving SDG 6 targets. Sustainable urban water management practices are essential for ensuring water security and resilience in urban areas.

Key facts on SDG 6

	Indicators	Arab region	World
6.1.1 Water resources management	Proportion of population using safely managed drinking water services (percentage), 2020	76.6	74.0
6.2.1 Safely managed sanitation services	Proportion of population using safely managed sanitation services (percentage), 2020	33.4	54.0
Handwashing facility	Proportion of population with basic handwashing facilities on premises (percentage), 2020	86.7	71.0
Open defecation	Proportion of population practicing open defecation (percentage), 2020	4.6	6.0
6.4.1	Change in water-use efficiency over time (dollar/m³), 2019	10.1	19.4
6.4.2 Freshwater withdrawal	Level of water stress: freshwater withdrawal as a proportion of available freshwater resources (percentage), 2019	120.8	18.6
6.5.1 Water resources management	Degree of integrated water resources management implementation (0–100), 2020	49.6	57.0
6.5.2 Water resources management	Proportion of transboundary basin areas with an operational arrangement for water cooperation (percentage), 2020	30.0	58.1
	Proportion of aquifers transboundary basin area with an operational arrangement for water cooperation (percentage), 2020	30.1	41.5
	Proportion of river and lake transboundary basin areas with an operational arrangement for water cooperation (percentage), 2020	28.1	65.1

ource: ESCWA, Arab SDG Monitor. Accessed on 15 January 2023.

(Figure 3.1. Status of SDG6 implementation in the Arab World and Worldwide (ESCWA, 2021

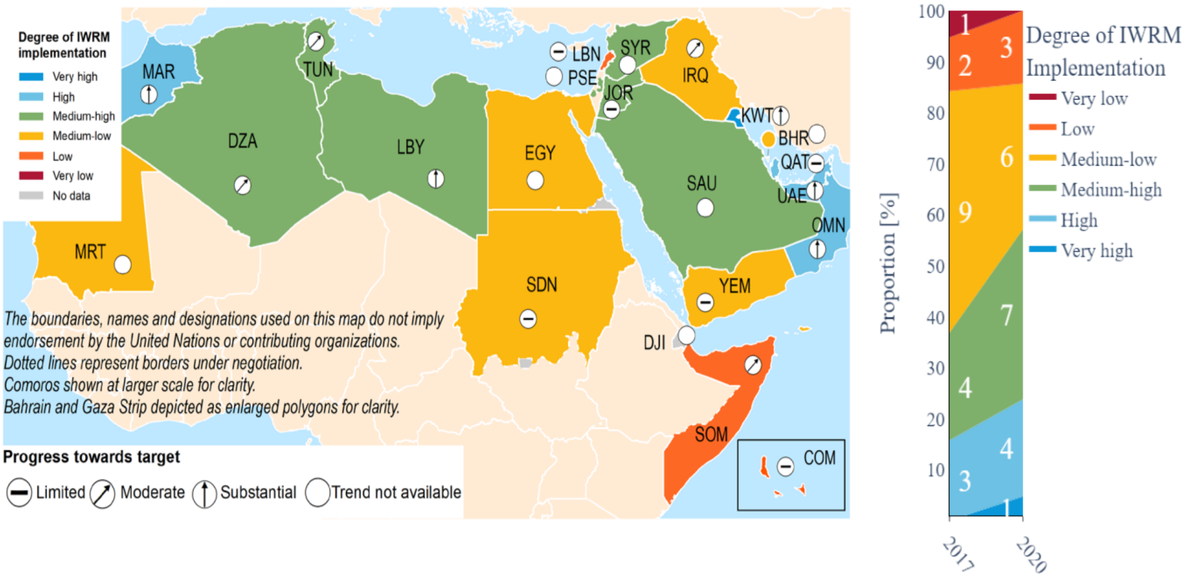
4. The status of IWRM in the Arab World

Integrated Water Resources Management (IWRM): Several Arab countries have recognized the importance of integrated water resources management (IWRM) in achieving water sustainability and resilience. Efforts have been made to implement IWRM principles, such as promoting water conservation, investing in water infrastructure, and enhancing water governance. Indicator 6.5.1: Degree of IWRM implementation in the Arab World is about 49% compared to 57% worldwide.

There is a need to accelerate the implementation of integrated water resources management (IWRM) and innovate ways to manage competing demands on this valuable resource. SDG indicator 6.5.1 is measured on a scale of 0-100 across the four dimensions of IWRM:

a. the enabling environment of policies, laws and plans;
b. institutions and stakeholder participation;
c. management instruments;
d. financing for water resources management.

Degree of IWRM implementation, 2020 and level of progress towards SDG target 6.5, 2017 and 2020



(Figure 4.1. Status of IWRM implementation in the Arab World (ESCWA, 2021

5. Actions to Accelerate IWRM in the Arab World

Accelerating Integrated Water Resources Management (IWRM) in the Arab world requires concerted efforts, strategic planning, and collaborative actions at various levels. Here are some key actions that can be taken to accelerate the implementation of IWRM in the Arab world:

- Develop and Strengthen political will with legal and institutional frameworks:
  - Establish or enhance legal and institutional frameworks that support IWRM at national and regional levels.
  - Define clear roles and responsibilities for government agencies, water authorities, and other stakeholders involved in water management.
  - Ensure that legal frameworks address issues such as water allocation, pollution control, and transboundary water management.
- Promote Integrated Planning and Decision-Making:
  - Integrate water management into broader national and regional development plans, considering the interconnectedness of water with other sectors such as agriculture, energy, and urban development.
  - Encourage the use of decision support tools, modeling, and scenario analysis to inform integrated planning processes.
- Enhance Stakeholder Engagement and Public Awareness:
  - Engage a wide range of stakeholders, including government agencies, local communities, NGOs, and the private sector, in the decision-making process.
  - Raise public awareness about the importance of water resources and the benefits of IWRM through education campaigns, community involvement, and information dissemination.
- Invest in Water Infrastructure and Technology:
  - Invest in modern and sustainable water infrastructure to improve water storage, distribution, and treatment.
  - Embrace technology, such as smart water management systems, sensors, and data analyt-

ics, to enhance monitoring, early warning systems, and efficient water use.

- Encourage Water Conservation and Efficiency:
    - Implement water conservation and efficiency measures at the household, industrial, and agricultural levels.
    - Introduce incentives and regulations to promote responsible water use and reduce water wastage.
- Address Transboundary Water Management:
    - Foster regional cooperation and collaboration on transboundary water issues through bilateral and multilateral agreements.
    - Establish joint committees and mechanisms for sharing data, coordinating management efforts, and resolving disputes related to shared water resources.
- Support Sustainable Agriculture Practices:
    - Promote sustainable agricultural practices that optimize water use, reduce water-intensive crops, and implement efficient irrigation techniques.
    - Provide incentives for farmers to adopt water-saving technologies and practices.
- Climate Resilience and Adaptation:
    - Incorporate climate change considerations into water management strategies and plans.
    - Develop and implement climate-resilient water infrastructure and practices to cope with changing climatic conditions.
- Capacity Building and Training:
    - Invest in capacity building programs for water professionals, policymakers, and local communities.
    - Provide training on the principles and practices of IWRM, including the use of modern technologies and data-driven decision-making.
- International Collaboration and Knowledge Exchange:
    - Collaborate with international organizations, neighboring countries, and global initiatives to share knowledge, best practices, and technical expertise in water management.
    - Participate in regional and international forums to learn from the experiences of other countries facing similar water challenges.

6. Concluding Remarks

In conclusion, Integrated Water Resources Management (IWRM) stands as an imperative framework for addressing the intricate water challenges in the Arab region. The distinctive geographical, climatic, and socio-economic characteristics of Arab countries necessitate a tailored and collaborative approach to water management. As the region grapples with water scarcity, transboundary issues, climate change impacts, and socio-economic development goals, the adoption of IWRM principles becomes increasingly crucial.

Efforts to accelerate IWRM in the Arab region must be underpinned by a commitment to sustainable practices, efficient resource allocation, and inclusive governance. The success of IWRM hinges on the convergence of various key actions, including the development of robust legal frameworks, integrated planning, stakeholder engagement, and the infusion of technological innovations. Moreover, fostering regional cooperation on transboundary water resources is paramount to ensure equitable and efficient water use across borders.

As the Arab world seeks to achieve Sustainable Development Goal 6 – ensuring availability and sustainable management of water and sanitation for all – there is a need for holistic solutions that transcend traditional sectoral boundaries. Sustainable water management is not only essential for addressing immediate water challenges but also for safeguarding the livelihoods, ecosystems, and resilience of communities in the face of future uncertainties.

Achieving effective IWRM in the Arab region is inherently linked to the commitment of governments, collaboration among diverse stakeholders, and the integration of water considerations into broader development agendas. While progress has been made in certain areas, challenges persist, and ongoing efforts are required to build resilience, adapt to changing conditions, and ensure the equitable distribution of this precious resource.

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MODELING OF PAVEMENT CONDITION FOR URBAN ROAD NETWORK

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Abstract: A pavement condition prediction model was developed using historical data from the Saudi road network. The modeling incorporated a range of factors, including pavement age, thickness (both surface and base), traffic volume, the percentage of operating trucks traffic, and interactions among these variables. The power format emerged as the most effective prediction model. Statistical tests and validation against actual data points confirmed the model's efficacy in accurately predicting future pavement conditions. The model has been applied in real-world scenarios to effectively plan pavement maintenance and repair strategies. Moreover, creating differentiated models tailored to specific pavement thicknesses and truck levels, is another application of the model.

Keywords: Prediction, pavement condition, performance, maintenance, modeling, index

1. INTRODUCTION

Predicting road pavement condition is crucial for effective pavement management systems (PMS) and infrastructure maintenance, ensuring safe transportation. The prediction process includes data collection, reduction, modeling, and analysis of historical pavement performance to create a mathematical model that forecasts pavement conditions. This leads to better maintenance resource allocation, improved safety, and enhanced infrastructure durability.

The main goal of pavement performance modeling is to predict pavement condition throughout its service life based on influencing factors. Various data-driven and mechanistic models help assess maintenance and repair needs by relating pavement performance to parameters such as riding quality, safety, structural adequacy, and surface distresses (Hu et al. 2022). This research analyzed urban road pavement data, utilizing structural and traffic information to explore different modeling equations and conduct multiple regression analysis using the STATISTICA program to develop pavement deterioration equations.

2. REVIEW OF PAVEMENT PERFORMANCE MODELS

2.1 Pavement Performance

The Present Serviceability Index (PSI) correlates user opinions with road measurements such as roughness, cracking, and rutting, a concept introduced in 1962 by Carey and Irick via the AASHO Road Test (Haas et al. 1994). PSI is determined by a panel rating pavements on a scale from 0 to 5 (Yoder and Witczak. 1975, Haas et al. 1994). The five fundamental assumptions of the serviceability concept are (Haas et al. 1994):

1. Highways should be safe and smooth for public comfort.
2. User opinions on highway performance are subjective.
3. Certain highway characteristics can be objectively measured and correlated with user evaluations.
4. Serviceability can be expressed through user evaluations.
5. Performance reflects the serviceability history of the pavement.

The PSI correlates with objective measurements, represented by the equation (Yoder and Witczak, 1975):

$$PSI = 5.03 - 1.90\log(1+SV) - 0.01\sqrt{C+P} - 1.38\overline{RD}^2 \quad (1)$$

where:

PSI = Present Serviceability Index,

SV = Slope Variance,

C = Lineal feet of major cracking per 1000 ft2 area,

P = Bituminous patching in 1000 ft2 area, and

RD = Mean Rut Depth in inches (both wheel track) measured with 4-foot straightedge.

2.2 Pavement Condition Evaluation

Distress evaluation is one of the important steps in pavement evaluation which in turn, is the most critical component of any pavement management system. Pavement distresses are usually grouped in different classes depending on the viewpoint of the evaluator and the purpose of the survey. These groups may be as follows (Ramadhan 1996):

1. Type-wise grouping: cracking, surface deformation, surface defect, and others,
2. Pavement-type grouping: flexible or rigid pavement distresses,
3. Failure type-wise grouping: structural or functional failure distresses,
4. Cause-wise grouping: load associated, environmental, built-in cause, and construction practice associated distresses,
5. Location-wise grouping: localized or wide-spread distresses, and
6. Performance-wise grouping: riding quality, skid resistance, or structural related distresses.

Distress evaluation, or condition survey, includes detailed identification of pavement distress type, severity, extent, and location. To combine these details, an index is assigned to each pavement which is transferred to a general rating (excellent to failed). Every highway agency either develops a pavement distress evaluation procedure or selects a developed one for its pavement condition survey. This procedure usually starts with a clear definition of the different distresses and their severity and extent levels. There is a wide variety of pavement distress manuals available, examples of those are found in (Shahin, 1994; SHRP, 1993; KFUPM-RI, 1989; Ghosh and Smadi, 2021; Ragnoli, et al. 2018; Du et al. 2021)

In Jordan, there were several studies for developing pavement condition prediction models. Al-Sulieman and Abu Daud (2021) conducted research for performing pavement condition survey in Jordan to evaluate the condition of primary roads using the Strategic Highway Research Program (SHRP) procedure. The analysis indicated that most of the primary roads in Jordan failed prematurely and require major M & R before the end of their design lives because of heavy traffic loading. In early 1990's, Khedaywi, et al. (1991) conducted condition survey for some roads in the Jordanian network using the US Army Corps of Engineers guidelines outlined in Technical Report M-294 Pavement Maintenance Management for Roads and Parking Lots (Shahin and Khon 1981). The Jordanian Civil Aviation Regulatory Commission provides guidance material for pavement surface conditions on aerodromes and ground services (CARC, 2017). Several other studies were carried out to investigate and pavement condition for rural and urban road network and some airfield pavements examples like (Msallam et al. 2014; Obaidat, et al. 2007)

In all distress evaluation methodologies, each distress is specified by severity level (low, medium, or high) and an extent level described in measurable units (linear or area) or descriptive measure (few, intermittent, frequent, or extensive). Each distress type, severity level, and extent level combination are assigned a deduct value which is an indication of how this combination, when available, affects the perfect pavement. The total deduct value is the summation of the deduct values of all available distresses. An index representing the pavement condition (usually out of 100) is calculated by subtracting the total deduct (after correction for the interaction effect, if needed) from 100. A general descriptive rating is assigned according to some specified ranges of this index such as excellent, good, fair, poor, and failed.

3. PERFORMANCE MODELING

3.1 Model Definition

The empirical deterministic regression modeling was selected for this study for the following reasons:

1. It is simple and easy to implement and update,
2. It captures as many factors as available that affect the pavement performance both quantitative measurable and qualitative subjective,
3. It does not require elaborate involvement of any mechanistic structural testing for the fundamental pavement responses, and
4. It does not require any engineering judgment for transition probability matrices.

Considering types and amount of collected data, multiple independent variables (IVs) were used as regressors against one dependent variable (DV), the Pavement Condition Index (PCI) as the predictor in the following general form:

$$PCI = f\,(AGE, ACTH, SBTH, TRAF, TRUK, ENVR, MATR, INTR) \qquad (2)$$

Where:

1. PCI = Condition Index of any pavement condition rating method,
2. AGE = The time, in years, from the construction date or the last major maintenance (overlay),
3. ACTH = The combined thickness of all asphalt layers, cm, (including overlays),
4. SBTH = Subbase (stabilized or aggregate) layer thickness, cm,
5. TRAF = Average daily traffic (ADT), vehicle per day per lane,
6. TRUK = Number of trucks in the traffic mix,
7. ENVR = Environmental factors such as temperature and moisture conditions,
8. MATR = Materials used in the pavement construction such as aggregate and asphalt types,
9. DRAN = Drainage conditions of the pavement structure,

10. INTER = any interaction of the preceding factors.

It was found from the collected data that the first six factors were the ones commonly available or accessible. The seventh and eighth factors were either not available or not dependable. The information regarding the subbase and subgrade type were not included in the above model because it was found that there were no diverse types used in all pavement sections considered in the study. Therefore, this factor was removed from the analysis since it will not add any significance or importance to the prediction models. For drainage facilities factor (ninth), there was not enough data available for those sections considered in the analysis, therefore, this factor was also excluded.

3.2 A Priori Hypothesis

Based on the literature review, logic and engineering judgment, and developed models of similar studies, the following assumptions and boundary conditions can give a general idea about the expected shape and behavior of the targeted prediction model:

1. A newly constructed or recently resurfaced pavement section starts with a condition index value of 100, regardless of the condition survey method used (i.e., at AGE = 0, the condition index = 100). This initial condition can be modeled in various ways. One approach is to adjust the intercept value by adding or subtracting the product of each independent variable and its corresponding regression coefficient. Alternatively, an exponent or power function (e^{AGE} or A^{GEB}) can be employed to manipulate variables, ensuring a PCI value of 100 at AGE = 0, since these functions yield a value of one at that age.
2. The total pavement thickness (ACTH + SBTH) is assumed to represent the support capacity for traffic loads (whether TRAF or TRUK).
3. Generally, pavement deterioration begins at a slow rate but accelerates sharply after a certain point. This deterioration process can be modeled using power, exponential, or polynomial functions. The specific shape and curvature of these functions can be adjusted through the regression coefficients.
4. Data regarding operational traffic, truck percentages, and traffic composition (including passenger cars, heavy trucks, light trucks, and axle loads) was often unavailable. As a result, the percentage of both light and heavy trucks was combined during the modeling process.
5. For older pavements (where AGE is significantly greater than 0), the condition can deteriorate to an extremely poor state, approaching failure. Therefore, the prediction model should account for a condition index value of zero around the end of the pavement's design life (typically 20 to 30 years) if the pavement is left without maintenance.
6. This study focused on pavement sections within the Saudi Arabian road network that contain information related to pavement condition and performance. Most of the collected data originated from regions with a hot climate, which is a defining characteristic of the Saudi environment. Consequently, the temperature factor was excluded from the analysis, as there was minimal variability of this factor in the collected data.
7. In the performance model outlined above, the hypothesis posits that AGE, TRAF, and TRUK are inversely proportional to the PCI, while ACTH and SBTH are directly proportional to the PCI.

3.3 Sample Size Determination

The performance model needs sufficient data points or cases to adequately explain or predict the pavement performance. Although there is no firmly agreed-on minimum case to variable ratio, at least three considerations are relevant: skewness in dependent variable, effective size, and measurement error. The lower case-to-variable ratio, the more important it becomes that the residuals are normally distributed. The minimum number of cases or data points was determined, for this study, based on the following recommendations and criteria)Tabachnick and Fidell 1983):

1. One must have more cases than variables included in the regression model, or the regression solution will be perfect yet meaningless.
2. Ideally one should have 20 times more cases than variables.
3. If stepwise regression is to be used, the case-to-variable ratio should be 40 to 1.
4. A suggested minimum required is to have at least 4 to 5 times more cases than independent variables (IVs).

Considering the above criteria, and the fact that stepwise regression will be used, there is a need of 40 data points for each independent variable. There are five independent variables in the condition model, which means a minimum of 200 cases are required (case-to-variable ratio is 40). For this study about 433 cases were collected. Moreover, the minimum sample size was also checked by statistical parameters and was found to be the same. The predicted pavement condition adequately represents the actual condition, depending on the allowable error in the prediction of the sample mean, standard deviation, and the desired degree of accuracy. The following equation was used for this purpose (Walpole and Myers 1978):

$$n = \left(\frac{z\alpha/2 \quad \sigma}{e} \right)^2 \tag{3}$$

Where:

n = required minimum number of cases for regression analysis,

$z_{\alpha/2}$ = normal distribution value for a given confidence level,

σ = standard deviation of the overall samples (cases) considered, and

e = allowable error in the estimate

A confidence level of 95% ($z_{\alpha/2}$ = 1.96) was selected as an accuracy level for the pavement condition estimates. The allowable permissible error in estimating the pavement condition was set to ± 5 points (100-point scale). Additionally, the average variance (σ^2)of all collected data was 231.07. Using these values in the above equation, n equals to 35.5. Therefore, a minimum of 36 data points is needed for modeling the pavement condition. The available data cases are much more than this number. It should be noted that the deficiency of using the collected samples' variance instead of the unknown population variance was covered by using sample size much greater than 36.

3.4 Study Area

To obtain generic models that can be utilized with a significant level of confidence, the study covered all accessible pavement ranges of Saudi pavement network. The study included both intercity highways as well as municipal and local roads and streets. Roads under the authority of Saudi Ministry of Communication (MOC) later named Ministry of Transportation (MOT) both in Riyadh and Dammam areas were considered to represent the intercity highways. Municipal roads in Dammam, Dhahran, Khobar, Jubail, and KFUPM campus roads and streets were considered as urban pavements. Other road pavements, in the cities of Jeddah, Makkah, and Medinah, were not considered since no relevant .pavement condition data were available

3.5 Preliminary Data Analysis

The collected data was normalized and checked for outlier cases. The outliers are extreme cases on one or more section variables. Basic statistics of the collected data were summarized and tabulated, and general observations on these data were made. The collected data were sorted according to their sources and checked thoroughly. The collected data were subjected to a filtering process for any irrational, irregular, or illogical behavior. Two criteria were specified in this process:

1. Old sections of more than 7 years in service, with a condition index of 100 (perfect condition) were excluded from the analysis. The perfect condition can only happen when the pavement is new, or the pavement was not exposed to any external factors of traffic and environment.
2. New sections of less than 5 years in service, with condition index approaching zero (failure condition) were also excluded for the analysis. Situations may exist where some sections are exposed to very severe load and environmental conditions, or where pavement sections have some built-in defects during design or construction. These situations result in a premature failure in these sections.

The collected data from all sources, after checking, were stored, and tabulated in worksheet files and then transferred to the STATISTICA computer package (STATISTICA 1995) format for pavement condition model development and calibration. The overall data points (cases), from each data collection method, are summarized in Table 1. The AGE has a range of 1.5 to 15.33 years. These are considered good ranges for pavement condition and performance modeling. Combined asphalt layer thickness has a range of 9 to 25 cm. Other factors also have wide ranges as shown in the table.

Table 1. Statistical summary of the PCI collected data.

Statistic	Modeling Factor					
	AGE	PCI	ACTH	SBTH	TRAF	TRUK
Mean	5.4	83.7	15.4	38.0	1077.9	343.8
.Std. Dev	3.2	16.2	5.5	7.9	1029.2	390.7
Maximum	15.33	100	25	55	4662	1541
Minimum	1.5	20.00	9	30	103	8
Number	433	433	433	433	433	433

Model Formulation and Testing 3.6

The collected screened data was processed, tabulated, and used in the STATASTICA PC-package to obtain the regression model. Stepwise regression was first used to check those factors that were significant to pavement condition prediction. Different linear and non-linear models were tried according to a set of a priori hypothesis. The final models were checked against several model adequacy tests such as normality, linearity, and homoscedasticity, for the residuals (errors) between the observed and predicted pavement condition values.

As stated before, the five variables that affect the pavement condition are age of the pavement (AGE), asphalt layer thickness (ACTH), subbase or aggregate base layer thickness (SBTH), operating traffic (TRAF), and truck percentage in the traffic mix (TRUK). Initially, the general relationships between the dependent variable, pavement condition (PCI) with each of the other independent modeling variables (AGE, ACTH, SBTH, TRAF, and TRUK) to establish and confirm the logic of a priori hypothesis, stated earlier, for the general developed models. To improve the fit or the ability to predict the pavement condition, various linear and non-linear transformation of the five independent variables were tried.

As stated earlier, the polynomial and power equations were selected for modeling the pavement condition. The Polynomial equations used were of second, third, and fourth degree of the AGE independent variable, being the most important and influential variable to pavement condition. Other variables (i.e., ACTH, SBTH, TRAF, and TRUK), were kept in their linear form. The targeted model has the following general form:

$$PCI=a+b(AGE)+c(AGE)^2+d(AGE)^3+e(AGE)^4+f(ACTH)+g(SBTH)+h(TRAF)+i(TRUK)+error \quad (4)$$

Similarly, the power curve of AGE, ACTH, SBTH, TRAF, and TRUK were tried using the logarithmic transformation stated below:

Power Form

$$PCI = 100 - a.(AGE)^b . (ACTH)^c . (SBTH)^d . (TRAF)^e . (TRUK)^f . error \quad (5)$$

Transformed Logarithmic Form

$$\log (100 - PCI) = \log (a) + b.\log(AGE) + c.\log(ACTH) + d.\log(SBTH) + e.\log(TRAF) + f.\log(TRUK) + error \quad (6)$$

All possible and feasible PCI models generated from the collected data were tried. The best selected model (shown in Figure 1) was subjected to different evaluation and testing schemes to check that their predictions conform with the basic engineering and logical assumptions. It has also undergone different statistical checks.

The process of model evaluation (i) generating two-dimensional plots showing the pavement condition with age at average values of other independent variables, and (ii) generating fitting characteristic plots between the predicted values and the observed ones.

The equation of the selected model is:

$$PCI = 100 – 3.83* (AGE)^{1.25} * (ACTH)^{-0.185} *(TRUK)^{0.018} \; (R^2 = 0.775) \quad (7)$$

The pavement condition or deterioration model is shown in Figure 1.

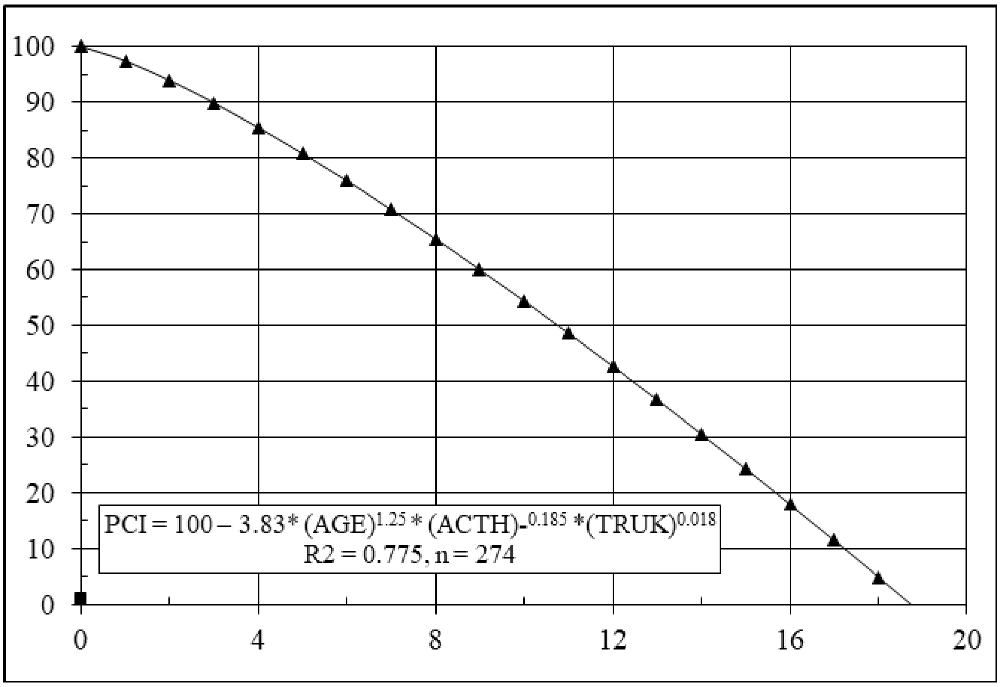

Figure 1. The developed model with average values of independent variables.

The fitting characteristics of the developed model are shown in Figure 2 where the observed values were plotted against the model predicted values. Ideally the perfect fitting model should have all points on the 45° line. From these figures, the selected model exhibited some scattered points around the 45° line. However, according to the type of the collected data and the incurred variations of sources, this prediction powers is reasonable.

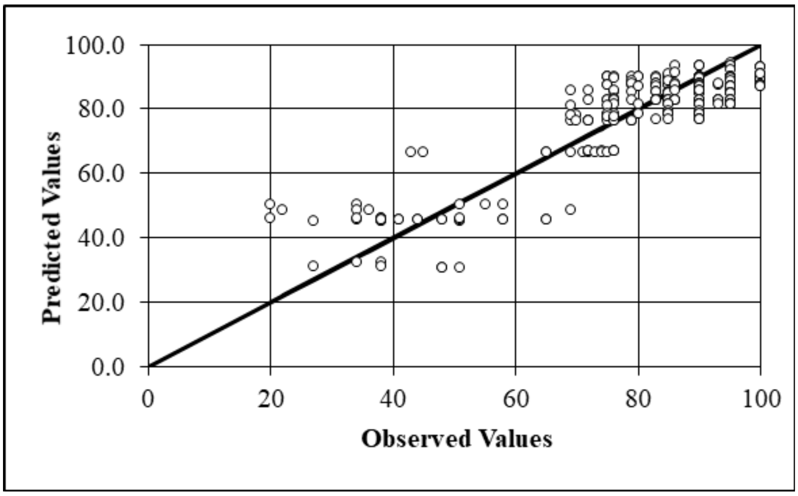

Figure 2. Goodness of fit of the selected model.

3.7 Model Validation

The final prediction models were used with the data points (cases) reserved for model validation. Predicted pavement condition values were compared with the actual measured values to check the reliability and the level of significance of the developed model in explaining or presenting the actual data points.

As stated earlier, part of the collected data was used for model development (274 data points) while the other part was reserved for model validation. A set of 159 data points were used to validate the developed models.

The procedure followed for model validation testing was done by fitting the reserved data points (validation data) of the selected prediction model of the set and determining the R^2 of these fittings. The R^2 value was compared with original model goodness of fit. Figure 3 shows the validation data goodness of fit plot using the developed model. The developed model fitted the validation data with similar goodness of fit (R^2 value 0.696 compared with 0.775) which means that the predicted data matched with the actual validation data. This is a reasonable value considering the type of collected data and the variation in its attributes. However, the developed model can be refined and modified when more consistent and accurate data of pavement conditions and other related information are available.

4. MODEL APPLICATION

4.1 Pavement Condition Prediction

Some areas of application of the developed models were specified. Different models for different combinations of the pavement parameters, such as thickness and traffic levels, were generated. The use of pavement condition models for planning the maintenance policies over the design life of the pavement was also tried.

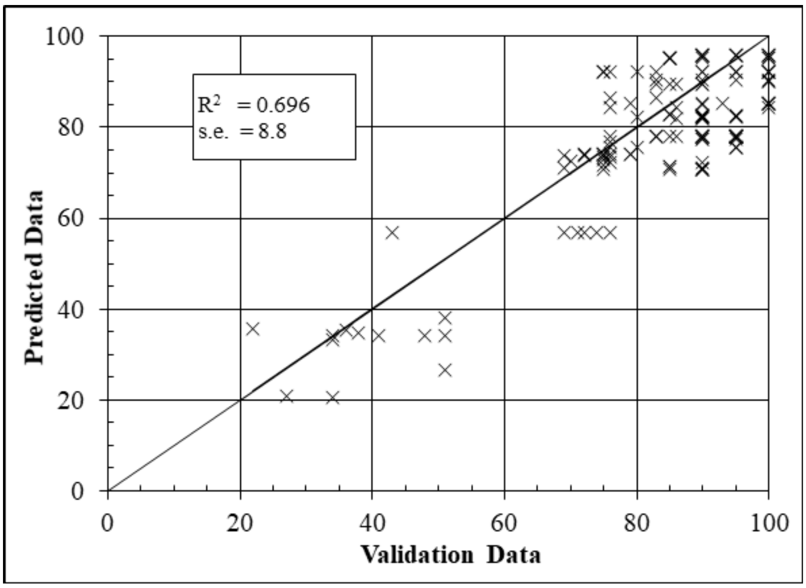

Figure 3. Developed model validation.

In urban road pavements, several combinations of asphalts layer thickness and truck percentages can be found, such as 5, 10, and 15 cm levels of ACTH, and 100, 500, and 1000 levels of TRUK are usually found. Using these levels, three different pavement prediction curves can be generated as the ones shown in Figure 4. One assumption is made in this figure that the truck levels have an annual increment rate of 5%.

4.2 Maintenance Plans and Policies

Another application and use of the developed model is for maintenance planning and setting maintenance policies (Al-Suleiman et al. 2020, Sharaf, et al 1988). Pavement condition prediction curves are usually used to forecast the pavement condition over time, so that maintenance activities as well as funds allocation can be scheduled ahead of time. Using the principle of critical pavement condition index that is a triggered condition value at which the pavement should receive some correction measure, otherwise, its maintenance cost will be much higher if it was left for further deterioration. Therefore, a selection of the best maintenance policy is one of the advantages of the pavement condition prediction model.

Preventive pavement maintenance is the one that is carried out to minimize the damage to the pavement under normal service, which needs to be implemented immediately to prevent further deterioration and to preserve the pavement components.

This maintenance type includes surface treatments such as crack sealing and slurry sealing. The corrective maintenance, on the other hand, is the work performed to restore the pavement to its prescribed level of service after the damage has occurred. Examples of this type include overlays and reconstruction.

Two typical examples of preventive and corrective maintenance activities in relation to the pavement are shown in Figures 5 and 6. The PCI developed model was used in these two figures. In the first figure, a preventive maintenance (slurry seal for example) is applied four times, once every 3.75 years, through the pavement section service life. The service life, where the PCI value equals zero, is predicted to be 17 years. Therefore, four applications of this type of maintenance are required to keep the pavement section above a PCI assumed acceptable level of 85.

However, if this pavement section does not receive any maintenance during its service life, it will fail at the age of 17 years and needs a reconstruction that costs much more than the application preventive maintenance.

In Figure 6, another policy is selected, where a corrective maintenance action of an overly is applied when the pavement condition drops to a level of 60. Here, two applications are needed through the pavement section service life. Again, the cost of these two overlays will be less compared with the cost of reconstruction alternative at an age of 17 years.

A cost analysis can be done to compare the three maintenance policies:

1. Application of four preventive maintenance actions
2. Application of two corrective actions.
3. Reconstruction.

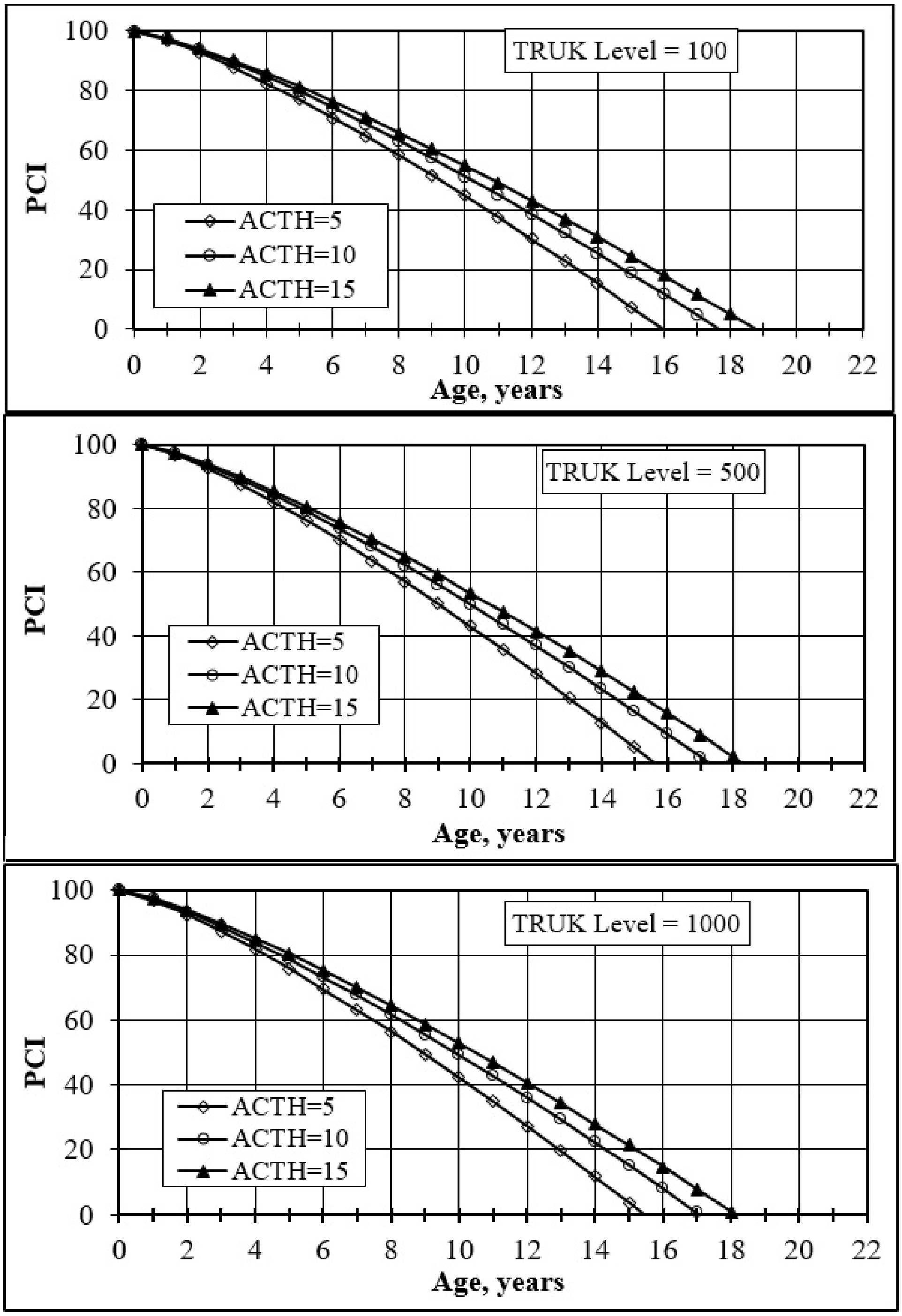

Figure 4. Sensitivity analysis at different thickness and truck levels.

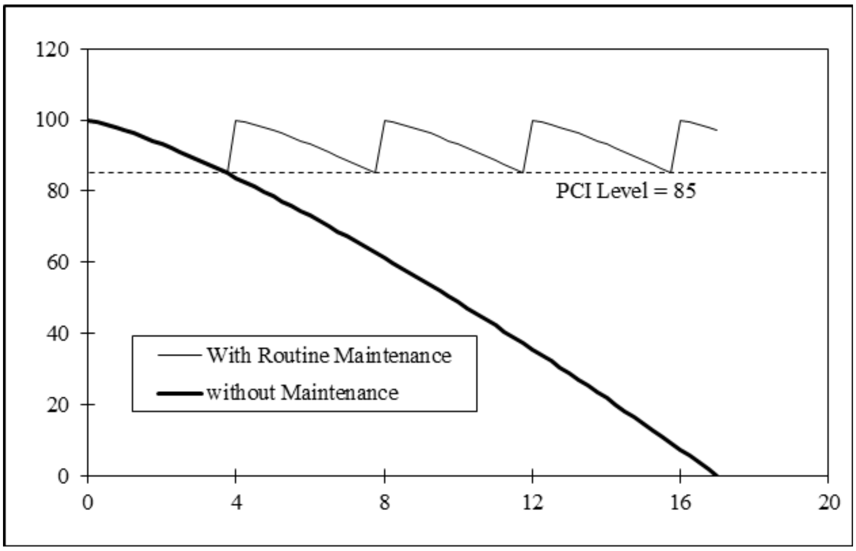

Figure 5. Pavement performance with preventive maintenance.

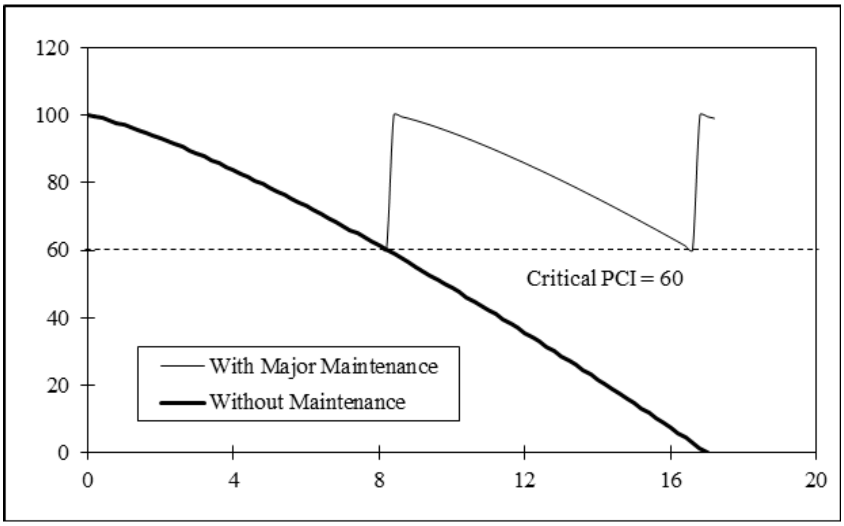

Figure 6. Pavement performance with corrective maintenance.

Depending on the cost of each alternative, pavement authorities can select the most cost-effective one. A typical pavement section of 500 meters long and 10 meters wide is considered with the following assumptions:

1. The unit cost of slurry seal/seal coat is. SAR 7 (1.5 JD)/m^2,
2. The unit cost of 5 cm. milling and repaving is SAR 30 (6 JD)/m^2,
3. Inflation or discount rate is 5 percent every year,
4. Reconstruction of new pavement is SAR 80 (15 JD)/m^2, and
5. Other non-monetary parameters in both benefits and user costs are ignored.

Table 2 shows the calculation of cost analysis of this typical pavement section using the above assumptions. In this table, the future worth method was used, where the spending in the future is calculated using the initial cost and inflation rate. From this table it is very clear that the application of preventive maintenance over the span of pavement service life will help not only keeping the pavement in a good acceptable level of service but it will reduce the overall maintenance cost to about 40%

compared with the corrective maintenance (i.e. SAR22,5851 to 557,676), and to about one-fourth (24.6%) compared with the reconstruction (i.e. SAR225,851 to 916,807). This is without considering non-monetary benefits such as safety and comfort.

Table 2. Cost analysis for three pavement maintenance policies.

Maintenance Alternative	Maintenance Cost (SAR)								
	Activity No. 1		Activity No. 2		Activity No. 3		Activity No. 4		Total (SAR)
	Cost (SAR)	Age (Yrs)	Cost (SAR)	Age (Yrs)	Cost (SAR)	Age (Yrs)	Cost (SAR)	Age (Yrs)	
Preventive Maintenance	42,027	3.75	50,465	7.5	60,597	11.25	72,762	15	225,851
Corrective Maintenance	223,791	8.2	333,884	16.4	-	-	-	-	557,676
Reconstruction	-	-	-	-	-	-	916,807	17	916,807

This example can be used as a confirmation to the general conclusion, mentioned in several similar research that the maintenance cost of the pavement while in poor condition is about four times the cost if the pavement is maintained while in good condition.

5. CONCLUSIONS

The pavement condition survey data utilized in this research was carefully selected from a vast pool of collected data, ensuring consistency and the availability of all performance-related information. This data underwent a thorough analysis process for filtering and preparation to facilitate the generation of predictive models. The resulting model demonstrated a reasonable goodness of fit, indicated by an R^2 value of 0.775. It was found that the pavement age (AGE) factor had the most significant influence on capturing pavement condition, followed by the percentage of trucks (TRUK), and lastly, pavement thickness (ACTH). The model was validated against actual collected data, yielding satisfactory goodness of fit. Two applications of the developed model were identified: (i) creating differentiated models tailored to specific pavement thicknesses and truck levels, and (ii) assisting in the planning and scheduling of maintenance policies.

Although the developed model is tailored for the urban pavement network in Saudi Arabia, it can be applied to other contexts with minimal adjustments to the underlying assumptions. Furthermore, the model development process is applicable to various geographical and environmental conditions.

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Smart Cities in Jordan: Challenges and Barriers
(Greater Amman Municipality projects as a Case Study)

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ABSTRACT

Many developed countries in Europe, Asia, and North America have turned to the Smart City system. This has been attempted by either retrofitting the established cities or creating new cities to provide their services instantly to citizens. Success stories of smart city projects have spread recently in various regions of the Middle East, and Amman is not among those successes.

This study explores the implementation of the global Smart city concepts at the local level by examination the factors affecting the implementation of smart city projects in a developing one, specifically in Jordan, through two stages, namely a qualitative technique that included interviews with experts. Secondly, a case study in which four constructed projects in terms of smart city concepts were chosen in Greater Amman Municipality (GAM) and private sector projects.

The research results showed that GAM approaches the implementation of the global concept of a Smart City in Amman. The executive committee for innovative solutions stated that the main dimensions that had been applied in GAM are city Mobility and Environment projects area. On the contrary, marginal regions in the adoption of smart projects are limited to living and social services.

According to the study results, a lack of cooperation and coordination, unclear smart city vision, and poor private-public participation from the governmental group are found to be the top factors that hinder the transformation into a smart city, so this research suggested a roadmap to implement the smart city concepts as a smart solution for projects in Jordan.

Keywords: Smartcity, Jordan, GAM.

INTRODUCTION

Villages and towns of all sizes and characteristics grow in a dynamic manner that corresponds to economic and social development. The rate of change in the city's growth has become high due to the influence of organization, nature, and conditions with different factors. Managing this development and directing it towards using all the elements available for its realization will increase progress and efficiency in the cities (Lebiedzik, 2020).

A recent United Nations report found that by 2050, 70% of the world's population will live in urban areas.

On this basis, the Smart Cities project was launched, encompassing 70 European cities, and aims at identifying strengths and weaknesses and achieving appropriate local development for all to become more competitive cities (Anon., 2019).

New technological developments have helped governments realize the dream of smart cities, as advances in the Internet of Things, which are based on the networking of devices,the exchange of data, and the introduction of centralized control systems, have helped to reduce energy consumption, and improve the traffic management system (Lombardi et al., 2012).

LITERATURE REVIEWS

"The Technopolis Phenomenon: Smart Cities, Fast Systems, Global Networks" book was published in 1922 in which the term smart city appeared for the first time as a new Research (Mora et al., 2017). Since then, supporting the growing interest in the "Smart City" concept within the framework of universal sustainable development,this research field has attracted different research areas and more actors, from government organizations to enterprises and social communities (Patrão et al., 2020, p. 1119).

A smartcity is defined as a city that operates ambitiously and innovatively that covers the areas of the economy, people, administration, environment, mobility, and living. This innovation relies on an intelligent mixture of support and active participation from independent, informed citizens who can make decisions (Anthopoulos & Vakali, 2012).

Smart Municipalities

Like a smart city, a competent municipality opens many new possibilities. Starting to develop a group of municipalities in a town,then achieving the concept of a smart municipality and then a smart city (Spicer et al., 2021).

"Smart municipality" is a description of an imperative state of development outcomes;it is a case of an initiative to bring about change by exploring relevant, innovative processes to achieve social and financial development of life in the municipality; a smart municipality cannot be an end or a goal to be completed (Mwesigwa &Mubangizi,2018). But because of growth, access to the smart municipality is an achievement that is being sought. The term "smart municipality" can refer to the style of work followed and the progress made in the municipality's development, which in turn testifies to the extent to which the "smartness" of the municipality has grown (Trencher, 2019).

In 2017,The German-Czech Chamber of Commerce and Industry carried out the first study in cooperation with the Municipalities of the Czech Republic.One hundred andt wenty municipalities and towns of various types from all over the Czech Republic took part in the survey to determine which Municipal should become smart. As the survey shows, the most significant barrier to executing smart solutions was a lack of financial resources(Lebiedzik, 2020, p.4).

Greater Amman Municipality

Amman is considered one of the most important cities in the Arab world. It is classified according to the World City Index as a global city as an important financial center in the world and one of the fastest-growing and developing Arab cities, in addition to being an urban, economic, and development center and competing with the world's major cities through several factors, most notably the institutional framework and infrastructure Health, education, the economic environment, the development of financial markets, technological readiness, the development of business management and creativity (Bogaert, 2013).

The Greater Amman Municipality intends to transform into a "smart city" by launching ten projects at once to be one of the smart cities in the region, reflecting the significant development that has occurred in the "Government" and its work. The projects include bus feeding services for express buses, parking and queuing management, shared transport services, pedestrian and bike paths, intelligent traffic control,traffic monitoring,and control platform, smart street lighting, electric vehicle charging, flood warning systems, and smart asset management.

METHODOLOGY

The overall goal of this research is to apply the concepts of the smart city to the GAM and private sector by studying the projects that can be constructed, the projects that have been applied and thatcan contribute to achieving those concepts and evaluating the challenges for each project within the smart city categories through the smart city assessment matrix. Thus, developing a roadmap to assist other projects in following the GAM approach to achieving the concept of the smart city.

The study took a qualitative exploratory approach because smart cities are still a relatively new topic with few detailed examples and case studies to back it up. Instead, employed an analysis method to examine available literature sources and case studies to determine the types of smart cities available and the elements, challenges, and strategies that go with them to understand better the entire emerging smart city landscape around the world.

Twenty engineers were interviewed, including the rapid bus operation team, Al-Ghabawi landfill project team, engineers from the traffic department, the Executive Director of the Arab Smart Cities Forum, the Head of the Bids and Contracts Department/Information Technology Department who is the Rapporteur of the Executive Committee for Smart Solutions.

Some direct questions through interviews were asked regarding the concept of the smartcity; their opinion towards achieving the idea of a smart city on their work, studying the challenges of implementing smart city projects, their plan to meet these challenges, and discussing examples of projects that have been applied and can be considered within the smart city projects to allow understanding the projects current social and economic reality and the different challenges they face.

Based on the smart city pillars mentioned in the literature, the research looked at the areas that are easy to achieve in the GAM areas, mainly in mobility projects, waste management facilities,and governance projects. This is done to see how close GAM to adopting more advanced techniques and services.

The research methodology is summarized in (figure1).

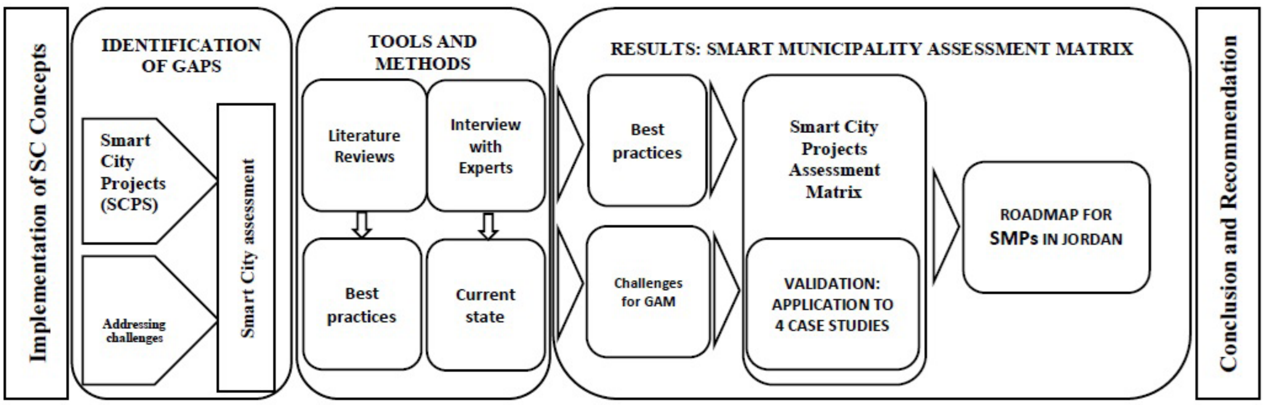


Fig1:Structure of study

DATA ANALYSIS AND COLLECTION

Identification of Gaps

Two significant gaps have been identified through the study;the first is the need to evaluate GAM as an innovative municipality project as the primary implementation tool for smart municipalities. The second is the need to address challenges to smart projects. The smart city assessment developed in this study confirmed the need for assessment methods that consider these two factors.

Inputs

An investigation was conducted to identify general and specific inputs for the evaluation tool for developing the case study. A classification of SMPs was developed and divided into three levels. The classification was created in three-phase: selecting and analyzing best practices, developingan initial SMPs classification, and validating external experts. In the first phase, Twenty GAM experts from various specialties were interviewed (e.g., the Rapporteur of the Smart Solutions Committee in Amman). The experts chose 60 project actions; the second phase involved distributing these projects to project areas; and the third phase involvevs ending the classification to the same experts, who participated in the second phase, where their comments and suggestions were used to modify the structure by adding or changing specific project measures.The final project action classifications showed in (Table2). Identifying Jordan's smart projects challenges occurred in three stages (Table 4). The first list of 26 challenges was compiled, and these were with the different dimensions of Environment, Governance, Mobility, Economy, People, and Living.

FINDINGS

Smart Projects Assessment Matrix (SPAM) was the main result of this study. It had a dual purpose. The first goal is to conclude the ability of various types of smart municipal projects to address Jordan's projects' challenges. The second goal, prioritizing challenges for different municipalities, lays the ground work for future research.The SPAM's was made up of three phases. First, it was created based on a thorough review of the literature and an examination of several projects identified as best practices in various dimensions. It was then double-checked with expert opinions in a subsequent step (members of the Management Committee of Smart Solutions within the GAM). Finally, it was implemented in four different SCPs. The SPAM contributed to suggesting a roadmap for developing innovative smart projects in Jordan, validated with case studies.

A selection of smart projects has been selected according to the current situation, which can effectively be implemented in a short period and which can be implemented. Long-term work was then analyzed to find a way to systematize their structure.This study proposes breaking down and classifying a Common smart project into different dimensions and identifying various types of project areas and project actions included in the project. Fifty-six project actions were recognized, classified into six dimensions, and organized into twenty-two regions. The classification proposed here can be used to manage projects and develop proposals. It is designed to be adaptable and modifiable, allowing for new solutions to emerge in the future.

The SCPs classifications were implemented in 22 districts of GAM. The result of the survey which was conducted from September to November 2021 showed in (Table1). Specifically, the interview questions focused on reviewing the categories related to the concept of the smart city projects related to each class, and Amman's steps to join cities Smart, according to the memorandum of understanding signed by GAM with the European Bank for Reconstruction and Development (EBRD). Six significant categories were examined primarily, which are the so-called "smart municipality dimensions": environment, transportation, governance, economy, living, and people. Sample projects are included for each category to know if such a project or a similar project has been undertaken or if it will implement in the future.

The matrix has been tested in four different case studies thanks to the SPAM validation process. The projects cover various topics and impact all six city dimensions. The projects are all GAM projects that have either been completed or are in the process of completion.The findings indicate that the previous effort to synthesize challenges, project areas, and potential interactions between them was successful. Furthermore, the connections between 22 project actions and the selected challenges have proven correct, demonstrating that they produce correlations between challenges and projects or can produce these connections by incorporating minor changes into the project.

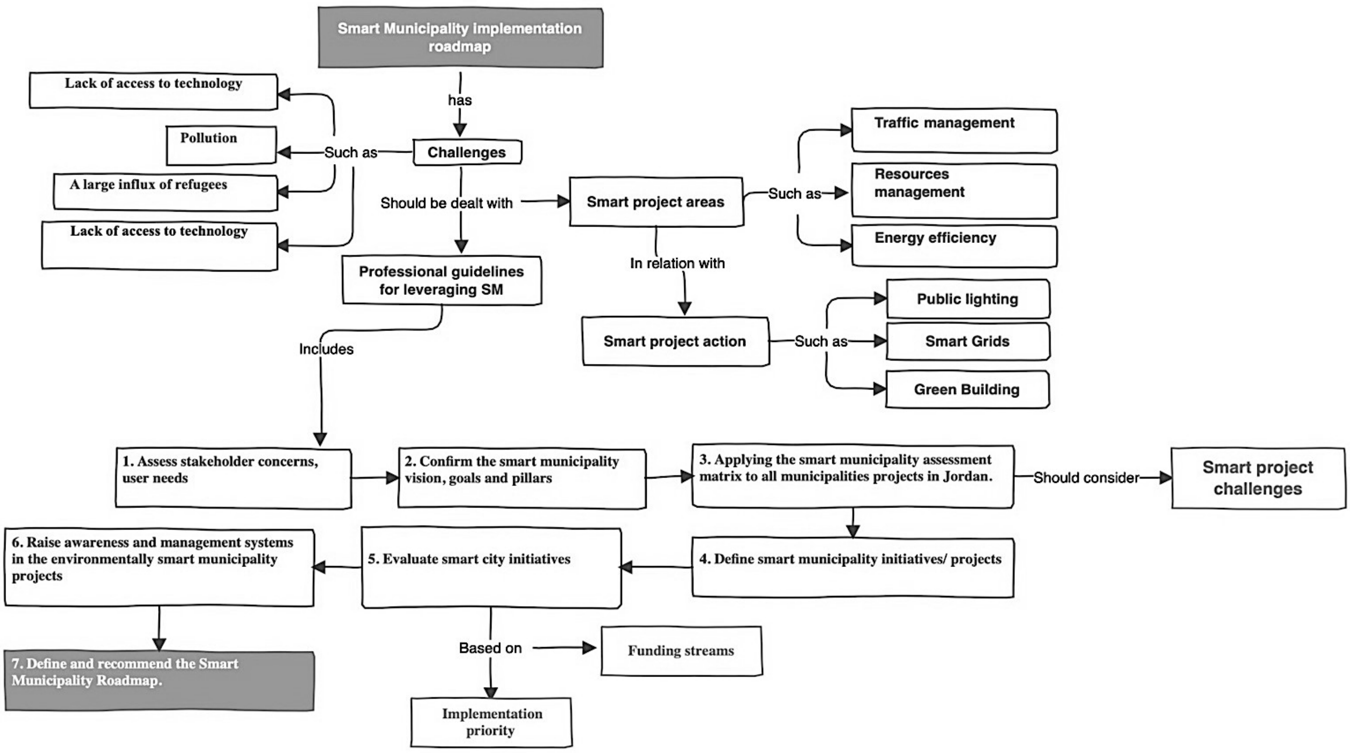
Identifying missing elements is also helpful in gaining insights into the project's limitations and addressing possible gaps in the proposal.The matrix has been verified as valuable for visualizing the project and identifying potential synergies between initiatives. A summary of the case study results is shown in (Table1). The number of challenges addressed grows in direct proportion to the complexity of the case studies (Table3). Comparing the BRT and traffic management case studies reveals more significant potential for increasing the number of challenges in mobility projects, affecting two dimensions and five common project areas.

Table1:Summary case studies validation results.

Project	Project Dimensions	Project Area	Impacted Challenges	Probable Impacted Challenges	Effects (intersections)
BRT	3	6	7	17	25
Traffic management	2	7	7	19	23
Digital Transformation	2	3	11	23	26
GhabawiLandfill	3	5	19	24	24

Roadmap development for smart municipalities in Jordan

Aflexible roadmap for implementing smart municipality initiatives in Jordan was developed based on current data extracted from the matrix explained in the detailed smart municipalities roadmap (Figure 2).



.Fig.2: Detailed smart municipalities roadmap

Table 2: Implementation of project actions.

Dimension	Project Areas	Project Actions	Available/ Not	Dimension	Project Areas	Project Actions	Available/ Not
Environment	SEn1. Network and environmental monitoring	Pollution sensors	Not available	Economy	SEc1. Innovation	Innovative entrepreneurship and business	Available
	SEn2. Energy efficiency	Environmental protection	Available		SEc2. Entrepreneurship	Entrepreneurs (in building e.g., optical networks, sensor systems)	Not available
		Green/renewable energies	Available		SEc3. Local and Global interconnectedness	Social taxi/Car Driver (collection)	Not Available
		Smart Grids	Available		SEc4. Productivity	Participatory business models and service or citizen	Available
		Public lighting	Available			Shared babysitting	Available
	SEn3. Smart buildings and building renovation	Green buildings	Available			Ride share (vehicle sharing)	Not available
	SEn4. Resources management	Waste management	Available	People	SPe1. Creativity	Co-working centers	Not Available
		Water management	Not Available			Integrated platforms for media services	Not Available
		Food and agriculture	Not Available		SPe2. Community building and urban life management	urban farming networks	Not Available
Governance	SGo1. Participation	E-municipality and E-participation	Available			internet platforms to disseminate information about urban events on different topics.	Not Available
		Electronic voting	Available	Living	SLi1. Tourism	Tourism applications	Not available
		Complaints and claims	Available			Tourist card	Not available
	SGo2. Transparency and information accessibility	Transparency tools (social translucence mechanisms)and Tracking and analysis	Not available			Online tickets	Not available
		Interactive GIS maps of cities	Not available		SLi2. Culture and leisure	The use of ICT systems (e.g. augmented reality technologies) for delivering new customer experience in enjoying the city's cultural heritage.	Not Available

		Public Sector Information (PSI) portals	Available		SLi3. Technology accessibility	Open data (data acquisition and sharing, map portals	Not Available
		Information sharing among government staff	Not available			Implementation of public Wi-Fi connections	Not Available
Mobility	SMo1. Traffic management	Sectional vehicle speed measurement	Available			Camera systems	Available
		Intelligent public transport stops	Not Available			Integrated alarm systems (floods,smog)	Not Available
		Charging Stations	Not Available			Online reporting of faults and errors in the field.	Available
		Traffic monitoring	Not Available		SLi4. Public spaces management	Green infrastructure concepts	Not Available
		Ramp metering	Not Available			Integrated solutions for parks management	Available
		Smart parking systems	Not Available			On-site and around site interviews to define users' needs and expectations. (lively cities)	Not Available
	SMo2. Public Transport	Card of public transportation,	Available			Identification of users and key stakeholders	Not Available
		Public Transportation Applications	Available			Integrated solutions for parks management	Available
		Intelligent bus stops,	Not Available			On-site and around site interviews to define users' needs and expectations.	Not Available
		Public bicycles	Not Available			Identification of users and key stakeholders	Not Available
	SMo3. ICT Infrastructure	Parking sensors, parking information	Not Available				
	SMo4. Accessibility	Accessibility on public transport stations and devices	Available		SMo5. Multimodality	Intermodality between different types of public transport	Available
		Systems of transport pricing according to incomes	Not Available			Intermodality between public and private passenger transportation networks	Not Available
		Transport adaptation for disabled people an elder	Available				

Table 3: Smart cities in Jordan challenges.

Pollution [Amr, A., & Saad, M. (2015); Bogaert, K. (2013)]	Urban poverty and inequality [Chan, D. K.-h. (2016); Bogaert, K. (2013)]
Lack of quality of neighborhoods and public space [Bogaert, K. (2013)]	Low educational level and digital skills [Bogaert, K. (2013); Çubıkcı, M. (2019); Bogaert, K. (2013)]
Lack of accessible and affordable public transport [Chan, D. K.-h. (2016); Çubıkcı, M. (2019)]	A large influx of refugees [Lebiedzik, M. (2020).]
Increase in private car ownership and use [Lebiedzik, M. (2020).]	Threats to culture identity and particularities [Çubıkcı, M. (2019); Bogaert, K. (2013)]
Major infrastructure failure [Amr, A., & Saad, M. (2015); Bogaert, K. (2013)]	Urban violence and insecurity [Amr, A., & Saad, M. (2015)]
Limited access to financial aid [Chan, D. K.-h. (2016)]	Lack of accessible entertainment facilities [Mora, L., Bolici, R., & Deakin, M. (2017)]
Lack of competitiveness [Bogaert, K. (2013); Çubıkcı, M. (2019)]	Poor quality services, especially in the field of health and education [Çubıkcı, M. (2019)]
Uneven geographic development [Chan, D. K.-h. (2016); Bogaert, K. (2013)]	Climate change effects [Amr, A., & Saad, M. (2015); Bogaert, K. (2013)]
Lack of access to technology [Bogaert, K. (2013)]	Inefficient resources cycle management [Bogaert, K. (2013); Bogaert, K. (2013)]
Low urban institutional capacities [Lebiedzik, M. (2020); Çubıkcı, M. (2019)]	Lack of equality in access opportunities and resources [Çubıkcı, M. (2019)]
Instability in governance [Amr, A., & Saad, M. (2015)]	Lack of awareness, engagement & participation [Mora, L., Bolici, R., & Deakin, M. (2017)]
Lack of access to information [Mora, L., Bolici, R., & Deakin, M. (2017)]	Very rapid urbanization [Amr, A., & Saad, M. (2015)]
Gap between government and governed	Urban poverty and inequality [Mora, L., Bolici, R., & Deakin, M. (2017)]

ble 4: Smart Projects Assessment Matrix:
’AM.

	Dimensions																					
	Environment					Mobility					Governance		Economy				Living				People	
	Network and environmental monitoring	Energy efficiency	Urban planning and urban refurbishment	Smart buildings and building renovation	Resources management	Traffic management	Public Transport	ICT Infrastructure	Accessibility	Multimodality	Participation	Transparency and information accessibility	Innovation	Entrepreneurship	Local and Global interconnectedness	Productivity	Tourism	Culture and leisure	Technology accessibility	Public spaces management	Creativity	Community building and urban life management
Pollution																						
Lack of quality of neighborhoods and public space																						
Lack of accessible and affordable public transport																						
Increase in private car ownership and use																						
Major infrastructure failure																						
Limited access to financial aid																						
Lack of competitiveness																						
Uneven geographic development																						
Lack of access to technology																						
Low urban institutional capacities																						
Instability in governance																						
Lack of access to information																						
Gap between government and governed																						
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Threats to culture identity and particularities																						
Urban violence and insecurity																						
Lack of accessible entertainment facilities																						
Poor quality services, especially in health and education																						
Climate change effects																						
Inefficient resources cycle management																						
Lack of equality in access opportunities and resources																						
Lack of awareness, engagement & participation																						
Very rapid urbanization																						

CONCLUSION

The conclusions can be classified as follows:

1. The smart city is a worldwide concept that seeks to incorporate information and communication technologies and tools to improve city management and popularize its development.It may be indicated that this definition understands the concept in principle by most engineers in GAM municipalities who participated in an empirical survey.
2. From the study’s findings, GAM can be transformed into a Smart Municipality becaus ethe local administration has made efforts to plan and build facilities based on the city’s needs, which can be used as the foundation of a Smart Municipality system. These efforts have enhanced traffic layouts and proposals for improved public transportation. Living dimensions are virtually neglected, despit etheir massive potential for meeting the region’s creative requirements due to a lack of understanding of their abilities.

To bridge the gap between smart cities (municipalities’) conceptual frameworks and the implementation status of the concept, it is critical to understand the role of smart municipality projects and their particular requirements and challenges. Therefore, this research proposes the SMPAM as a platform to connect smart municipality projects and their potential effects in specific challenges.

The following are the significant innovative highlights of the proposed tool:

- Working with smart municipal projects serves as the foundation for implementing smart municipal proposals. The matrix provides a classification of projects that various experts have confirmed. The proposal is also adaptable; technological advancements are rapid so that new smart municipality project actions may be added to the SMPAM in the future.
- To suggest a tool for prioritizing assessments for a specific municipality. The SMPAM can be

customized to any municipality by identifying the most challenging issues associated and determining the potential of various project actions to address them. To develop a multi-scalar prioritization tool that can be used with different scales to extract general guidelines, analyze strategies, or assess smart municipality projects.

RECOMMENDATIONS

Recommendation (1): Projects classification and selection process

- The application of matrix, indicators, and measurements for the smart project to a selected group of projects in detail.
- Preparing a comprehensive list of the projects includes fundamental indicators such as population, history, number of industries, number of academic institutions, size of roads, and any other matters.This study will help select a subset of suitable projects to start the process of smart transformation.
- Determine the resources that can be secured for each organization if decided to start planning for the smart transformation process.

Recommendation(2):Studies of the current situation

Studying and evaluating the status of the municipality can be prepared in two successive stages:

- A general municipality survey to assess the approved development policies and strategies related to the six essential pillars of a smart municipality: the economy, government, mobility, environment, people, and living.
- Identify areas in which smart applications can be developed within the frameworkof the smart municipality transformation.

Recommendation(3):Incremental development

- Forming a stakeholder working group to participate in decision-making on defining the sectors to be studied to determine the necessary processes, data, and infrastructure and identify the needs assessment components for potential work in the program before implementing the smart transformation.
- Preparing a pure investigation into the possibility of gradual development: This is accomplished by identifying vertical elements and processes that can b etransformed into smart municipality components, such as smart services, optimal transportation policies, and strengthening and preparing infrastructure for the environment, energy, and other services.

Recommendation(4): SmartAward

In India, an annual competition is held in which different cities from India participate in obtaining the Smart Project Award.

Suppose this idea is applied at the private and public sectors in Jordan. In that case, it will increase competitiveness among the participating and facilitate the dissemination of the concept of smart projects.

FUTURE STUDY

Two new study areas were identified for further investigation: Incorporated the SPAM as a complete smart project assessment method, converting it into a synthesis matrix that provides numerical values. This method can provide a holistic index, making it easier to compare different projects.

The other area of study is the application of the roadmap to Jordanian projects. The SPAM can analyze and provide a broad overview of the projects included in a smart strategic plan.

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"SOLAR PASSIVE HEATING STRATEGIES PERFORMANCE AND MANAGEMENT INVESTIGATION OF JORDAN LOW-MIDDLE INCOME HOUSES"

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Abstract
Pressure and depletion, scarcity, and high costs of non-renewable resources in Jordan and the world in general called searching for the use of environmentally and friendly alternative renewable energy resources.

The most important concern for Jordanian families with low- middle income in the winter season is the availability of a source of heating; this is because of its high cost. However, the relentless in the field of alternative energy research helped to reach the best results, especially in regions that were classified with the highest wavelength during the winter season. Jordan in one of these regions where most of its areas are characterized by availability of sunny days in most of seasons, and for a long period of the day. Karak city, in the southern region of Jordan, is one of Jordanian cities that is exposed to sunny days throughout most of season, and hence the investment in alternative energy is very effective.

In this research, a model was designed for a house whose southern façade contains a Trombe Wall system. The system consist of layers that allow the exploitation of the solar irradiation that reaches the two-layer glass and open from the top and bottom in the inner layer to accelerate the heating of the air, which in turn gains the concrete wall the heat that is transmitted through the wall and stored for heating the house. Two methods were used to analyze the Trombe Wall system. The first is the Numerical method, where the wall gain is equivalent to 5.55◦C at the outer layer in the first time step, which means that the wall works well. The second method is using the software (Ansys), where the data were entered to the program and a simulation was made, as the system recorded, after two days, the maximum of temperature was 83̊c and the maximum amount of energy gained was equivalent to 18,000W. This system saves 69% of the energy used for heating.
Keywords: passive heating, solar energy, saving energy, Trombe wall, Karak.

1. General Framework

Introduction:

Correlations between population growth and energy efficiency in the housing sector in the Middle East region indicate that planned future developments and interventions need to be prioritized. (Curado and de Freitas, 2019)

The consequences of overpopulation, rapid urbanization and the growing inequality in wealth between residents in the developing countries like Jordan have brought the issue surrounding the sustainability of low-income housing to the forefront (Bhikhoo et al. 2017)

Importance of Energy Conservation in Jordan

Jordan is a non-oil producing country with very limited natural resources, and a challenging energy situation, thus, the country imports 97% of its needs of primary energy from neighbours (Dar-Mousa and Makhamreh, 2019).

Due to the high cost of fuel, most of the residential buildings in Jordan don't have or use heating systems, and instead have flue-less gas, paraffin heaters, and instant-gas-water heaters installed, these heaters are always fixed inside without exhaust ducts to the outside. (Sulaiman and Beithou, 2011)

Fuel combustion of such heaters generates poor indoor air quality and emits GHGs. GHG emissions produced by domestic stock in Jordan was increased by 59% by 2018 (Ahmad and Subhes, 2016). The same study indicated that around 50% of the households reported different health problems related to asthma which could partially be due to the use of these heating devices. Moreover, the study confirmed that 75% of households lived in apartments are constructed with external envelopes of cement hollow blocks which cause a poor, fabric performance and envelope conditions (Younis et al. 2016).

Research Sample (Al-Karak city)

Al-Karak city was chosen as the study sample due to its varied geography covering approximately 2.850 square km, with an average elevation of about 770 m, the city weather in summer is mild with few hot days, but in winter the temperature often drops below freezing (Gubser, 1973). Generally, the weather al-Karak city in winter makes the city a perfect candidate fora passive solar strategy investigation.

Research Objectives

The current research aims to maximize the effect of using Trombe wall in investing the solar energy in heating systems. Thus, the aim of the research can be formulated through the following objectives:

1. To define the measures of improving thermal performance and minimizing energy use of low-middle income households in Jordan, dealing with climate-conscious, energy-efficient and environmental wise measures at the building level.
2. To investigate and optimize the selection of the Trombe wall materials and its thickness of different external walls configurations' in the heating season in Jordan based on the climatic conditions in Al-Karak,
3. To determine the heat transmission values (U-value) through heat flux management capacity and the resulted temperature difference of the wall external and internal surfaces for a room with a Tombe wall for a range of thermal boundary conditions relevant to Al-Karak climatic conditions.

Research Questions

1. What materials combinations can work best for a Trombe wall in Jordan?
2. How much heat difference can Trombe wall offer between the internal envelope and the external in the weather file of al-Karak climate zone?
3. How much energy bills can Trombe Wall reduce through the year, and which season the households are highly to benefit more from the installation in al-Karak?
4. Can Trombe Wall energy savings outreach the installation cost and energy bills?
5. Is Trombe Wall installation in al-Karak climate zone cost beneficial?

Research Design and Methodology

In the beginning, this project was addressed on both; building and urban levels to justify the choice of the study sample type and size; (based on majority, easiness to model, floor plan, function, etc.) considering the current building regulations in Jordan, in terms of energy use, building materials, and architectural features, then will proceed to optimize the first data sources through literature review.

Furthermore, a comparison of cases studies in Jordan based on laboratory measurement of the construction samples daily thermal changes during the coldest month of the year experiment will be studied and analysed in order to investigate the most successful solutions in the weather of Jordan.

The two main categories of thermal conductivity measurement techniques are steady state methods and transient methods

After choosing the proper assessment method and tool that can provide a reliable evaluation for the used construction systems and materials, a comprehensive analysis was done to relate thermal performance with the social and economic impacts; hence, a more accurate selection may ground not only on thermal and hydrothermal concerns.

The evaluation process is divided into three stages:

In the first stage; the level of performance is measured for each indicator, in the second stage; the researcher grouped the indicators by each category; and in the third stage, the level of efficiency was quantified. This work specifically studied a traditional uninsulated one layer brick houses, with plaster.

The data collected from laboratory measurements was analysed using simulation software and tested in weather chambers for better optimization of the needed result.

To design the required set of changes to the study samples structure and envelope, the used methodology worked in a parallel time frame.

Ansys Software

Ansys is used to determine how a product will function with different specifications, without building test products or conducting crash tests. For example, Ansys software may simulate how a bridge will hold up after years of traffic, or how to design a slide that uses less material without sacrificing safety.

Most Ansys simulations are performed using the Ansys Workbench system, which is one of the company's main products. Typically, Ansys users break down larger structures into small components that are each modeled and tested individually. A user may start by defining the dimensions of an object, and then adding weight, pressure, temperature and other physical properties. Finally, the Ansys software simulates and analyzes movement, fatigue, fractures, fluid flow, temperature distribution, electromagnetic efficiency and other effects over time.

Significance of the Research

There is lack of research in Jordan in the field of materials thermal performance and solar passive strategies. This research is important to fill this gap, help establish a new database for the chosen sample location (Al-Karak), reflect on the issue and address new more sustainable options to the existing dwellings. Furthermore, this project works in the form of a retrofit intervention, rather than a design project from the start, which may help many people retrofit their existing houses rather than rebuild it.

2. Theoretical Background

This section includes review of energy management, and passive solar heating system.

Jordan's Need for Renewal Energy

The nature of Jordanian climate is very appropriate to use an alternative energy, since the summer lasts for long periods, and in winter there is sunshine during most days of the season. Thus, this energy can be stored in special batteries to store energy. According to Ali and Alzu'bi (2017), winter is proportional to the use of alternative energy, where solar cells generate energy and store them in storage batteries. This litt le average of energy stored in winter for 2-3 hours per day is sufficient to illuminate the road at night (Bhikhoo et al., 2017).

The growth of population and economics in Jordan leads to a continuous rise in demand for energy and electricity; where the energy demand witnessed a growth of 4%, and the demand for electric energy increased by more than 7% (Sada et al., 2015). This significant change in energy demand in Jordan called three energy-related organizations: The Royal Commission for Energy, the Minis try of Energy, and Mineral Resources to prepare national strategy, because they believed that it is necessary to expand the market share of renewable energy, which currently does not exceed 9% in Jordan (Al-Qinna et al., 2018).

One of the most important motives for developing alternative energy sources is that they become more available and their costs are sometimes competitive with the costs of oil extraction. For Jordan, renewable energy is not only an alternative energy, but an energy that is able to drive economic growth forward (Kaptan, 2019).

2.2 Description of Passive Solar Heating Systems

Passive solar design integrates a combination of building features to reduce or even eliminate the need for mechanical cooling and heating and daytime artificial lighting. According to (Ansari et al. 2013). Designers need to pay particular attention to the sun to minimize heating and cooling needs. The design does not need to be complex, but it does involve knowledge of solar geometry, window technology, and local climate.

Passive solar heating system depends on the building components for collecting, storing, and distributing heat gains. This system does not require mechanical equipment because the heat flow depends on the natural means, such as radiation, convection, and conductance (Shwany, 2018).

According to some studies, such as Chen, Zhang, & Gao, (2016) and Kabeel & Abdelgaied (2016), from the physical view, there are four fundamental approaches for forming different types of passive solar systems, which are: thermal storage walls, direct gain, roof ponds, and convection loops. Whichever a technique used for passive solar heating systems, it can be either direct gain, indirect gain, or isolated gain depending on the way in which energy is collected, stored, and transferred (Lohrasbi, Miry, & Gorji-Bandpy, 2017):

- **Direct gain:**

It is the most popular application of passive solar energy systems. This may be attributed to its simple use and relatively low cost. In this passive solar energy design, the living areas work as solar energy collectors through the use of south-facing windows that allow entry of sunlight directly to the house (Chen et al., 2016). However, direct gain has some disadvantages, for instance it cannot control temperature effectively because of lack of some thermal storage.

- **Thermal Storage Wall (Trombe wall):**

It's known also as Trombe wall. It is constructed from two exterior walls, one is made of concrete or concrete-filled block, and the other is made of glass. Trombe wall is a massive thermal store formed from common building materials, (i.e: concrete, brick) or Phase change materials (PCM). Trombe wall is located in the front of the south and covered by a single or double glass layer (Su, Zhao, Lei & Deng, 2016). It is painted with dark to absorb the sunlight passing through the glass during the day (Abbas & Azat, 2018).

Trombe wall work differently in summers and winters as described below (Sharma & Gupta, 2017):

a) **Trombe walls in summer:**

In summer, the wall is usually shaded using overhang to not receive sunlight directly. In case it is sheltered, it remains cool and its intrinsic qualities absorb heat keeping the rest of the place cooler. The immanent wall materials are responsible for absorption and transfer of the heat gradually. The overhang is used for blocking the summer sun from hitting the Trombe wall.

b) Trombe walls in winter:

In winter, when the sunlight hits the Trombe wall, it gets heat up and then transfers the heat inside the house to warm it. The thermal mass increases as it absorbs the heat, and then releases it gradually inside the house. Thus, in winter when the temperature of ambient air drops in the night, the thermal mass extend s releasing the stored heat energy to keep the house relatively warm for longer period of time. A fter the thermal mass has just liberated its heat, it will then be ready to gain heat in the next day. Figure (1) shows the Trombe Wall in summer and winter.

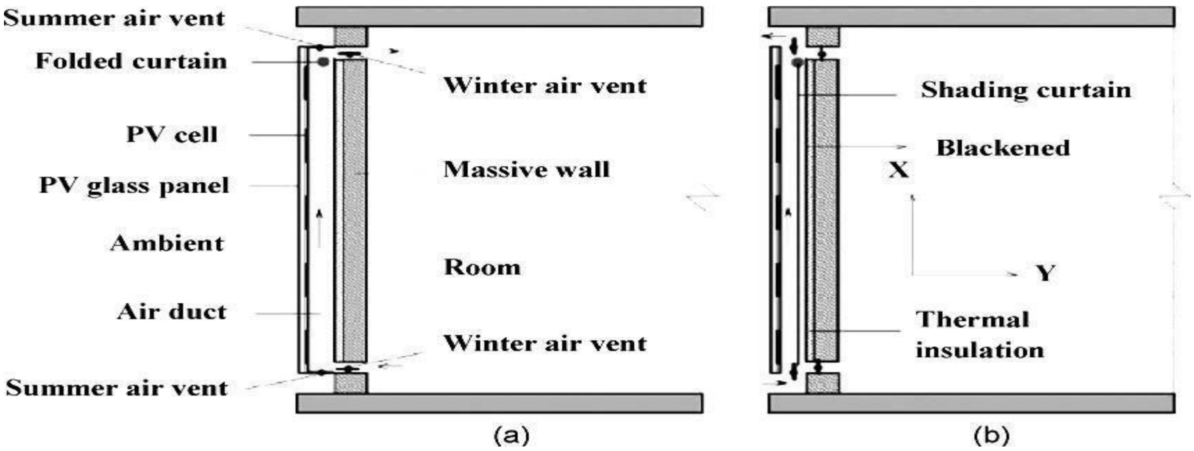


Fig.1: Trombe wall for (a) winter heating and (b) summer cooling (Sharma & Gupta, 2017)

3. Review of literature

Martzopoulou, Vafiadis, & Fragos (2020) improved a simple passive solar system that consisted of plastic sleeves filled with water to increase the energy in greenhouses. To achieve the study aim, three different experiments were conducted for examining the benefit of the solar energy system in the greenhouse during CO2 enrichment at high temperatures. In the first stage with duration of 42 days, there was not passive solar system applied but just thermal capacity was considered. In the second stage in autumn with duration of 39 days, a passive solar system was applied to get benefit from its thermal capacity. The third stage was a replica of the second stage but was conducted in the next spring with duration of 28 days. The temperature variation between the control and the experimental greenhouses without applying passive solar system ranged between 0c◦ to 1.55c◦, whereas it ranged between 0.3c◦ to 2.9c◦ in the second stage during the autumn and 0.75c◦ to 2.1c◦ in the third stage in case of applying the passive solar system. The energy captured by the experimental houses was about (10% to 25%) more than those captured by the control greenhouses during springtime.

A study applied by Abbas & Azat (2018) to investigate the mass flow rate and Rayleigh number on the passive solar using Trombe wall that consisted of (industrial wax) and used as phase change material (PCM). Trombe wall was covered with glass with 6 mm in thickness. An air gap channel with six different widths (10, 15, 20, 25, 30, and 35) was used through six experiments that were conducted during the winter season in Kirkuk city. The study results showed that the mass flow proportionally rate to the channel width and inversely with Rayleigh number. Also, the highest level of efficiency was attained at the depth of 30 cm, which was 2.45 times the efficiency of 10 cm.

Su, Zhao, Lei & Deng (2016) used computational fluid dynamics (CFD) simulation method to numerically simulate air flow rate and heat transfer in a built-in PV-Trombe wall with vertical inlet. When the width of the channel increased, the natural convection of the heat transfer was enhanced and the PV surface was cooled better by the air which reflected on improving slightly the efficiency of PV electricity. The rate of ventilation through the built-in PV-Trombe wall achieved its maximum at an optimal ratio of the channel width to its height (b/H)opt=1/5). Multiple regression analysis proved that there was a significant correlation between averaged Nusselt number, Reynolds number and Rayleigh number.

The study by Vrachopoulos et al. (2015) aimed to present the results of experimental and numerical study for the performance of test PCM chamber for passive solar applications. The numerical section of the study depended on a one dimensional model for the PC problem. The numerical treatment depended on a finite-difference technique, and its results were compared to the literature data and field measurements. The experimental test PCM chamber was applied in the campus of Central Greece University of applied Sciences at Psachna, Evia. GR 27 of Rubitherm was used as PCM in the numerical and experimental tests. The study results showed that the PCM does not work as an insulator but stabilization mean of temperature in the indoor temperature during the PC period. The results showed a good quantitative and qualitative agreement in applying the numerical model for simulating the performance of the experimental PCM chamber.

The current study has got benefit from the literature review of the previous studies through developing its theoretical background, from some methodologies, and from the analysis tools that were used in the previous studies.

The current study is differentiated from the previous studies in the follows:

The current study is differentiated from the previous studies in its aim which is focused in maximizing passive solar energy use, and minimizing energy use of low-middle income households in Jordan, dealing with climate-conscious, energy-efficient and environmental wise measures at the building level. Second; the current study is differentiated in its approach and methodology, where it has been applied practically in residential building that is not concerned with the importance of energy management.

The current study is differentiated in its application place, where it has been applied in Karak city, a city that helped the researcher to apply her study easily because of its climate conditions. Third; what gives the current study to be differentiated from the previous studies that there is not any previous study applied in Jordan in its topic that gave it more support to be as a unique study in energy management domain.

4. Data Analysis and Discussion

The heat load of the building was calculated before modification and after modification by using Trombe wall system, and making comparison between the two cases..

Heating Load Calculation

The building in this study has an area about (137) m^2 as shown in the Figure (2):

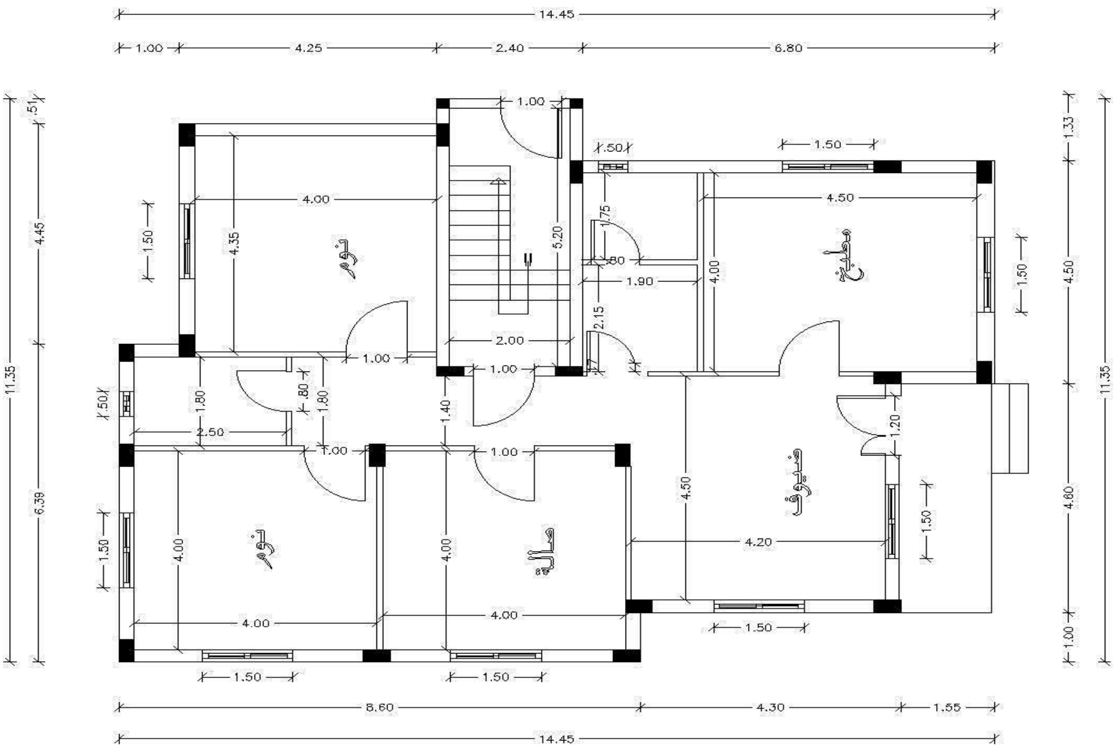


Fig.2: Design Plan for House

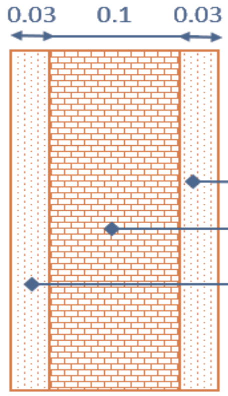
The Area of component of building is shown in Table (1):

Table 1: The Area of Building Component

Type of area	Area(m^2)
Wall	144
Windows	14.12
Doors	4.4
Ceiling	137
Ground	137

Heat Loss through Walls:

Figure (3) Shows details for wall:



Layer	K (W/m.°C)	Thickness (m)
Plaster	1.2	0.03
Hollow Brick	0.9	0.01
Plaster	1.2	0.03

The h

Q_w= U

Where

Q: is

U: is

A: is the area of heat transfer (m^2)

(T_i-T_o): is the difference between the inside and outside temperature

The total resistance can be found given that the heat transfer by the load and conduction takes place respectively. The thermal resistance of the thermal circuit can be obtained by summing the resistances of each one of them as in equation (2) & (3) (Alsaad, 2005):

$Rt = R_p+R_h+R_p$...(2)

$Rt = (\frac{L}{K})_p+(\frac{L}{K})_h+(\frac{L}{K})_p$ .... (3)

$Rt= (\frac{0.03}{1.2})_p+(\frac{0.1}{0.9})_h+(\frac{0.03}{1.2})_p =0.1611$

$U=\frac{1}{R} = \frac{1}{0.1611} =6.21$ W/m² C°

Area of wall=144 m²

Q= 6.21*144*(24-8) =14307.84 W

Heat Loss through Window

In the building type of (A) (single glazing ,clear ,aluminum frame) U for window is (5 w/m²ċ) from Appendix equation(4) (Alsaad, 2005)

$Q_w= UA\ (T_i-T_o)$ ....(4)

A = 14.12m²

Q= 5*14.12*(24-8)=1129.6 W/m²ċ

Heat Loss through Door

Building has two doors metal can be calculate by equation (5).

$Q_d= U_dA_d\ (T_i-T_o)$… ....(5)

U for metal door is (5.8) W/m²ċ

A=4.4m²

Q= 5.8*4.4*(24-8) = 408.32 W/m²ċ

Heat Loss Due to Infiltration

Since the outside temperature is only known the crack method is to be used to calculate heat loss due to infiltration by windows

a. **Heat Loss Due to Infiltration by Windows**

Heat loss due to infiltration by windows is given by equation (6), (7) & (8) (Alsaad, 2005):

$Q_{s,f}= (1250/3600)\ V_f(T_i-T_o)$ .... (6)

$V_f= KL\ (\Delta p)^{2/3}$ .... (7)

$\Delta P=0.613(S_1S_2V.)^2$ ....(8)

$\Delta P= 0.613*(1.1*0.63*6)^2 =10.6$

$V_f= 0.43*(7(2*1.5+2*1.25))+(2(2*0.5+1*2))*(10.6)^{2/3}=717 m^3/s$

Q=(1250/3600)* 92.33*(24-8)=3983 W

a. **Heat Loss Due to Infiltration by Doors**

Infiltration can be calculated by equation (9) & (10):

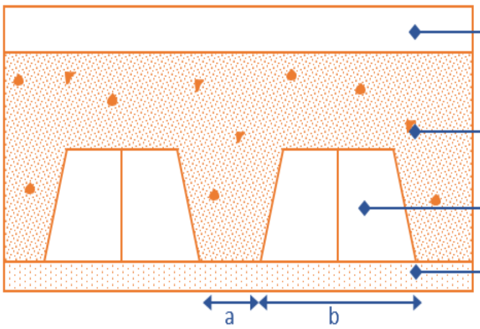
$$Q = \frac{1250}{3600} V_f\ (T_i-T_o)\text{…}..(9)$$

$V_f = KL\ (\Delta P)^{2/3}$ .... (10)
$\Delta P = 0.613(1.1*0.63*6)^{2/3} = 3.5$
$L = [2*1+2*2]+[2*1.2+2*2] = 12.4$ m
$V_f = 0.65*12.4*3.5 = 28.21$ m^3/s

$$Q = \frac{1250}{3600}*28.21*(24-8) = 157 \text{ W}$$

b. Heat Loss through Ceiling

Figure (4) shows the details for ceiling in the house:



Layer	K (W/m.°C)	Thickness (m)
Concrete Morter	1.05	0.06
Reinforced Concrete	0.88	0.06
Cement Block	0.95	0.18
Plaster	1.2	0.02

$R_t = R_i + \left(\frac{L}{K}\right)_p + \left(\frac{L}{K}\right)_r + \left(\frac{L}{K}\right)_c + \left(\frac{L}{K}\right)_m + R_o$ .... (12)

Where R_i and R_o is the inside and outside thermal resistance for the ceiling and obtain from appendices.

$$R_1 = 0.1 + \left(\frac{0.02}{1.2}\right)_p + \left(\frac{0.18}{0.95}\right)_r + \left(\frac{0.06}{0.88}\right)_c + \left(\frac{0.06}{1.05}\right)_m + 0.04 = 0.47$$

$U_1 = 0.62 W/m^2 °c$
$Q_1 = 0.62*109.6*(24-8) = 1087W$
Similarly for the area A2
$U_2 = 0.57 w/m^2 °c$
$Q_2 = 0.57*27.4*(24-8) = 250$ W
The total heat loss through the ceiling is:
$Q_t = Q_1 + Q_2$ .... (13)
Qt= 1087+250 =1337W

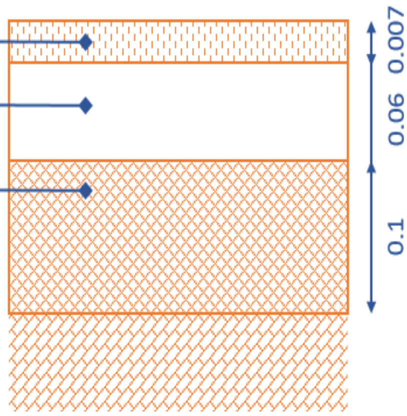
c. Heat Loss through Ground

Figure (5) shows the details for ground in the house.

Fig. 5: Details of Ground

$Q = U*A*(Ti-Tg)$ .... (14)

Layer	K (W/m.°C)	Thickness (m)
Ceramic Tiles	1.1	0.007
Sand	0.2	0.06
Reinforced concrete	0.88	0.1



$R= \left(\frac{0.007}{1.1}\right)_t+\left(\frac{0.06}{0.2}\right)_s+\left(\frac{0.1}{0.88}\right)_c =0.42$

$U= 2.38/m^2\mathring{c}$

$Q=2.38*137*(24-10) =4565W$

Table (2) content the result data calculated for heat load in the house

Inside design conditions T_i: 24

Outside design conditions T_o: 8

Table 2: The Result Data for Heat Load in the House

	Area (m^2)	$U_{ov.}$ ($W/m^2\mathring{c}$)	T_i-T_o ($\mathring{c}$)	Q (W)
Walls	144	6.21	16	14307.84
Ceiling	137	0.62 0.57	16	1087 250
Floor	137	2.38	14	4565
Windows	14.12	5	16	1129.6
Doors	4.4	5.8	16	408.32
Infiltration			16	4140
Total				25888

Calculating the Heated Load through Trombe Wall

Figure (6) below shows the building with Trombe Wall.

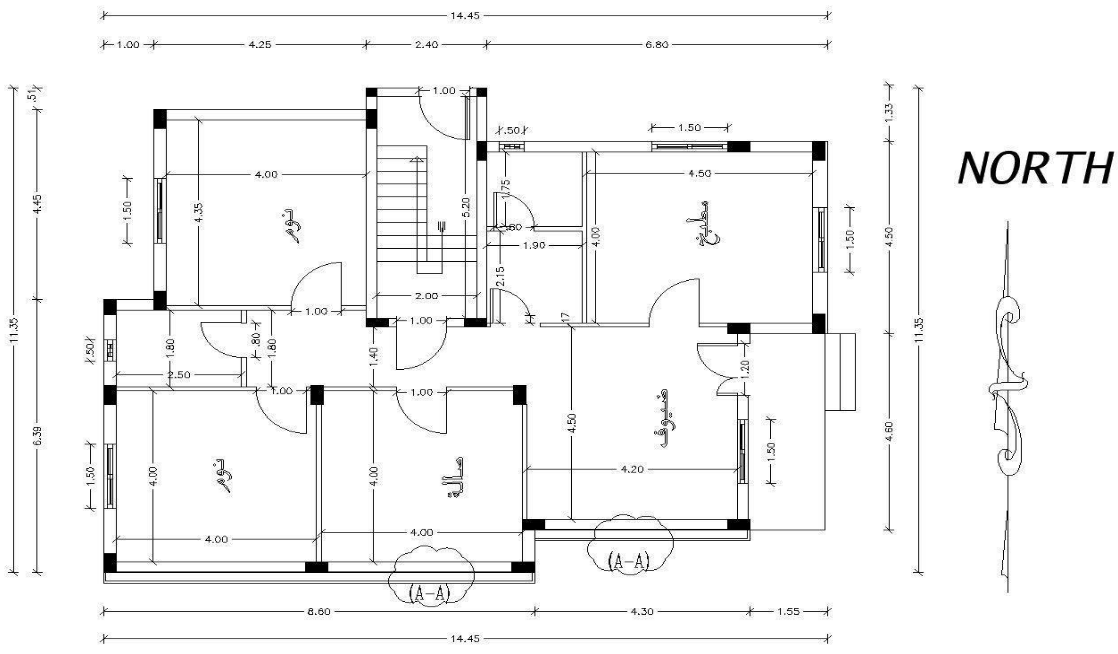
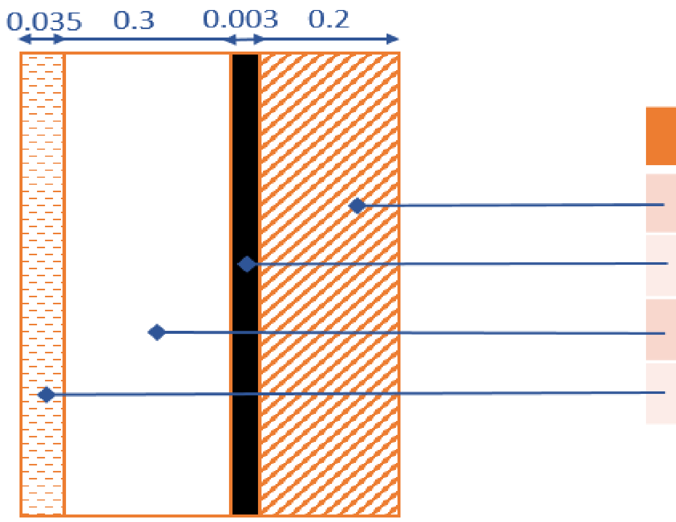


Fig. 6: Building with Trombe Wall

a. Numerical Method

Trombe wall system is used on the southern face, as the area that will be worked on is a small area in relation to the rest of the interfaces, as its area is estimated at 39 m^2 and its initial construction cost is minimal and has an aesthetic on the building. The design for Trombe Wall contains of double glazing window open interior from up and down that increases circulation of air, air gap that includes air that is heated from radiation of sun , layer of black paint that increases the wall temperature, a layer of concrete that transfers and stores heat as show in figure (7) :



Layer	Thickness (m)
Wall	0.2
Black Paint	0.003
Air Gab	0.3
Glass	0.035

Fig.7: Details of Trombe Wall

The thickness of layer concrete is 0.2m, its thermal conductivity is (k=0.69 W/m.c̊), and its thermal diffusivity is (α= 0.75*10^{-6} m^2/s). The variation of the temperature T_{out} and solar heat flux q_{solar} incident on south facing vertical surface throughout the day.

Table 3: The hourly variation of monthly average temperature and irradiation for January in Karak

Time of day	Temperature c̊	Irradiation W/m^2
7AM-10AM	7	150
10AM-1PM	26	622
1PM-4PM	25	509
4PM-7PM	8	65
7PM-10PM	3	0
10PM-1AM	2	0
1AM-4AM	2	0
4AM-7AM	2	0

The absorptivity transmissivity product of κ = 0.71, heat transfer coefficient out hout = 34.1 $W/m^2.k$.
The interior of house is maintained at T=24 c◦ at all time, heat transfer coefficient
h_{in} = 9.26 $W/m^2.k$.

Assuming the temperature to vary between 24 c̊ at the interior and 8 c̊ at the exterior at 7AM .Used the method with a uniform nodal spacing of Δx= 0.05m determines the temperature distribution along the thickness of the Trombe Wall and determines the heat transfer to the wall (Equation 15):

The nodal spacing:

$$M = \frac{L}{\Delta x} + 1 \;\ldots\ldots\; (15)$$

L: thickness the wall concrete m

Δx: spacing between nods

M= 5, we number nodes as 0, 1,2,3,4. Shown in figure (8).

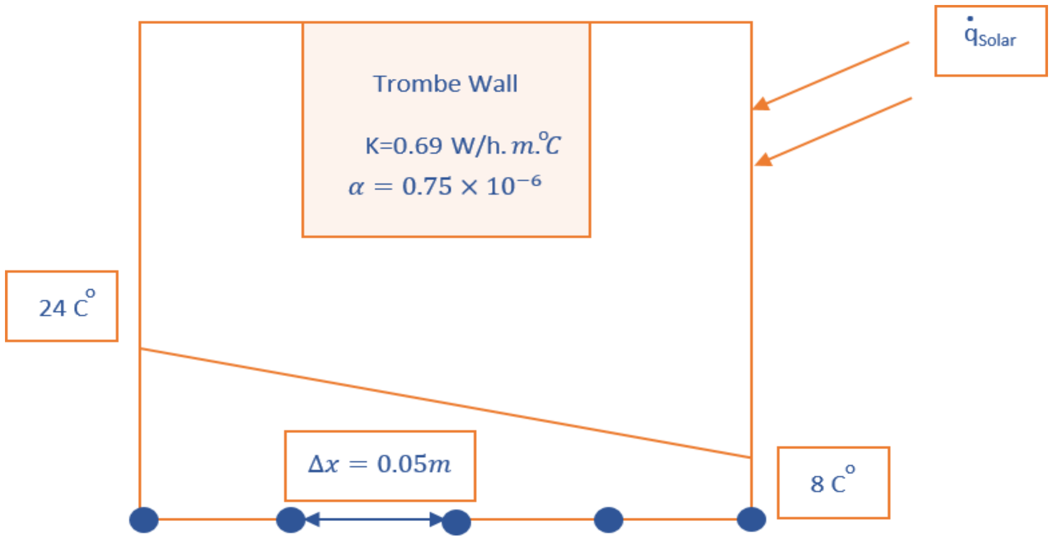


Fig. 8: The nodal network for the Trombe Wall

Equation (16) gives the temperature $T_m i+1$ explicit method (Yunus, 2009).

$$T_m^{i+1} = \tau (T^i_{m-1}+T^i_{m+1}) + (1-2\tau)T^i_m + \tau \frac{g^i_m \Delta x^2}{k} \cdots\cdots (16)$$

T_m^{i+1} new temperature
T^i_{m-1} last temperature
T^i_m surface temperature
g^i_m heat generation
Δx spacing between nods
τ mesh Fourier number
k thermal conductivity

The dimension mesh Fourier number is defined in equation (17) (Yunus, 2009)

$$\tau = \frac{\alpha \Delta t}{\Delta x^2} \ldots\ldots (17)$$

α thermal diffusivity
Δt time step
Δx spacing between nods

Nodes 1 through 3 are interior nodes and the explicit finite difference formulation of these nodes are obtained from Eq.(16) to be (Younis et al., 2009):

Nod 1(m=1): $T_1^{i+1} = \tau (T_0^i + T_2^i) + (1-2\tau)\ T_1^i \cdots\cdots (18)$
Nod 2(m=2): $T_2^{i+1} = \tau (T_1^i + T_3^i) + (1-2\tau)\ T_2^i \cdots\cdots (19)$
Nod 3(m=3): $T_3^{i+1} = \tau (T_2^i + T_4^i) + (1-2\tau)\ T_3^i \cdots\cdots (20)$

The interior surface is convection that can be expressed by the explicit formulation of the node 0 (Yunus, 2009):

$$T_0^{i+1} = (1-2\tau - 2\tau \frac{h_{in}\Delta x}{k})\ T_0^i + 2\tau T_1^i + 2\tau \frac{h_{in}\Delta x}{k} T_{in} \ \ldots\ldots(21)$$

Where:
τ mesh Fourier number
h_{in} heat transfer coefficient inside
k thermal conductivity
T_{in} temperature interior the house
Δx Spacing between nods

Substituting (h_{in},Δx,k,and T_{in})

$$T_0^{i+1} = (1- 3.34)T_0^i + \tau(2T_1^i + 32.2) \ldots\ldots(22)$$

The exterior surface of nod 4 the explicit finite difference formulation of these node is obtained from Eq.(23) simplifies to (Yunus. 2009).

$$T_4^{i+1} = (1-2\tau - 2\tau \frac{h_{out}\Delta x}{k})T_4^i + 2\tau T_3^i + 2\tau \frac{h_{out}\Delta x}{k} T_{out} + 2\tau \frac{\kappa \dot{q}_{solar}\Delta x}{k} \ \ldots.. (23)$$

h_{out} heat transfer coefficient outside
k thermal conductivity
T_{out} temperature exterior the house
Δx spacing between nods
κ absorptivity transmissivity product
$q^{\cdot}_{solar}$ Solar irradiation

Where:

$$\tau = \alpha \frac{\Delta t}{\Delta x^2} \quad (24)$$

Where:
τ the mesh Fourier number
α thermal diffusivity m^2/s
Δt time step s
Δx the nodal spacing m

Substituting (h_{out}, Δx, k and κ) into equation (25) gives:

$$T_4^{i+1} = (1- 6.94\tau)\ T_4^i + \tau(2T_3^i + 4.94T^i_{out} + 0.103q^{\cdot}_{solar} \quad (25)$$

Where the unit $q^{\cdot}_{solar}$ is $w/h.m^2$
In this case is coefficient of T_0^i in the formula of node 0
Since $1 - 3.34\tau < 1 - 6.94\tau$
$1 - 3.34\tau \geq 0$

$$\tau = \alpha \frac{\Delta t}{\Delta x^2} \leq \frac{1}{3.34}$$

The maximum allowable value of the time step is:

$$\Delta t \leq \frac{\Delta x^2}{3.34\alpha}$$

$\Delta t = 998$ s
Any time period can be shorter for example 900s =15min
$\tau = 0.3$ for Δt =15min
Initially at 7 AM or t=0
Temperature change between two nodes on all length is (24-8)/4=4c̊
Therefor the initial nodal temperature is
T_0^0=24C̊ , T_1^0=20 C̊ T_2^0=16 C̊ , T_3^0=12 C̊ , T_4^0=8C̊

Then the nodal temperature at Δt =15min (at 7:15AM) is determined from (1,2,3,4,5) equation to be:

$T_0^1 = (1- 3.34\tau)\ T_0^0 + \tau(2T_1^0 + 32.2) = 21.6$C̊
$T_1^1 = \tau\ (T_0^0 + T_2^0) + (1-2\tau)\ T_1^0 = 20$C̊
$T_2^1 = \tau\ (T_1^0 + T_3^0) + (1-2\tau)\ T_2^0 = 16$C̊
$T_3^1 = \tau\ (T_2^0 + T_4^0) + (1-2\tau)\ T_3^0 = 12$C̊
$T_4^1 = (1- 6.94\tau)\ T_4^0 + \tau\ (2T_3^0 + 4.94\ T_{out} + 0.103q^{\cdot 0}_{solar} = 13.55$C̊
Note that the inner surface temperature of the Trombe wall dropped by 2.4C̊ and the outer surface temperature rose by 5.55C̊ during the first time step.

The amount of heat transfer during the first time step (i=1) or during the first 15 min period is (Yunus, 2009):

$$Q^1_{trombewall} = h_{in}A[(T_0^1 + T_0^0)/2 - T_{in}]\Delta t \quad (26)$$

Substituting (A, h_{in}, T_0^1, $T_0^0 T_{in}$, Δt)
$Q^1_{trombewall}$= -432501 $kw/m^2.s$
The negative sign so heat loss.
The total amount of heat transfer during the two days is as follows (Yunus, 2009):

$$Q_{trombewall} = \sum^I_{i=1} Q_{trombewall} = \sum^I_{i=1} h_{in}\ A[(T_0^i + T_0^{i-1})/2 - T_{in}]\Delta t \quad (27)$$

Because we don't have reading per 15, therefore we can't complete the calculation. Thus, ansys software was used to find reading for T and $Q_{trombewall}$ during day .

b. Ansys Software:

Thermal properties including temperature, heat capacity, and heat flux were investigated for Trombe Wall painted with black paint material and exposed to direct sun radiation. The study was conducted and solved through transient thermal finite element solver in ANSYS Software, Product Release 2020 R1.

Table (4) shows the thermal material properties of Trombe Wall system parts, and the differences in values. Air Gap and glass are used to isolate wall from outer environment, therefore thermal conductivity was low and specific heat had high value. Black paint has high thermal conductivity in order to absorb and transmit sun irradiation immediately.

Table 4: Thermal Material Properties of Trombe Wall System Parts.

Material	**Thermal Conductivity W/m·°C**	**Density kg/m³**	**Specific Heat J/kg·°C**
Trombe wall (Brick)	0.69	2350	840
Black paint	200	710	30
Air Gap	0.02	1.16	1007
Glass	0.03125	11.6	840

Isometric view and dimension of Trombe Wall system parts is presented in Figure (9)

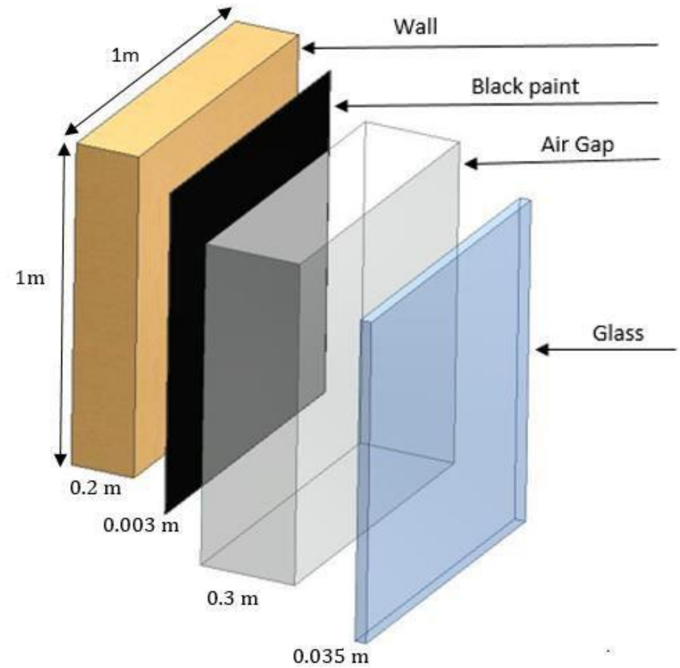


Fig.9: ISO View of Trombe Wall System Parts

Finite elemenst were used to solve the problem as shown in Figure (10). Each part was divided and meshed into certain number of elements, the type of element used is thermal element ,total numeber of nodes are 11280 and 1980 elemnts.

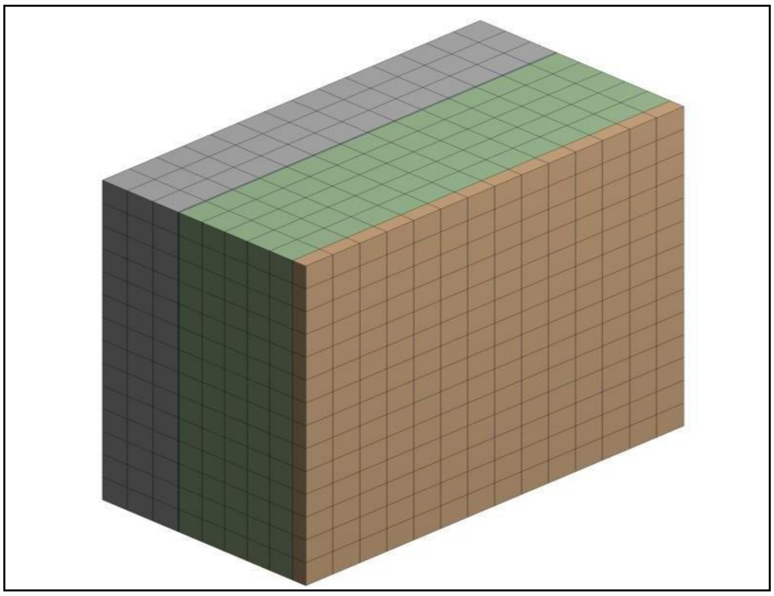


Fig.10: Finite Element Mesh of Trombe Wall System Parts

After entering the data and running the model, the program starts with giving results for temperatures at each point over a period of two days and also gives results for load heat flux during the two days. The program can give results for any second during the two days.

The highest temperature reading was recorded on the second day, which is approximately 83c◦. It was also recorded that the highest thermal radiation reading is 18,000 w.

The change in heat flux recived from sun starts at 7 Am and continues for 48 hours. It can be noticed that these values are used as input heat flux to Trombe Wall .

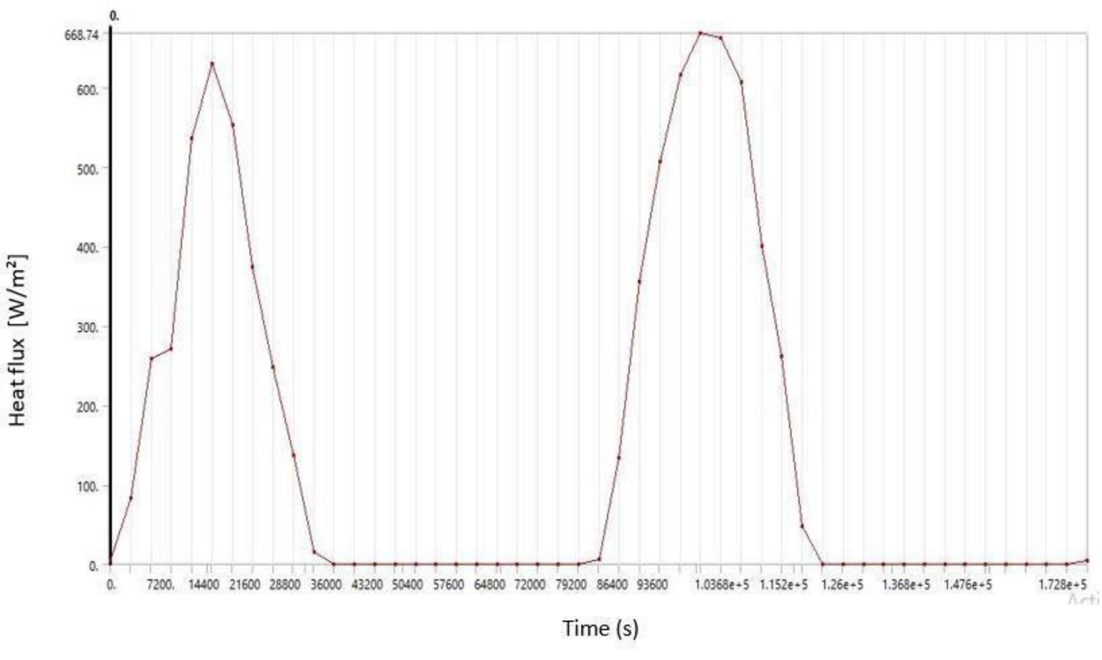


Fig.11: Input Heat Flux through 48 Hours

It has been noticed through Figure (11) that the heat flux is highest in the middle of the day and that means the heat flux increases when the sun is vertical in the middle of the day. This is because the amount of solar irradiation that reaches its highest is in the middle of the day.

Figures (12) and (13) show maximum values of temperature (83̊c) and heat flux (452) w/m^2 each 1m^2 distribution during 48 hours for only Trombe Wall. Also figures (14) and (15) below show maximum values of temperature and heat flux contour respectively for Black Paint, Air Gap and Glass during 48 hours.

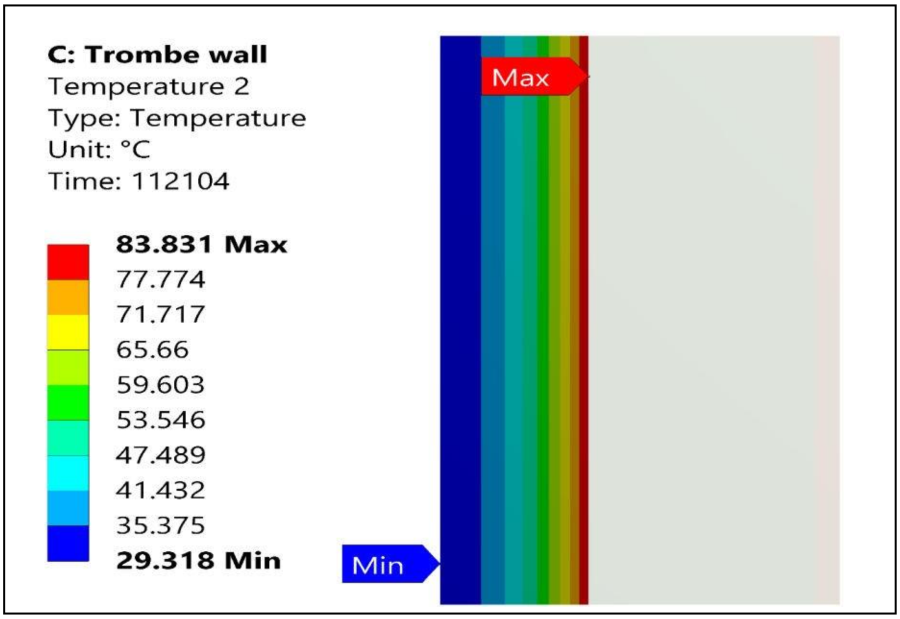


Fig. 12: Maximum of temperature contour values for Trombe Wall during 48 hours

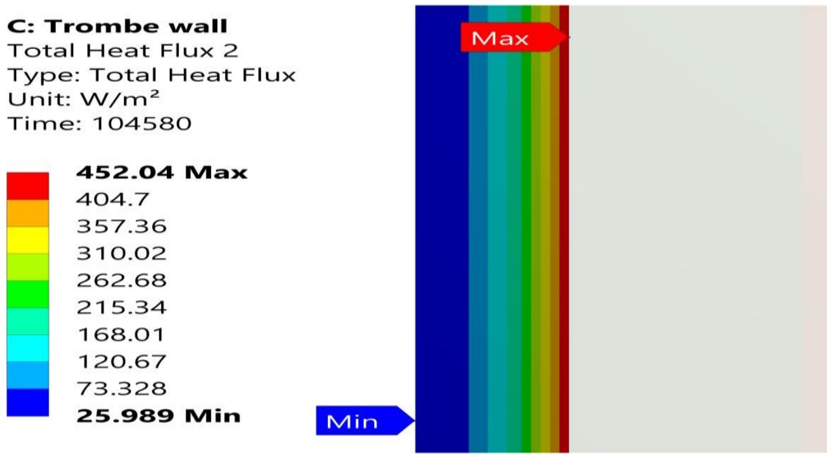


Fig. 13: Max Heat Flux Contour Values for Trombe Wall During 48hours.

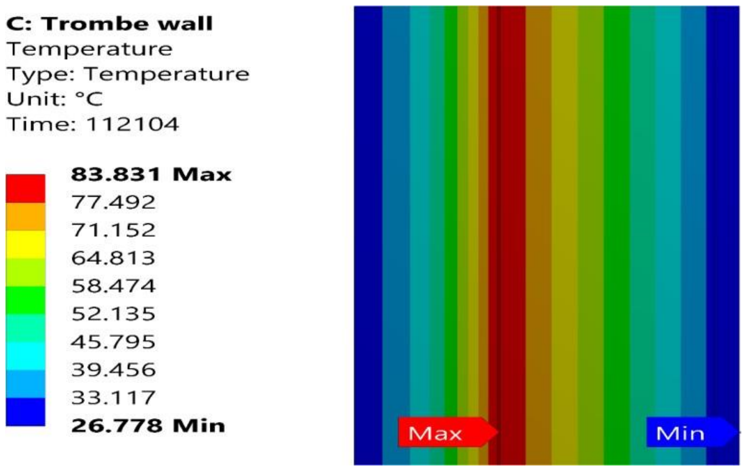


Fig.14: Max temperature contour values for Black Paint, Air Gapand Glass during 4

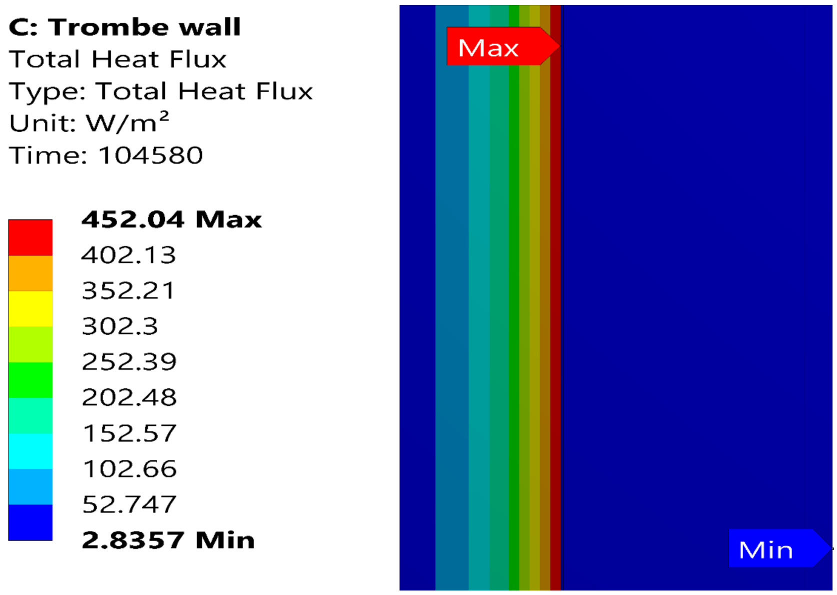


Fig. 15: Max Heat Flux Contour values For Black Paint, Air Gap and Glass during 48 Hours

The maximum temperature on the surface of the Trombe Wall in the outside is 83c◦. This means that the amount of heat gained by the wall is high. This is attributed to that as solar irradiation falls on the glass and heats the Air Gap; the black paint absorbs heat which transfers to the wall concrete so that the heat gained is cumulative during the day. Heat is transferred through the concrete wall to reach the interior surface of the wall. The maximum heat flux on the surface Trombe wall in the outside is 452 w/m^2. This means that the Trombe wall is gaining 18000w/m^2 because its area (39m^2). The interior temperature on the surface is 29◦C. This is enough to keep the room temperature moderate after the sunset and during the night. Area of Trombe Wall is 39 m^2, and its ratio is 10% of house area.

The house loses heat of 25888w from all area but the Trombe Wall gains heat of 18000w. Saving energy ratio through this area is 69%, which constitutes 10% of the area of the house.

Table (5) represents temperature values at measuring points on Trombe Wall every 1 hour.

Table 5: Temperature Values at Measuring Points on Trombe Wall Every 1Hour.

Time h	T1 [°C]	T2 [°C]	T3 [°C]	T4 [°C]	T5 [°C]
0.01AM	24	24	24	23.998	24.011
7AM	24.001	24.005	24.04	24.312	26.865
8AM	24.014	24.069	24.405	26.103	34.838
9AM	24.089	24.341	25.497	29.636	40.359
10AM	24.313	24.961	27.239	33.658	52.842
11AM	24.752	26.004	29.9	40.291	64.63
12AM	25.466	27.591	33.42	46.65	69.456
1PM	26.482	29.602	36.899	50.437	66.804
2PM	27.683	31.674	39.484	51.192	61.603
3PM	28.858	33.436	40.93	50.163	55.392
4PM	29.821	34.686	41.351	47.843	47.857
5PM	30.474	35.354	40.882	44.708	42.83
6PM	30.789	35.478	39.893	42.089	39.847
7PM	30.807	35.207	38.76	40.039	37.778
8PM	30.616	34.703	37.635	38.38	36.197
9PM	30.302	34.08	36.565	36.991	34.923

10PM	29.925	33.409	35.562	35.797	33.859
11PM	29.525	32.733	34.63	34.749	32.944
Time h	T1 [°C]	T2 [°C]	T3 [°C]	T4 [°C]	T5 [°C]
12PM	29.125	32.074	33.767	33.816	32.141
1AM	28.736	31.447	32.97	32.978	31.427
2AM	28.367	30.857	32.236	32.218	30.787
3AM	28.02	30.306	31.559	31.528	30.208
4AM	27.697	29.795	30.937	30.898	29.679
5AM	27.397	29.323	30.365	30.321	29.195
6AM	27.12	28.887	29.841	29.811	28.941
7AM	26.866	28.496	29.436	29.861	33.096
8AM	26.652	28.23	29.563	32.104	43.467
9AM	26.553	28.305	30.779	36.996	55.151
19AM	26.695	28.942	33.15	43.109	66.205
11AM	27.178	30.203	36.363	49.556	75.259
12AM	28.015	32.005	40.015	55.471	81.307
1PM	29.144	34.168	43.672	60.184	83.94
2PM	30.448	36.455	46.883	62.862	79.276
3PM	31.779	38.569	49.048	62.439	72.207
4PM	32.965	40.209	49.913	59.915	61.121
5PM	33.819	41.146	49.439	55.51	52.956
6PM	34.259	41.342	48.058	51.522	48.202
7PM	34.289	40.955	46.378	48.391	45.01
8PM	34.012	40.21	44.686	45.865	42.59
9PM	33.545	39.278	43.07	43.753	40.65
10PM	32.982	38.271	41.555	41.941	39.035
11PM	32.381	37.252	40.147	40.355	37.652
12PM	31.778	36.259	38.843	38.944	36.439
1AM	31.192	35.312	37.639	37.677	35.359
2AM	30.634	34.421	36.529	36.529	34.387
3AM	30.11	33.589	35.507	35.483	33.507
4AM	29.622	32.817	34.567	34.529	32.706
5AM	29.169	32.102	33.701	33.656	31.974
6AM	28.754	31.45	32.915	32.879	31.468

We notice that the temperature increases with time during the day, but after the sun sets, it begins to decrease gradually, and it does not decrease to significant degree. The wall stores the temperature it has gained during the day and at night after the room temperature drops, the heat stored in the wall flows into the room. During the next day, temperature rises from a higher degree than the previous day.

Figure (16) shows the relationship between changes in temperatures at measuring points through time.

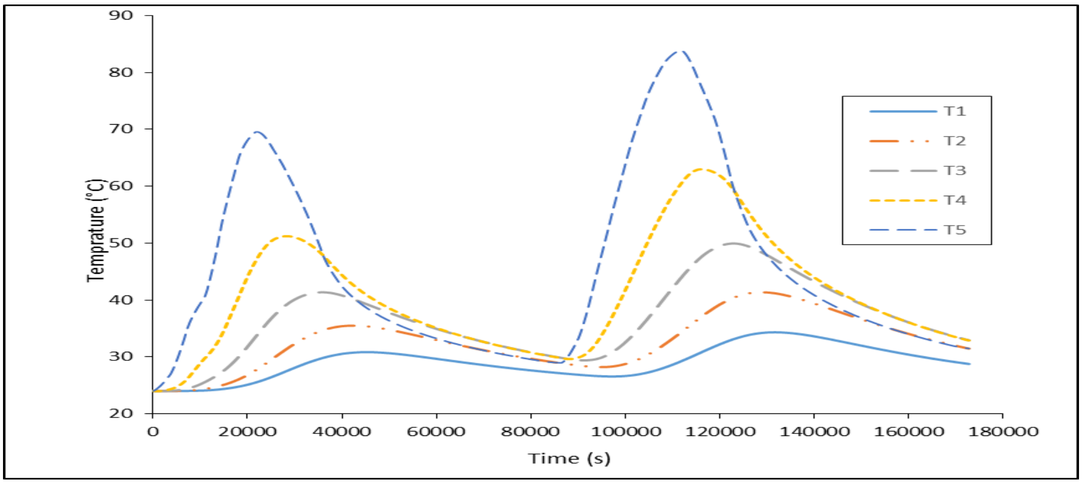


Fig.16: Change in temperatures at measuring points through time

Table (6) represents heat transfer values at measuring points on every 1 hour. Maximum heat transfer as shown in figure (17) was recorded at the measuring point (q5) on the outside surface of the Trombe Wall. The value is near to (18000 W), and happened at the middle of second day.

Table 6: Heat Transfer Values at Measuring Points on Trombe Wall Every 1 Hour.

Time [h]	**q1(w)**	**q2(w)**	**q3(w)**	**q4(w)**	**q5(w)**
0.01	0.25	0.41	1.84	1.77	16.72
7AM	1.89	6.53	13.13	591.12	2261.45
8AM	12.14	23.65	365.72	2343.82	7287.54
9AM	16.59	231.64	1335.75	3720.05	7808.97
10AM	33.57	594.52	2056.67	6191.64	14771.64
11AM	151.41	1105.22	3634.45	8760.57	17504.37
12AM	371.62	1870.48	5080.92	9547.98	14817.66
Time [h]	q1(w)	q2(w)	q3(w)	q4(w)	q5(w)
1PM	739.52	2647.63	5711.94	8346.39	8964.54
2PM	1212.24	3159.86	5386.29	6379.23	4626.57
3PM	1687.65	3327.44	4651.92	4353.96	1125.93
4PM	2082.33	3243.16	3714.24	2253.97	2379.16
5PM	2358.17	2967.82	2613.74	832.73	2838.38
6PM	2495.88	2592.21	1835.96	154.01	2526.69
7PM	2509.46	2246.67	1337.04	171.12	2229.47
8PM	2440.39	1966.89	1014.23	333.26	1991.22
9PM	2324.48	1743.73	800.59	410.67	1795.83
10PM	2185.52	1562.07	654.93	440.74	1629.81
11PM	2037.87	1410.05	552.08	444.09	1486.52
12PM	1889.98	1279.55	476.23	432.74	1360.01
1AM	1746.69	1165.28	418.00	413.21	1246.32
2AM	1610.47	1063.73	371.52	389.59	1143.01
3AM	1482.55	972.54	333.25	364.44	1049.61
4AM	1363.32	890.10	300.69	339.71	965.95
5AM	1252.72	815.10	272.13	316.08	889.43
6AM	1150.38	746.19	247.24	254.95	668.85
7AM	1052.73	676.49	257.26	709.61	2948.17
8AM	951.60	675.36	805.74	3121.17	9400.17
9AM	867.48	919.07	2105.22	5905.38	13799.37
19AM	866.85	1459.54	3600.25	8314.80	16629.21
11AM	1003.00	2183.81	5049.33	10044.84	17615.52
12AM	1285.09	2973.83	6226.74	10895.04	16831.23

1PM	1692.02	3718.18	6987.24	10834.59	14596.92
2PM	2183.61	4336.02	7259.85	9148.62	8195.46
3PM	2710.50	4694.04	6594.51	6762.60	3549.43
4PM	3198.35	4714.71	5562.96	3749.15	2719.90
5PM	3566.00	4428.45	4024.41	1445.85	4214.73
6PM	3766.19	3923.01	2827.81	305.03	3820.75
7PM	3791.74	3414.33	2057.99	221.60	3368.86
8PM	3692.44	2991.65	1559.96	480.32	3006.71
9PM	3520.76	2652.43	1230.72	603.14	2708.08
10PM	3312.78	2376.08	1006.90	650.99	2453.72
11PM	3090.83	2145.16	849.46	656.68	2233.80
12PM	2868.06	1947.31	734.10	639.48	2041.26
1AM	2651.88	1774.34	645.72	610.39	1870.36
2AM	2446.28	1620.76	575.09	575.76	1716.86
3AM	2253.11	1482.82	516.59	538.94	1577.08
4AM	2073.01	1357.98	466.79	502.05	1450.02
5AM	1905.93	1244.45	423.35	466.60	1334.81
6AM	1752.82	1141.41	385.46	400.92	1103.62

We notice that the heat transfer increases during the day, but after the sun sets, it begins to decrease gradually, but it does not decrease to significant degree. The wall stores the heat it has gained during the day and at night after the room temperature drops, the heat stored in the wall flows into the room. During the next day, the heat transfer rise from a higher reading than the previous day.

Figure (17). The relationship between changes in heat transfer at measuring points through time

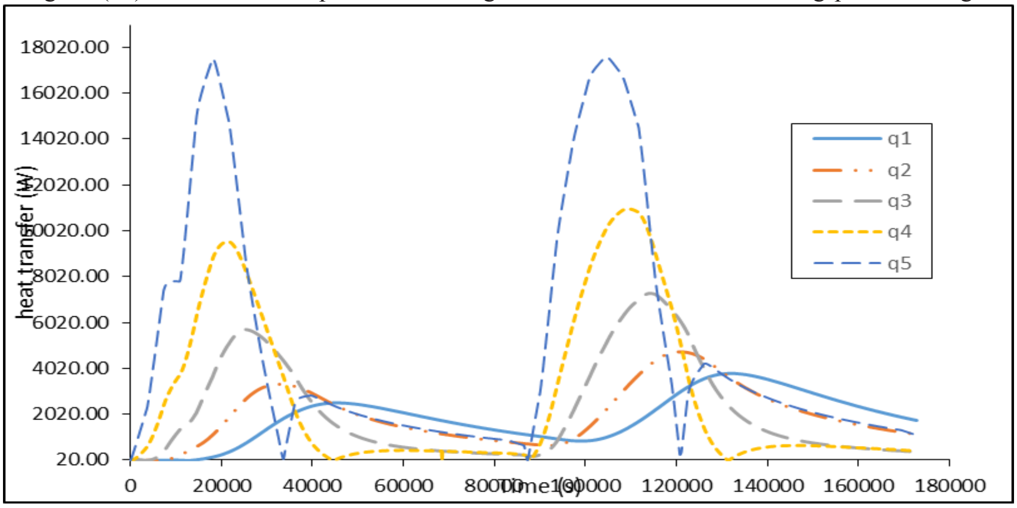


Fig. 17: change in heat transfer at measuring points through time

Saving Energy

The energy saving can be calculated by comparing the calculated heat flux and heat loss values for the home.

$Q_{\text{heat loss}} = 25888W$

$Q_{\text{heat transfer}} = 18000W$

Saving energy % = 18000/25888 =69%

This high percentage contributes to saving 69% of energy for the home through the Trombe wall system.

4.5 Feasibility

This system only has an initial cost.

Table (7) Bill of Quantities for the Trombe Wall system.

Table (7) Bill of Quantities

Description	**Unit**	**Quantity**	**Unite price JD**	**Total price JD**
Double glass with aluminum frame	m^2	39	65	2535
Concrete thickness(20cm)	m^3	8	30	240
Total				2775

Fuel consumption for heating:
The cost of gas in heating during the four winter months (120 days), where every three days a gas cylinder is replaced, and the price of the cylinder is 7 JD.
The cost= (120/3)*7 = 280JD
Using a 2-ton electric air conditioner (120 days) consumes 15 kilowatts per day, 450 kilowatts per month, costs 34 JD/month.
The cost in four months = 34*4=136JD
Total cost =280+136 = 416 JD
Payback period=2775/416 =6.6
There is no operating cost.

5. Conclusion and Recommendation

Conclusion

Trombe Wall system is working well, and through the readings we have obtained

1. The highest temperature outside is 83̊c on the surface Trombe wall and the highest temperature inside is 29̊c on the surface Trombe wall, the heat transfer is 18000W in the Trombe Wall from the outside to inside. This is due to the amount of solar radiation reaching the Trombe wall, because the climatic conditions in Al Karak and winter temperatures are very suitable for that.
2. This system saves the house's temperature in case of disconnection from the sources of heating the house during the winter season, where the Trombe Wall retains energy.
3. The possibility and ease of applying the system to buildings and the possibility of adding the system to pre-built buildings.
   - **a.** This system was applied to the southern façade only, with a rate of 27% of the façade area**.**
   - **b.** Making a lower and upper hole in the inner layer of the glass accelerates the heating of the air Gap.
   - **c.** The saving energy ratio is 69%, which means that the Trombe Wall saves energy for the house. This reduces the use of fuel for heating and reduces carbon emissions.
   - **d.** The payback period is 6.6, and there is no operating cost.

Recommendation:

1 . This system is the first of its kind in Al Karak, and modifications can be added and developed to serve its purpose. The use of the Southern facade is a challenge in changing the culture of the people in exploiting this facade in a different way to what is there. The concrete wall thickness can be adjusted by increasing the thickness to reduce the amount of heat received in high temperature areas.
2. The possibility of providing solutions to reduce the solar radiation reaching the southern façade in the summer season. These solutions can be done by using modern technologies for shading, such as shading the glass or the entire façade through mechanical arms that open in the summer to shade the façade. Using the high heat stored by the wall to heat the house water**.**

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The researcher presents this research to all those who believe in her ques t to build a better future for the passive heating profession in Jordan.

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Nill

Authors Contributions
"Zubayda Riyad Al-Madadha" designed the study; collected the data, involved in interpreting the data, and performed all the statistical analysis and writing the manuscript.

Conflict of Interests
Declared none.

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Appendix (1)

Values of infiltration air coefficient K for windows			
Window type	**Infiltration air coefficient K**		
	Average	**minimum**	**maximum**
Sliding			
Iron	0.36	0.25	0.40
Aluminum	0.43	0.25	0.70
Hung			
Iron	0.25	0.10	0.60
Aluminum (side pivoted)	0.36	0.07	0.70
Aluminum (horizontal pivoted)	0.30	0.07	0.5
PVC	0.10	0.03	0.15

Appendix (2)

Value of the factor S_1		
No.	Topography of location	value of S_1
1	Protected locations by hills or building (wind speed = 0.5 m/s)	0.9
2	Unprotected locations such as sea shores, hill tops, etc.	1.1
3	Locations other than that listed in item (1) or (2) of this table	1.0

Appendix (3)

Outside film resistance R_0				
Wind speed / **Element**	**material Type**	**Less than 0.5 m/s**	**0.5 – 5.0 m/s**	**more than 5.0 m/s**
		Outside Resistance R_0, m2 .c/W		
Walls	Construction materials	0.08	0.06	0.03
	Metal	0.10	0.07	0.03
Ceilings	Construction materials	0.07	0.04	0.02
	Metal	0.09	0.05	0.02
Exposed floors	Construction materials	0.09	-	-

Appendix (4)

Inside film resistance R_i			
Element	**heat direction**	**material type Ri (m^2./W)**	
Walls	Horizontal	Construction materials	0.12
		Metals	0.31
Ceiling and Floors	Upward	Construction materials	0.10
		Metals	0.21
	Downward	construction materials	0.15

Appendix (5)

Overall Heat Transfer Coefficient for Windows, W/m^2.c						
	Wind speed, m/s					
Material type and frames	**Single Glass**			**Double Glass, 6 mm air gap**		
	< 0.5	**0.5 – 5.0**	**>5.0**	**< 0.5**	**0.5 – 5.0**	**>5.0**
Wood	3.8	4.3	5.0	2.3	2.5	2.7
Aluminum	5.0	5.6	6.7	3.0	3.2	3.5
Steel	5.0	5.6	6.7	3.0	3.2	3.5
PVC	3.8	4.3	5.0	2.3	2.5	2.7

Appendix (6)

values of the factor S2

location class	class 1			class 2			class 3			class 4		
building height, m	A	B	C	A	B	C	A	B	C	A	B	C
3	0.47	0.52	0.56	0.55	0.60	0.64	0.63	0.67	0.72	0.73	0.78	0.83
5	0.50	0.55	0.60	0.60	0.65	070	0.70	0.74	0.79	0.78	0.83	0.88
10	0.58	0.62	0.67	0.60	0.65	0.78	0.83	0.88	1.00	0.90	0.95	1.00
15	0.64	0.69	0.74	0.78	0.83	0.88	0.91	0.95	1.00	0.94	0.99	1.03
20	0.70	0.75	0.74	0.85	0.90	0.95	0.94	0.98	1.03	0.96	1.01	1.06
30	0.79	0.85	0.90	0.92	0.97	1.01	0.98	1.03	1.07	1.00	1.01	1.06
40	0.89	0.93	0.97	0.95	1.00	1.01	1.01	1.06	1.03	1.00	1.05	1.09
50	0.94	0.98	1.02	1.00	1.04	1.08	1.04	1.08	1.12	1.06	1.10	1.14
60	0.98	1.02	1.05	1.02	1.06	1.10	1.06	1.10	1.14	1.08	1.12	1.15
80	1.03	1.07	1.10	1.06	1.10	1.13	1.09	1.13	1.17	1.11	1.15	1.18
100	1.07	1.13	1.15	1.09	1.12	1.16	1.12	1.16	1.19	1.13	1.17	1.20
120	1.11	1.13	1.15	1.11	1.15	1.18	1.14	1.18	1.21	1.15	1.19	1.22
140	1.12	1.15	1.17	1.13	1.17	1.12	1.16	1.19	1.22	1.17	1.20	1.24
160	1.14	1.17	1.19	1.15	1.18	1.12	1.18	1.21	1.24	1.19	1.22	1.25
180	1.16	1.19	1.20	1.15	1.18	1.23	1.19	1.22	1.25	1.20	1.23	1.26
200	1.18	1.21	1.22	1.18	1.21	1.24	1.21	1.24	1.26	1.21	1.24	1.27

SHEAR RESISTANCE OF UHPC GIRDERS:EXPERIMENTAL DATABASE EVALUATION OF THE FHWA-HRT-23-077

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Abstract: The study presents a comprehensive evaluation of the shear model adopted by the FHWA-HRT-23-077 for Ultra-High Performance Concrete bridge girders. The evaluation is based on a statistical analysis of a surveyed experimental database that includes 198 UHPC girders tested in shear. As the FHWA method requires the localization strength f_{tloc} of the concrete as an input, an equation to predict the f_{tloc} was developed based on the concrete compressive strength and the fiber's characteristic ratio. The results showed that increasing the localization strain $\varepsilon_{t,loc}$ results in less conservative estimates. At $\varepsilon_{t,loc}$ of 0.004, the statistical analysis showed an average value for V_{exp}/V_{pred} of 1.18, and a CoV of 24.2 %, with 144 out of 198 tests showing ratios $V_{exp}/V_{pred} \geq 1.0$.

Keywords: Ultra-High Performance concrete (UHPC); Modified compression-field theory (MCFT); FHWA; Shear capacity; Shear design model.

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1. Introduction

Ultra-high-performance concrete (UHPC) is a class of materials with a dense cementitious matrix and steel fibers known for its distinct mechanical and durability properties, including post-cracking tensile strength of at least 5 MPa [1], high compressive strength; around 150 MPa, ductility, energy absorption, and exceptional crack control [2]. Additionally, UHPC can be designed to have strain-hardening behavior in tension [3]. Such properties make UHPC an attractive material for several structural applications and offer reduced member dimensions, less reliance on steel reinforcement, reduced load demand, and consequently less cost [4]. Studies show bridge girders with web thicknesses of 50-80 mm, depending on reinforcement, cover, and microfiber size. [5]. Despite the widespread interest in using UHPC in bridge superstructures, the usage of UHPC has been limited to small-scale applications due to the lack of structural design models verified with large-scale experimental tests, specifically, the shear resistance. Over the past two decades, several researchers have focused on evaluating the shear response of UHPC throughout experimental testing [6-17]. Although the testing programs in the literature revealed the key aspects of the behavior of UHPC girders, they did not provide sufficient information to correlate the shear response of these girders with respect to the tensile behavior of UHPC, particularly its strain-hardening behavior in tension. To address this, the Federal Highway Administration (FHWA), in coordination with the AASHTO Committee on Bridges and Structures, developed UHPC structural design guidance. FHWA has published research on UHPC's material properties, structural behavior, prestressing losses, and tension testing. In October 2023, FHWA released the FHWA-HRT-23-077 [18] "Structural Design with Ultra-High-Performance Concrete "to aid in developing formal UHPC design provisions, including shear design. This guidance informed the AASHTO "Guide Specifications for Structural Design with Ultra-High Performance Concrete", 1st Edition, released in March 2024[1].

This study presents a detailed statistical evaluation of the shear design procedure for the FHWA-HRT-23-077 report [18] (referred to as FHWA method). The evaluation is conducted using a compiled extensive database of experimentally tested UHPC beams under shear. The database encloses 198 specimens that include prestressed and non-prestressed specimens, specimens with and without shear reinforcement, different cross-sectional shapes and dimensions, and a wide range of variables.

2. Shear Resistance According To FHWA-HRT-23-077

The shear resistance framework in the FHWA-HRT-23-077 [18] was derived from the El-Helou and Graybeal study [19]. The nominal shear resistance of a member (V_n) is given in Eq.1 as the sum of the contributions of UHPC strength (V_{UHPC}) in Eq. 2, shear reinforcement (V_s) in Eq. 3, and the vertical component of prestressing force resisting vertical shear (V_p). An upper limit on (V_n) is given in Eq. 4 to capture the failure mode in which the UHPC in the web of the girder crushes prior to, or at the development of, the critical crack [18].

$$V_n = V_{UHPC} + V_s + V_p \tag{1}$$

$$V_{UHPC} = \gamma_u f_{t,loc} b_v d_v cot\theta \tag{2}$$

$$V_S = \frac{A_v f_{v,\alpha} d_v cot\theta}{s} \tag{3}$$

$$V_n = 0.25 f'_c b_v d_v + V_p \tag{4}$$

where γ_u is a reduction factor to account for the variability of tensile stresses carried by UHPC (shall not be taken greater than 1.0), $f_{t,loc}$ is the localization tensile strength (MPa), b_v is the effective web width (mm), d_v is the depth of a component effective in resisting shear forces (mm), $f_{v,\alpha}$ = uniaxial stress in the transverse steel reinforcement at nominal shear resistance (MPa), it shall not be greater than the specified minimum yield strength of transverse steel reinforcement, A_v = area of transverse reinforcement to resist shear (mm^2), α = angle of inclination of transverse reinforcement to longitudinal axis (degree), θ is the angle of inclination of diagonal compressive stresses (degree), and s is the spacing of transverse reinforcement measured in a direction parallel to the longitudinal reinforcement (mm). $\rho_{v\alpha}$ is the transverse reinforcement ratio. The crack angle (θ) and the stress in the transverse shear reinforcement ($f_{v,\alpha}$) at nominal resistance are determined iteratively by solving Eqs. 5-8. This requires obtaining the localization stress and strain ($f_{t,\,loc}$, $\varepsilon_{t,\,loc}$) experimentally based on direct tension testing in accordance with AASHTO T 397 [45]. A minimum value of 0.0025 for the $\varepsilon_{t,\,loc}$ is adopted in the FHWA.

$$\gamma_u \varepsilon_{t,loc} = \frac{\varepsilon_s}{2}(1 + \cot^2\theta) + \frac{2f_{t,loc}}{E_c}\cot^4\theta + \frac{2\rho_{v,\alpha} f_{v,\alpha}}{E_c}\cot^2\theta(1 + \cot^2\theta) \tag{5}$$

$$\varepsilon_2 = -\frac{2f_{t,loc}}{E_c}\cot^2\theta - \frac{2\rho_{v,\alpha} f_{v,\alpha}}{E_c}(1 + \cot^2\theta) \tag{6}$$

$$\varepsilon_v = \gamma_u \varepsilon_{t,loc} - 0.5\varepsilon_s + \varepsilon_2 \tag{7}$$

$$f_{v,\alpha} = \frac{E_c \varepsilon_v}{\sin\alpha} \le f_y \tag{8}$$

The longitudinal strain at the level of reinforcement ε_s in Eqs. 5 and 7 are calculated according to Eq. 9. If the value of ε_s calculated from Eq. 9 is negative or is positive and less than $\varepsilon_{t,cr}$, it should be taken as $\varepsilon_{t,cr}$, or the value should be recalculated according to Eq. 10.

$$\varepsilon_s = \frac{\frac{|M_u|}{d_v}+0.5N_u+|V_u-V_p|-A_{ps}f_{po}-\gamma_u f_{t,loc}A_{ct}}{E_sA_s+E_pA_{ps}} \tag{9}$$

$$\varepsilon_s = \frac{\frac{|M_u|}{d_v}+0.5N_u+|V_u-V_p|-A_{ps}f_{po}}{E_sA_s+E_pA_{ps}+E_cA_{ct}} \tag{10}$$

where $|M_u|$ is the absolute value of the factored moment at the critical section (MPa), N_u is the factored axial force at the design section (kN), taken as positive if tension and negative if compression, V_u is the shear force at the design section (kN), A_{ps}, A_s and A_{ct} are the area of prestressing steel, non-prestressed steel, and UHPC in the flexural tension side of the member (mm^2), respectively. f_{po} is the parameter taken as the modulus of elasticity of prestressing steel multiplied by the locked-in difference in strain between the prestressing steel and surrounding UHPC and can be taken as 0.7 of the ultimate tensile strength of the strands (MPa), E_s and E_p are the moduli of elasticity of non-prestressed and prestressing steel (MPa), respectively. ε_2 is the diagonal compressive strain in the section, and ε_v is the vertical strain in transverse reinforcement at the design section. It should be noted that the elastic modulus of the concrete (E_c) is calculated according to the FHWA report [18].

3. Experimental Database

To evaluate the FHWA-HRT-23-077 shear resistance model, an extensive literature survey compiled an experimental database of UHPC beams tested in shear. Only specimens tested in three-point and four-point loading configurations with shear failure were included, along with those containing steel fiber, as FHWA defines UHPC as a strain-hardening fiber-reinforced concrete. The survey resulted in 198 specimens from 28 experimental programs [3, 5, 7, 9-11, 24-36, 37-44, 50, 51].

Of the 198 surveyed specimens, 101 were prestressed with a straight profile, and 82 had shear reinforcement. Most specimens were I-shaped (72%), rectangular (25%), T-shaped (2%), and box sections (1%) also included. Fig. 1 shows the distribution by reinforcement type, shear reinforcement, and section type. For each specimen in the database, variables collected included sectional dimensions, reported concrete compressive strength, non-prestressed reinforcement, prestressing area and stress, steel fibers volume and aspect ratios, shear reinforcement area and spacing (if provided), shear span-to-depth ratio (a/d), and experimental shear capacity (V_{exp}).

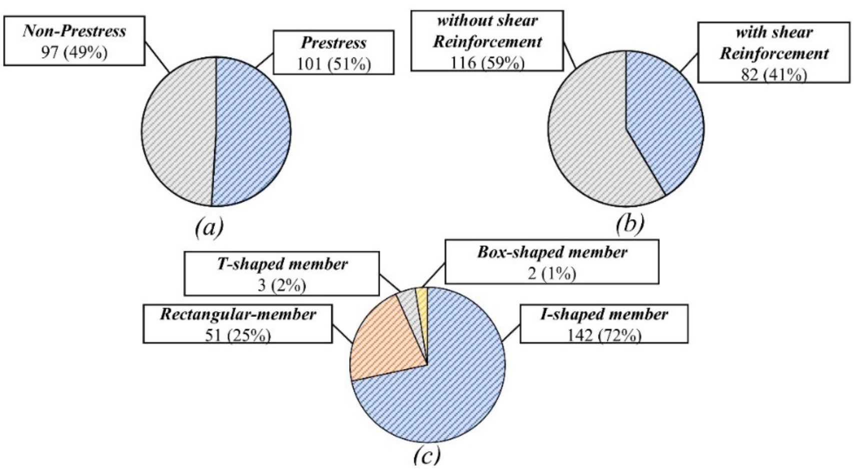

Fig. 1*- Characteristics of database: (a) reinforcement types, (b) shear reinforcement; and (c) cross section type.*

4. Localization Tensile Strength

The FHWA-HRT-23-077 provisions are based on UHPC with strain-hardening behavior, allowing it to resist tensile loads beyond initial cracking [49]. Shear failure in UHPC members occurs when a localized crack forms from closely spaced cracks and propagates through the web as bridging fibers pull out. Shear failure happens when diagonal tensile stresses reach the localization tensile stress ($f_{t,loc}$), defined as the stress at which tensile strength decreases with strain or falls below effective cracking strength (**Fig. 3**). The corresponding strain is the tensile localization strain ($\varepsilon_{t,\,loc}$). **Figure 3** illustrates the expected uniaxial tensile response of UHPC.

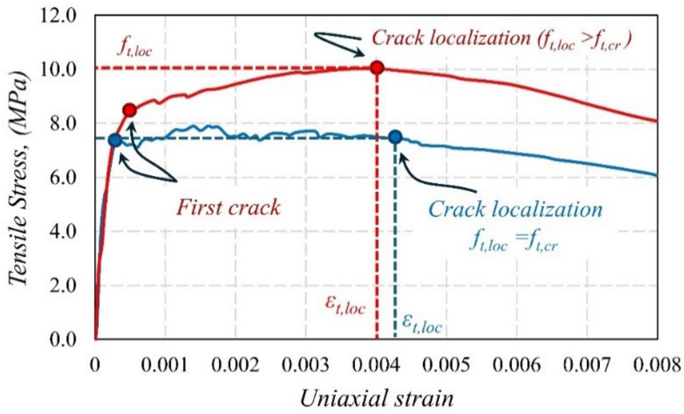

Fig. 3- *Typical tensile stress–strain of UHPC-class materials (El-Helou 2022 [19]).*

Accordingly, the localization strength and strain are utilized in the FHWA shear resistance framework as an input. The $f_{t,\,loc,}$ and $\varepsilon_{t,\,loc}$ parameters shall be determined based on direct tension testing by AASHTO T 397 (AASHTO 2022b) [45] and should be provided by the UHPC plant. However, in the surveyed database, these parameters were rarely provided.

Therefore, a database surveying direct tension tests of UHPC has been compiled. The database included 76 specimens. For each specimen, variables collected included concrete compressive strength f'_c, fiber volume content V_f, fibers aspect ratio (l_f/d_f), fiber tensile strength and shape, and the localization strength. Through correlation analysis, it has been found that the localization strength is mostly linearly correlated with f'_c and the characteristic ratio of fibers ($V_f l_f/d_f$). Accordingly, a linear equation predicting the localization strength was proposed as shown in Eq. 11. The proposed equation resulted in a coefficient of variation (*CoV*) of 16.1% and a root mean square error (*RMSE*) of 1.49 MPa. These statistical values indicate acceptable accuracy. Note that the term $V_f l_f/d_f$ is not substituted in percentage.

$$f_{t,loc}=0.279+0.035f'_c+3.4V_f\ l_f\ /d_f \qquad (11)$$

Using the proposed equation, the localization strength for the 198 shear specimens was determined.

5. Evaluation

To evaluate the performance of the FHWA method, the shear capacity of the 198 specimens in the database was determined according to it as described in section 2. A MATLAB code has been developed to determine the shear capacity according to the FHWA framework as shown in **Fig. 5**. The reduction factor that accounts for the variability of tensile stresses carried by UHPC (γ_u) is set to 1.0, and the effective shear depth d_v is taken as the greater of $0.9d_e$ or $0.72h$.

The FHWA framework begins with determining the design factored shear load V_u (which is assumed in this case) to calculate ε_s value. Subsequently, it is compared to the cracking stress ε_{tcr}, which is calculated by dividing $f_{t,loc}$ by modules of elasticity of UHPC; assuming the idealized stress-strain relationships for UHPC with relatively constant post cracking stress as the steel fiber volume less than 3% [18] ($f_{t,loc} = f_{t,cr}$, (**Fig. 3**)). If ε_s value is less than ε_{tcr}, it should be recalculated as shown in **Fig. 5**. Then, the value of θ must be determined by solving the equations shown in **Fig. 5**. For members without shear reinforcement, the value of θ can be found directly by solving the ε_{tloc} equation, while with members with shear reinforcement, it requires an iterative solution to determine θ and the stress in shear reinforcement $f_{v,\alpha}$. It can be seen that determining θ and $f_{v,\alpha}$ required the values of $f_{t,loc}$ and $\varepsilon_{t,loc}$ to be determined experimentally and used as an input. The value of $f_{t,loc}$ is determined according to Eq. 11 as discussed in section 5. Similar to the $f_{t,loc}$, the $\varepsilon_{t,loc}$ value was not reported for the majority of specimens in the database.

In this study, shear capacity was predicted using the framework in **Fig. 5**, with $\varepsilon_{t,loc}$ fixed at 0.0025, 0.004, 0.005, and 0.0075, within the typical range of 0.0025-0.008 [18]. **Fig. 6** plots experimental ($V_{n,Exp.}$) versus the predicted ($V_{n,FHWA.}$) shear capacities for each $\varepsilon_{t,loc}$ value, showing average and coefficient of variation (CoV) for the ($V_{n,Exp.}/V_{n,FHWA.}$) ratios. As the $\varepsilon_{t,loc}$ increased, estimates became less conservative, with the average decreasing from 1.35 to 1.01.

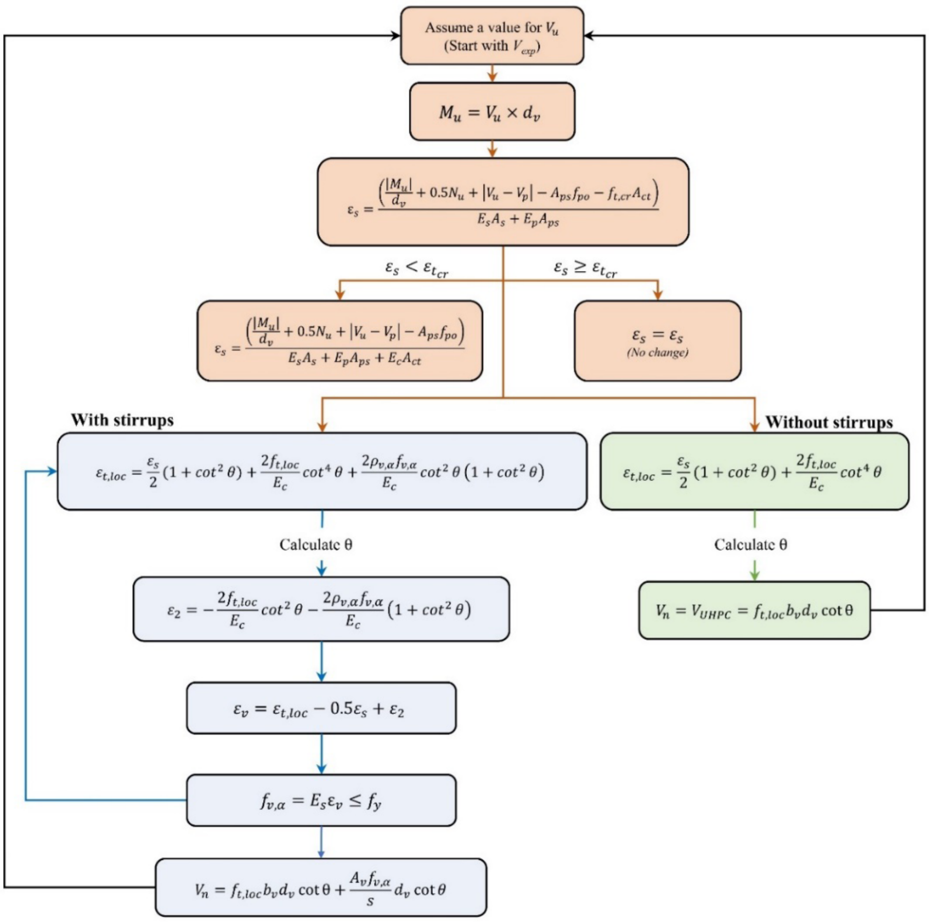

***Fig. 5**- Flow Chart of FHWA Shear Provision Evaluation for UHPC Beams.*

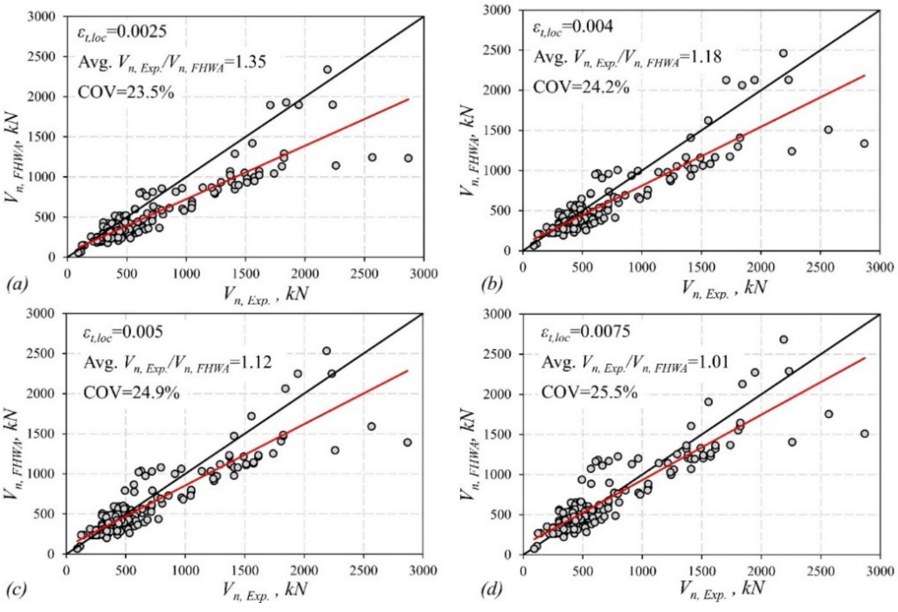

***Fig. 6**- Measured versus predicted shear strength according to the FHWA method with different values of strain localization :(a) $\varepsilon_{t,loc}$ = 0.0025; (b) $\varepsilon_{t,loc}$ = 0.004; (c) $\varepsilon_{t,loc}$ = 0.005, and (d) $\varepsilon_{t,loc}$ = 0.0075.*

To evaluate the performance of the FHWA method across the variable's ranges, the ratios $V_{n.exp}/V_{n.FHWA}$ was plotted concerning different variables, including concrete compressive strength, effective depth, prestressing stress, localization strength, beam width, and shear reinforcement ratio, as shown in **Fig.7**. As mentioned earlier, the $V_{n.FHWA}$ predictions were computed assuming $\varepsilon_{t,loc}$ = 0.004. It is worth noting that a flat trendline indicates a consistent prediction conservatism across the variable range, while a sloped trendline indicates a change in the conservatism of the predictions. Generally, the FHWA method results in relatively flat trend lines for all variables except for the effective web, where a slightly negative slope is observed. For further evaluation, Table 2 presents a statistical analysis of the database, where the database has been divided into four datasets based on the type of reinforcement (prestressed or non-prestressed) and the presence of shear reinforcement. The statistics include average, standard deviation (SD), coefficient of variation (CoV), relative root mean square error (RRMSE), and number of specimens with $V_{n.exp}/V_{n.FHWA}$ is less than 0.75 and larger than 2.0. The statistics obtained are very similar for all datasets, indicating the consistency of the prediction conservatism. In addition, the statistics obtained are like statistics obtained for conventional reinforced concrete and the ACI 318-19 model (as a comparison baseline).

Table 2. Statistical performance of FHWA method based on empirical database

Specimens	. V_{exp}/V_{pred} .Avg	. V_{exp}/V_{pred} (%) CoV	. V_{exp}/V_{pred} (%) RRMSE	$V_{exp}/V_{pred.}$ > 2	$V_{exp}/V_{pred.}$ < 0.75
(All specimens (*n*=198	1.18	24.2	35.7	2	12
(Prestressed (*n*=101	1.21	22.0	35.0	1	3
(Non-prestressed (*n*=97	1.16	26.4	29.0	1	9
(With stirrups (*n*=82	1.15	22.7	32.9	0	8
(Without stirrups (*n*=116	1.21	25.0	38.0	2	4

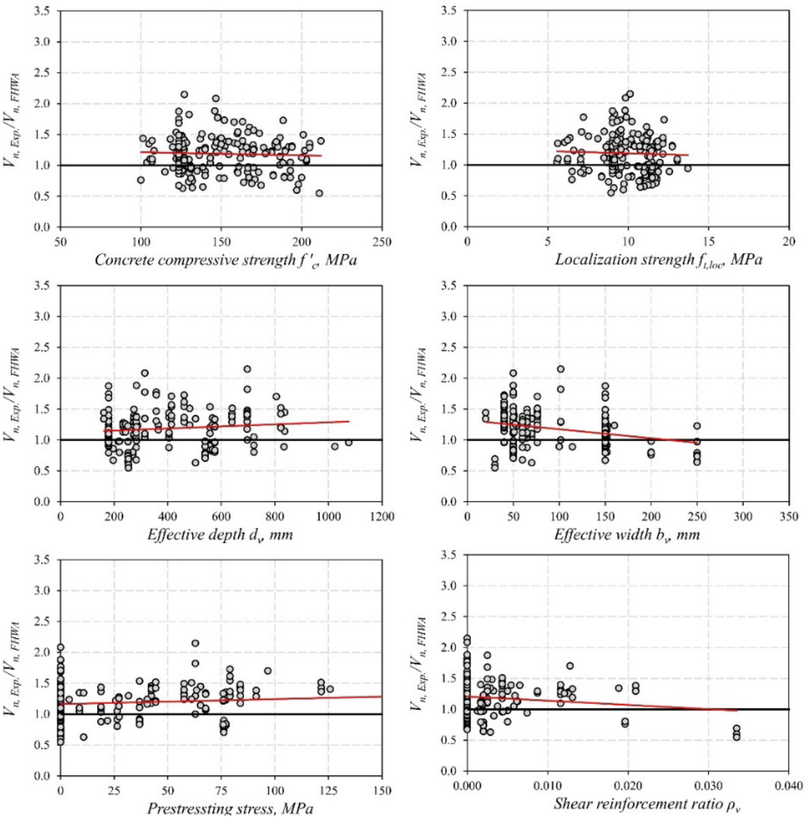

***Fig.** 7- Measured versus predicted shear strength for the FHWA method for the empirical database for concrete compressive strength, effective depth, prestressing stress, localization strength, beam width, and shear reinforcement ratio.*

6. Conclusions

The study provides a thorough evaluation of the FHWA shear model for UHPC girders, including statistical analysis of an experimental database and a reliability analysis of the strength reduction factor used in FHWA methods. Key contributions and conclusions of the study are:

1. The study presents an up-to-date experimental database for UHPC girders. The database comprises 198 UHPC girders tested and failed in shear from 28 studies. In the database, 51% of the specimens were prestressed, and the remaining included non-prestressed reinforcement (49%). In addition, 59 % of the specimens in the database were with shear reinforcement, while the remaining 41% of specimens had no shear reinforcement.

2. The FHWA requires the localization strength f_{tloc} of the concrete as an input. However, most studies in literature did not report it. Accordingly, an equation to predict the f_{tloc} was developed ($f_{t,loc}=0.279+0.035f'_c+3.4V_f l_f/d_f$). The correlation analysis showed that the localization was correlated with concrete compressive strength and the fiber's characteristic ratio. Regarding the localization strain ($\varepsilon_{t,loc}$), none of the tested parameters showed correlation, and thus, different fixed values of localization strain were tested.

3. A MATLAB code was written to evaluate the shear strength for all specimens in the surveyed database according to the FHWA framework. The $\varepsilon_{t,loc}$ was fixed at four different values (0.0025, 0.004,

0.005, and 0.0075). It was shown that increasing the $\varepsilon_{t,loc}$ results in less conservative estimates, where the average decreased from 1.35 to 1.01 when $\varepsilon_{t,loc}$ value was increased from its minimum value to its maximum value. The CoV of the ($V_{n,Exp.}$/ $V_{n, FHWA.}$) ratios were around 24%.

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AXIAL CAPACITY OF FRICTION DRILLED SHAFT: DESIGN OPTIMIZATION USING LOAD TESTS

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ABSTRACT

A friction-drilled shaft constructed into the soil is a type of deep foundation where the primary load-bearing capacity is achieved through skin friction along the length of the shaft, supplemented by a small amount of end-bearing capacity. This type of foundation is particularly suitable for construction projects involving high-load structures such as bridges and high-rise buildings in areas without an accessible rock layer.

The main objective of this study is to develop relationships to adjust commonly used shaft design formulas for friction-drilled deep foundations. The study evaluates the bearing capacity results from available design formulas, finite models, and experimental load tests. Numerical modeling with GTS NX was used to analyze load-settlement curves for axially loaded drilled shafts, with settlement results closely matching actual load tests, albeit with a slight prediction difference of 3%.

The bearing capacity estimation of drilled shafts using the Load and Resistance Factor Design (LRFD) method was examined and compared to actual findings from static load tests in both cohesive and non-cohesive soils. The research revealed a significant discrepancy, with the LRFD factored bearing capacity under-predicting the observed bearing capacity by 75%. This substantial underestimation suggests that the LRFD method may not fully capture the true load- bearing capacity of drilled shafts under field conditions.

Further analysis of settlement-load curves during load tests provided insights into shaft behavior under axial loading, noting variations in bearing capacity estimation between different formulasandmethods.Hansen'scriteria emerged as one of the most accurate methods for nominal load prediction, with a slight over-prediction of 15%.

By using an optimized resistance factor (φ=0.8) instead of lower factors (φ=0.45 for α and φ=0.55 for β method) in the LRFD design formula, the percentage difference between LRFD predictions and load test results decreased significantly. The predictive difference between the LRFD design formula and load tests decreased from 75% to 44%, and the difference between LRFD predictions and Davisson's method decreased from 46% to 24%.

The findings underscore the importance of further refinement and calibration of LRFD methodologies to better align with empirical observations from practical applications. Engineers and designers should consider the sedi screpancies when employing LRFD for accurate and reliable foundation designs, particularly in contexts where precise load-bearing capacities are critical for structuralsafetyand performance. This study contributes valuable insights into the assessment of drilled shafts'bearing capacities and highlights avenues for future research to enhance the accuracy and applicability of design methodologies in geotechnical engineering practice.

1. Background of Research

Friction drill shafts area mong the most popular deep foundation load transfer elements,as design can significantly depend on the frictional capacity. Drilling shafts, commonly called drilled piers, drilled caissons, bored piles, etc., are a type of foundation structure widely utilized worldwide(ReeseandO'Neill,1999).Drilling a cylindrical excavation, adding a reinforcing cage if needed, and then concreting the excavation is the easiest way to build a drilled shaft(**figure1.1** shows the drill shaft construction step).

Regarding drilled shaft capacity under axial stress, side resistance is essential, especially when uplift loading or much deeper depths are involved. Research in this field has been developing steadily during the last five decades.

Based on soil properties, side resistance method analysis can be roughly divided into two categories: total stress analysis and effective stress analysis. These analytical techniques can be further divided into three groups: lambda (λ), beta (β), and alpha (α) (Das, 2010).

"One test result is worth one thousand expertoptions"(vonBraun,1963).

Despite all efforts exerted to determine the performance and behavior of piles through design specifications and codes, pile behavior may deviate slightly from expectations. This is largely influenced by the site conditions and soil characteristic , even after conducting necessary soil tests, and geological, and geotechnical studies of the site. In some projects and locations, all required data may not be available, necessitating on-site load testing.

There are several main reasons that load tests such as conducted to obtain all information and details on load transfer in the side and base of the drilled shaft and also to reach the p-y curves between loads and settlements which give full indication about drill shaft behavior and bearing capacity undern atural site condition.Also,the purpose of static load tests is to verify the ultimate load capacity of a pile, which is the maximum load that it can support. Rapid settlement usually indicates the ultimate capacity when the pile fails or when an overly heavy load is applied. However, it frequently happens that the final load is unknown during the test (O'Neill & Reese, 1999).

Therefore, the pile's ultimate capacity can be determined with certain limitations using load-settlement data. Static pile loading tests are a kind of pile loading test with axial compression and axial tensile testing are examples of static loading investigations (Olgun et al., 2017).

Research Problem Statement

This study aims to modify friction-drilled shaft design formulas, which are increasingly popular in designing friction-deep foundations. The study will evaluate the result of bearing capacity from available design formulas, finite models,and experimental pile load tests, as studies show differences between the results of these methods.

1.3 Importance of The Research

The difference in the capacity estimation results of the friction drill shaft if using an experimental method versus a theoretical method.This study will improve the formulation method that is available. Optimized drill shaft design techniques allow construction processes to be improved more effectively and efficiently. Optimizing the design process allows engineers to save on needless expenditures, waste, and hasten project delivery times.

A well-designed drill shaf tguarantees that the structure will find its intended performance. Drill shaft strength and life span Apply optimized designs Consider load capacity Potential soil type Environmental considerations Construction techniques. The design process optimizes building elements and help to reduce the carbon footprint of construction actions. Optimized designs can save material and energy, minimize waste generated during construction to lead the forging of sustainable building practices resembling ecosystems.

1.4 Research Objective

The study aims to achieve the following aims:

- A comprehensive review of the use of available formulas to evaluate end bearing and side friction capacity for the drill shaft.
- Modeling friction drill shaft using finite element software.
- Optimize the drill shaft formula based on the load tests and the model.

1.5 Research Methodology

- Literature reviews for formals, specifications, designs, and soil reports for each resistance drill shaft will be reviewed accurately to define soil properties and conditions.
- Collect data for load tests, soil reports, and design methods.
- Estimate Drill shaft bearing capacity from available formula to compare the result of B.C of these formulas with the experimental pile load test.
- Model the friction drill shafts using the finite element method, then compare the B.C result with the formulas and pile load test result.
- Modifications should be made to the available formula to match the experimental results.

2. LITERATU REREVIEW

1.1. Drilled Shaft in Cohesive an dNon-Cohesive Soil

Drilled shafts, whether used in cohesive or non-cohesive soils, are required to provide stable foundations for construction. To guarantee successful implementation, engineers carefully evaluatethecharacteristicsofthesoil,therequiredloads,andtheconstructionprocesses (Brown, 2010).

1.2. Construction of Drilled Shaft

An economical method to transfer structural stresses above (or below) unstable (weak, compressible,swelling)surfacesoiltodeeper,stable(stiff, non-swelling)strataisthroughtheuse of deep foundations, such as drilled shafts or concrete cylinders cast into boreholes (Brown, Turner, & Castelli, 2010).

1.3. Drilled Shafts Design Formulas

Design of drilled shafts may be per Allowable Stress Design (ASD) or Load and Resistance Factor Design (LRFD).

ASD is an engineering arena for designing the permissible limits of stress a material can go through without failing (Coduto, 2001).

The Load and Resistance Factor Design (LRFD) design method of drilled shafts is a more unified approach to consider the capacities based on applied loads as well as the resistance of the shaft (Paikowsky et al., 2004).

1.4. Test for Deep Foundation Elements Using Static Axial Compressive Load

Test methods assess the axial deflection of individual vertical or inclined deep foundation elements or groups under static axial compression. These methods apply to various types of deep foundations, including drilled shafts, cast in place piles (such as augured cast in place piles, barrettes,and slurry walls), and driven piles (such as pre-cast concrete, timber, or steel sections).

The tests can be performed on single elements or groups, but the results may not fully represent the long-term performance of the entire deep foundation system (ASTM, 2020).

According to ASTM (D1143/D1143M – 20) specification (Standard Test Methods for Deep Foundation Elements Under Static Axial Compressive Load1). It clarifies that individual foundation elements and group elements can use the test methods.

1.5. Davisson Method

Based on load test results, the Davisson method, also called the Offset LimitMethod, is an effective method for estimating the ultimate load capacity of piles.

1.6. HansenMethod

The Hansen Method is a technique for estimating theload capacity of drilled shafts, also known as drilled piles, based on data from static load testing. This approach, created in1963 by J. Brinch Hansen, offers a mathematical foundation for analyzing load-movement curves collected during pile load testing (Hansen, 1963).

1.7. Modelling Drilled Shaft Using Finite Element

GTS NX , is finite element analysis software used for expert geotechnical studies of soil and rock deformation stability groundwater flow, dynamic vibrations, and soil-structure interaction in 2D and 3D.

3. Methodology

comprehensively describes for 12 data project has been collected from the FHWA database andform local company in Jordan,so the study methodology, including data, formulas, methods, and software programs has been done as follow :

1- Collecting data from FHWA and local company in Jordan where the data that has been collected for cohesive and non-cohesive soil were soil report that has been usedtopresentallsoil characteristic, drilled shaft details to determine the length and dimeter for each drilled shaft so all thestudied projects have lengths between (7-25 m) with a diameter between (45-107 cm), and static load test data to use the settlement-load curves todetermine the ultimate and failure load .
2- Use the static load test data (settlement-load) curve to determine the failure load from Davisson method which will used as failure limitation for drill shaft capacity , then use this data in Hanssen criteria to determine ultimate load for shafts.
3- Create FE Mmodel with the same applied load of test to compared with settlement of the test actual result .
4- Use the LRFD drilled shaft capacity from side and tip resistance to find the shaft capacity according to origin assumed resistance factor according to LRFD specification.
5- Assumed assumption of the optimized resistance factor by adding 20% each time.
6- Reach the best expectation resistance factor which is 0.8 for cohesive and non- cohesive soil .

4. Results

-Static load test Vs AASHTOO LRFD

The primary objective of this research is to study the correlation between the bearing capacity obtained from actual static load tests and that predicted using the AASHTO LRFD formula. This analysis is crucial for achieving the research goal. The design load for the test has been determined according to the Terzaghi equation. The applied load test is 200% of the design load. The design load from the AASHTO LRFD has been calculated using the AASHTO LRFD equation. It incorporates nominal and factored loads (α and β).While static load tests provide accurate results the AASHTO LRFD formula offers a practical alternative for estimating pile capacity in most engineering projects. Conservative designs are generally safer. However, an under-prediction of this magnitude might lead to overly conservative andpotentially uneconomical designs. Engineers may need to revisit the assumptions and factors used in the LRFD method. Therefore, the LRFD method or the factors applied within it might need re-evaluation or calibration based on the site's specific conditions and soil properties.

Table4.1:Bearing capacity result from Static load test and AASHTOOLRFD

Location	Cohesive andnon-cohesive soil	Nominal Design (Terzaghi equ.)(kN)	Applied Load Test (kN)	AASHTOO LRFD Factored (kN)	AASHTOO LRFD Nominal (kN)
London1	Cohesive	2060	4119	744.99	1655.536
London2	Cohesive	1753	3506	1112.69	2472.65
HowardFrankland	Cohesive	1869	3737	1204.14	2675.88
SouthCaroline	Cohesive	1557	3114	1249.29	2776.21
Canada	Cohesive	501	1001	403.94	897.64
Jacksonville	Cohesive	3154	6308	1510.14	3355.86
France	Non-Cohesive	979	1957	617.75	1123.19
USA	Non-Cohesive	801	1601	757.54	1377.36
Ontario	Non-Cohesive	890	1779	922.35	1677.01
Amman	Non-Cohesive	600	1200	409.32	744.22
Potash	Non-Cohesive	1140	2280	767.12	1394.77
DeadSea	Non-Cohesive	1500	3000	950.24	1727.7

Table4.2: Percent of AASH TO OLRFD load results with Static load test

Location	/AASHTOOLRFD Nominal Design load of Test	/AASHTOO LRFD Factored Applied Load test
London 1	0.80	0.18
London 2	1.41	0.32
Howard Frankland	1.43	0.32
South Caroline	1.78	0.40
Canada	1.79	0.40
Jacksonville	1.06	0.24
France	1.15	0.32
USA	1.72	0.47
Ontario	1.89	0.52
Amman	1.24	0.34
Potash	1.22	0.34
DeadSea	1.15	0.32

- **Under-Prediction by 75%**:
- If the LRFD method predicts a bearing capacity of Qf and the actual load tests show a capacity of Qt, the under-prediction by 75% can be expressed mathematically as: Qf=0.25×Qt
- This means the LRFD prediction is only 25% of the actual load capacity observed in the tests. In other words, the LRFD method significantly underestimates the true bearing capacity.

-

Table4.3 Result after optimization

Location	LRFD Nominal original	LRFD factored(O.45 for cohesive and .55 non cohesive	NewLRFD factoredby 0.66	New LRFD FACTORED LOAD BY .77	New LRFD factored load .8	Davisson
London 1	1655.54	744.99	1092.65	1274.76	1324.43	2213
London 2	2472.65	1112.69	1631.95	1903.94	1978.12	2928
Howard Frankland	2675.88	1204.15	1766.08	2060.43	2140.70	1796
SouthCaroline	2776.21	1249.30	1832.30	2137.68	2220.97	2197
Canada	897.64	403.94	592.44	691.18	718.11	756
Jacksonville	3355.86	1510.14	2214.87	2584.0122	2684.60	3940
France	1123.19	617.76	741.31	864.87	898.55	1147
USA	1377.36	757.55	909.06	1060.57	1101.89	1589
Ontario	1677	922.35	1106.82	1291.29	1341.60	1345
Amman	744.22	409.32	491.19	573.05	595.38	820
Potash	1394.77	767.12	920.59	1073.97	1115.82	2800
DeadSea	1727.7	950.23	1140.28	1330.33	1382.16	3455.38

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5. CONCLUSIONS AND RECOMMENDATIONS

The side resistance of drilled shafts under axial loading was evaluated using extensive load test data. A comprehensive analysis was carried out on both the measured and anticipated results. Several representative analytical models were assessed thoroughly. The conclusions and recommendations are applicable to both cohesive and non-cohesive soil. They apply in fully drained conditions for both long and short-term scenarios.

1.1 Conclusion

This thesis aimed to develop resistance-drilled shafts design methods. It focused on the importance and impact of this development on projects. The side resistance of drilled shafts under axial loading was evaluated using a wide range of load test data. Both measured data and anticipated results were extensively used. These were used to assess representative analytical models. In light of the assessment these conclusions and recommendations have been found. They were for cohesive and non-cohesive soil in fully drained soil for the long and short term.

1. The results demonstrated that using resistance factors in LRFD (0.45 and 0.55) yields very cautious and highly safe outcomes.These factors approximate 25% of the nominal load when compared to load test results, about 75% of the factored load. After making adjustments, the results became more accurate and safer. They were also closer to reality and on-site load tests. This underscores the importance of the study in reducing project costs and achieving safe design results that mimic on-site tests.
2. This thesis demonstrates the effectiveness of numerical modeling using GTS NX. It specifically-focuses on analyzing the load-settlement behavior of axially loaded drilled shafts.
3. The possibility of using the GTS NX model as an alternative to expected load tests was demonstrated.The settlement results were close to those from load tests at the same loads. The difference was approximately 3%. In conclusion, the observation emphasized the chance to modify and develop layout codes. This would make them more realistic and safer. Such changes would meet the needs of projects and contractors executing the work.
4. Key findings imply that the load and resistance element design(LRFD) technique appreciably overestimate the bearing capability of drilled shafts. The overestimation is significant when compared to real load exams. It reaches 75%. This discrepancy underscores the need to refine the layout methodology to enhance accuracy and cost-effectiveness.
5. Evaluation of P-Y curves, derived from load tests where shafts are loaded to their implemented load, offers distinct insights into shaft behavior under excessive conditions. These insights include settlement predictions.They also encompass stiffness assessment and load distribution along thes haft. Additionally, they allow for failure load prediction according to the Davisson method. All these factors are critical for ensuring foundation reliability and safety.
6. The study reveals that the LRFD nominal bearing capacity prediction is 6% lower than the Davisson method. This suggests as light under estimation. The Terzaghi method underestimates the bearing capacity by 31% compared to the Davisson method. This shows a more conservative bias.The LRFD factored bearing capacity prediction is the most conservative. It underestimates by 54%. This could potentially lead to overly cautious and costly designs.The Terzaghi method shows significant under estimation overall. The LRFD nominal method offers a closer yet still conservative estimate.
7. The Terzaghi equation differs from the LRFD AASHTO equation. It has an average underestimation of 25%. Hansen's criteria rank among the most accurate methods for predicting nominal loads. It typically overestimates by about 15%. These estimations are reliable and slightly conservative, making them suitable for practical engineering applications.

8. The Hansen vs. Terzaghi bearing capacity demonstrates a 42% underestimation. Meanwhile The Hansen vs. LRFD nominal load shows a 21% underestimation. Optimizing the resistance factor narrows the predictive discrepancy between the LRFD and load tests from 75% to 44%. It also reduces the discrepancy between the LRFD and Davisson from 46% to 24%.

   Overall, this research highlights the variability in bearing capacity predictions across different methods. It advocates for adjustments in design methodologies. The goal is to achieve a balance between safety and cost efficiency.

1.2 Recommendation

Based on data evaluations, the α and β techniques yield more realistic results. This is especially true when calculating the friction resistance bearing capacity of drilled shaft designs in homogeneous soil layers including sand or clay. The new correlation, developed using field load test data, can be considered an alternative analysis method for drilled shaft design as it prevents drilled shaft bearing capacity higher than non-optimized resistance factor result and more predictive to static load test .

Data-Driven Methodology for Improving Traffic Safety: Identifying Priority School Zones Enhancements in Riyadh, Saudi Arabia

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ABSTRACT

Traffic safety is a critical public health and urban planning issue, especially in rapidly growing cities like Riyadh, Saudi Arabia, where safeguarding the well-being of vulnerable populations such as schoolchildren and worshippers is paramount. An ongoing project titled "Enhancing Traffic Safety around Schools and Mosques in Riyadh: Phase I" aims to significantly improve road safety for vulnerable populations across Riyadh, particularly schoolchildren and worshippers. This phase aims to enhance 300 school areas, comprising over 841 schools and 160 mosques, integrating state-of-the-art traffic management strategies and engineering solutions.

This study evaluates the existing traffic safety measures around these institutions using the International Road Assessment Programme (iRAP) tools and its Star Rating for Schools (SR4S) methodology. It will identify the key risk factors contributing to traffic crashes and propose targeted interventions. Utilizing the iRAP methodologies, the study will assess current conditions and provide a star rating for each location, reflecting their safety levels.

The study's approach includes comprehensive data collection through multiple resources, including advanced mobile mapping systems and on-site surveys, to gather detailed information about road geometry, traffic volumes, and pedestrian behavior. The analysis will consider best practices from similar international studies and adapt them to Riyadh's specific context.

Key strategies to be explored include reducing speed limits around schools and mosques, improving pedestrian crossings, and implementing traffic calming measures. Additionally, educational campaigns and community engagement efforts will be designed to raise awareness about road safety. This data-driven approach provides valuable insights for stakeholders and decision-makers to effectively enhance traffic safety in Riyadh’s school zones.

Keywords: Traffic Safety; School Zones, Mosque Areas, iRAP, SR4S.

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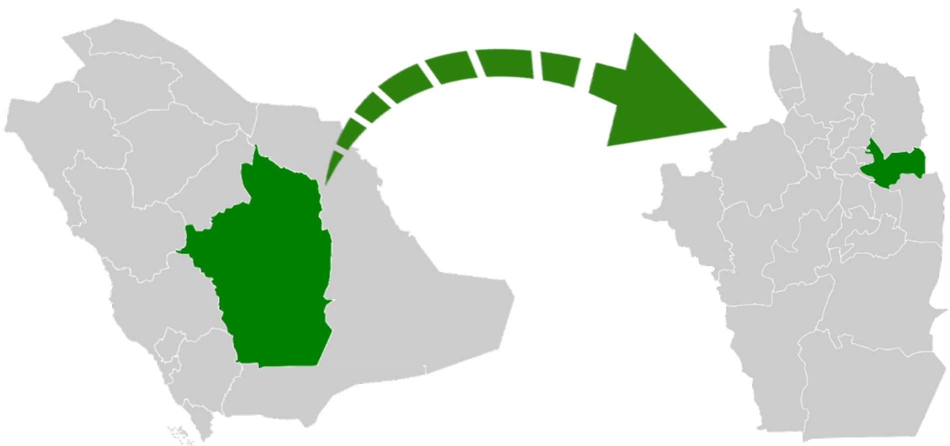
1. INTRODUCTION

Traffic safety is a global concern, as road traffic injuries remain one of the leading causes of death and disability worldwide. According to the World Health Organization (WHO), approximately 1.19 million people die each year as a result of road traffic crashes, with millions more sustaining non-fatal injuries (*WHO, 2023*). Vulnerable road users, such as pedestrians, cyclists, and motorcycles, are disproportionately affected. Traffic safety measures have become increasingly crucial in urban areas where vehicle-pedestrian interactions are more frequent, and the consequences of road crashes can be severe (*Thakur & Biswas, 2019*). Effective traffic management strategies, including speed reduction, traffic calming measures, and enhanced pedestrian facilities, are vital in reducing the incidence and severity of road traffic crashes (*Damsere-Derry et al., 2019*).

School zones, where children are particularly at risk, have been a focal point for traffic safety initiatives worldwide (*WHO, 2023*). Studies show that children are less able to judge vehicle speeds and distances, making them more vulnerable in traffic environments. In response, many countries have implemented specific measures to enhance safety around schools. For example, in the United States, the Safe Routes to School (*SRTS, 2015*) program focuses on creating safer walking and biking routes for children, incorporating measures such as reduced speed limits, improved signage, and better crosswalks. Similarly, in the United Kingdom, the "20's Plenty" campaign (*20's Plenty, 2024*) advocates for 20 mph speed limits in residential areas, including those near schools. These initiatives have proven effective in reducing traffic-related injuries and fatalities among schoolchildren, demonstrating the importance of targeted traffic safety interventions in school zones.

In Riyadh, the capital of Saudi Arabia (**Figure 1**), the challenge of ensuring safe school commutes involves multiple dimensions, including urban planning, traffic management, educational awareness, and technological solutions (*Oestreich et al., 2021*). The complexity of this issue requires a collaborative approach that brings together different stakeholders and leverages their capabilities and resources regarding road safety and school transportation policies, legislation, and regulations to achieve a common goal: the safety of students and road users around schools.



Riyadh Region in the Kingdom Riyadh City in the Riyadh Region

Figure 1. Riyadh City in the Kingdom of Saudi Arabia

As a rapidly expanding metropolis, Riyadh is at a critical stage where the implementation of proactive safety measures can profoundly influence the well-being of its younger population. The city's distinctive demographic, cultural, and urban characteristics, coupled with its swift pace of development, necessitate strategies specifically tailored to the local context while incorporating insights from global best practices. Several crucial considerations ground the study to enhance traffic safety around schools and mosques in Riyadh (Phase I) and the alignment of stakeholders. These include the growing traffic volumes, urban planning challenges, gaps in legislation and policy frameworks, advancements in technology, and the importance of community awareness and engagement (**Figure 2**).

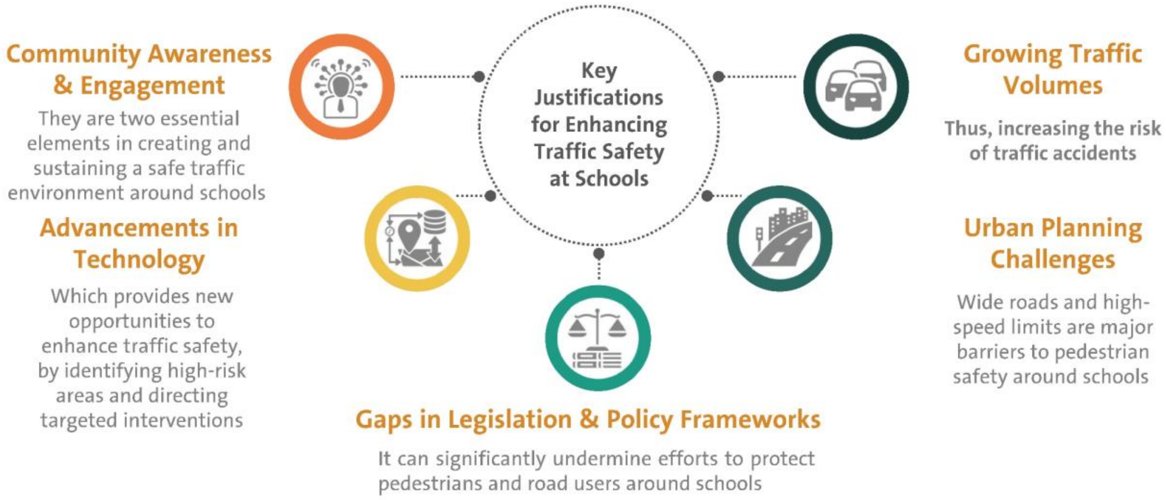


Figure 2. Justifications for Enhancing Traffic Safety at Schools (*Developed by the Authors*)

This study aims to enhance traffic safety across 300 school zones in Riyadh over a period of 18 months, focusing on creating a safer environment for students and the broader community. The objectives of the study are multifaceted and include the improvement of pedestrian pathways and waiting areas at school gates, ensuring these environments are conducive to the safety and convenience of students. Additionally, the study seeks to optimize the loading and unloading areas, as well as the parking and waiting zones for vehicles, to facilitate safer and more efficient traffic flow. A key component of the study is identifying and implementing reduced speed zones around schools, adhering to standard engineering requirements to minimize the risk of crashes. The study also aims to identify existing traffic safety issues and develop appropriate solutions, ultimately elevating the overall level of safety for schoolchildren. Furthermore, the study will address the behavior of traffic offenders by implementing targeted awareness and educational programs designed to foster safer driving habits and greater community involvement in traffic safety efforts.

In summary, this paper aims to conduct a thorough analysis of traffic safety measures around schools and mosques in Riyadh, with a particular focus on enhancing the safety of vulnerable populations like children and worshippers. The following sections of this paper will detail the methodologies employed in the study, starting with a comprehensive *Literature Review* in Section 2, which explores the current research landscape on traffic safety around school zones, international best practices, and the applicability of these findings to the context of Riyadh. Section 3, *Materials and Methods*, will detail the methodologies employed in this study, including the data collection processes, tools used for analysis, and the criteria for evaluating traffic safety. Sections 4 to 7, will present the study's preliminary findings, examining the current state of traffic safety around the targeted schools and discussing the implications of these findings in the context of international best practices. Finally, Section 8, *Conclusions and Recommendations*, will summarize the key insights derived from the study and propose actionable recommendations for enhancing traffic safety in the identified areas.

2. LITERATURE REVIEW

Recent studies on traffic safety in school zones have underscored the importance of implementing multifaceted strategies to protect children, among the most vulnerable road users. Implementing traffic calming measures, such as reduced speed limits, high-visibility crosswalks, and speed bumps, has proven to effectively reduce vehicle speeds and improve pedestrian safety. When combined with clear signage and crossing guards, these measures create a safer environment for children walking to and from school. The use of raised crosswalks, in particular, not only slows down traffic but also enhances the visibility of pedestrians, significantly reducing the likelihood of crashes (*Brenna Pearson, 2023*). Another crucial aspect of school zone safety is the enforcement of traffic regulations. Despite the presence of stringent laws aimed at safeguarding children, such as reduced speed limits and mandatory stops before crosswalks, violations persist, posing significant risks. A study from South Korea revealed that even with reinforced safety measures, issues like speeding and illegal parking remain prevalent, leading to tragic crashes. The efficacy of these laws is often compromised by inadequate enforcement, underscoring the need for continuous monitoring and stricter penalties to ensure compliance and protect young lives (*LEE HO-JEONG, 2023*).

International best practices emphasize the importance of integrating community involvement and technological advancements into traffic safety strategies. Public awareness campaigns aimed at educating both drivers and children about the dangers in school zones have been crucial in changing behavior and reducing crashes. Additionally, the use of technology, such as digital speed signs and surveillance cameras, has been effective in managing traffic and identifying high-risk areas. These tools, coupled with active community participation, ensure that safety measures are not only implemented but also respected and maintained over time (*Brenna Pearson, 2023*). In medium-sized cities, where traffic volumes can be significant but resources may be limited, targeted interventions in school zones have shown promising results. A case study in Greece highlighted the importance of customizing interventions based on specific traffic conditions and the unique needs of each school zone. By conducting detailed traffic inventories & audits, cities can develop precise, practical strategies that address the most pressing safety concerns. This approach improves safety and optimizes resource allocation, ensuring that interventions are cost-effective & impactful (*Papastavrinidis et al., 2021*).

Milch and Nævestad (2024) explored the impact of the Heart Zone initiative on fostering a traffic safety culture in four Norwegian schools, emphasizing the role of strong school management, adequate infrastructure, & active parental involvement in achieving successful outcomes. Their study showed that schools can significantly improve safety behaviors among parents, such as using designated drop-off zones and being more vigilant about student safety, when they effectively combine these factors. This initiative also provided a framework for future traffic safety culture programs. Similarly, *Ellizar et al. (2023)* applied the International Road Assessment Programme (iRAP) and Star Rating for Schools (SR4S) methodology in Indonesia, where youth participation played a critical role in identifying road safety issues and proposing solutions. The engagement of students in the process led to significant improvements, with safety ratings in the assessed school zones increasing from 1-2 stars to 4-5 stars, thereby reducing pedestrian risk by over 90%. This highlights the importance of involving the community, particularly youth, in safety initiatives.

In contrast, the study by *Dang et al. (2024)* in Pleiku City, Vietnam, revealed that simply implementing a speed limit of 30 kph in school zones had a limited impact on vehicle speeds, as many drivers continued to exceed the limit. This implies that the effectiveness of speed limits depends on additional enforcement and infrastructure measures. Further emphasizing the need for a holistic approach, *Wangzom et al. (2023)* examined how perceived safety in the built environment affects children’s active travel to school. They found that parental concerns about traffic safety, neighborhood security, and proximity to school heavily influence whether children walk or cycle. Improving infrastructure, such as providing lateral separation from traffic and maintaining walkable neighborhoods, can increase perceived safety and encourage active commuting. Building on this, *Kweon et al. (2023)* identified specific environmental factors that promote walking and biking to school, such as mature trees, higher intersection density, and mixed land use. However, concerns about traffic safety and convenience remain barriers to active commuting. Their findings underscore the need for strategic urban planning that incorporates these factors to boost student walking and biking rates. Together, these studies illustrate the multifaceted nature of traffic safety in school zones, highlighting the critical roles of community involvement, effective infrastructure, and supportive policies in creating safer environments for children. They also point to the necessity of tailored interventions that address specific local challenges, reinforcing the value of contextually adapted solutions like those proposed in this research.

Overall, while the research demonstrates significant progress in enhancing traffic safety in school zones, several critical gaps remain, particularly in the areas of enforcement, community engagement, and the adaptation of international best practices to local contexts. Many studies have focused on physical infrastructure improvements and technological integration, yet the challenges of effective enforcement and sustainable community involvement are often underexplored. Furthermore, existing literature tends to generalize solutions without fully considering the unique urban, cultural, and regulatory environments of rapidly developing cities like Riyadh. This gap underscores the necessity for localized research, such as this study, which aims to adapt and refine global best practices to meet the specific needs of Riyadh. By addressing these gaps, this research seeks to contribute to developing more effective, contextually relevant strategies for improving traffic safety around schools and mosques, ultimately ensuring a safer environment for vulnerable populations such as schoolchildren and worshippers.

3. MATERIALS & METHODS

This paper is structured around several critical stages, each designed to ensure a comprehensive and practical approach to enhancing traffic safety in school zones (**Figure 3**).

Figure 3. Key Stages in this Study (*Developed by the Authors*)

The initial stage thoroughly examines international best practices and advanced engineering solutions, providing a foundation of global knowledge tailored to the local context. This is followed by alignment with key stakeholders, ensuring that all relevant parties are engaged and their inputs are integrated into the study's framework. Subsequently, the study will define and classify the detailed scope of work, establishing clear objectives and deliverables.

A comprehensive survey of the defined scope, including traffic inventory and census activities, will then be conducted to gather essential data. This data will inform a rigorous traffic analysis, where the scope of work will be investigated, and traffic safety elements will be audited. Based on these analyses, detailed executive plans will be developed, outlining specific actions and interventions. The final stage involves the submission of the project's comprehensive outputs, including all analyses, plans, and recommendations, ensuring a complete and actionable set of deliverables for implementation. This methodology is systematically structured and developed in alignment with the iRAP (*iRAP, 2024*) and the SR4S (*SR4S, 2024*) framework.

While each component of traffic safety within school zones—such as engineering measures, education, and law enforcement—is critical in enhancing safety levels, these efforts alone may not achieve the desired effectiveness unless they are complemented and reinforced by other factors focused on cultivating a comprehensive traffic safety culture among all road users. Key aspects of this approach include the major 5 E's of road safety shown in **Figure (4)**.

Figure 4. The Five Main Elements for Achieving Road Safety – 5 E's (*ORSAPS, 2018*)

To determine the level of traffic safety in a school area, it is necessary to review the crash records that have occurred there. Additionally, it's important to analyze the causes of those crashes, examine the safety components on the site, and identify any potential factors that may threaten traffic safety. This process is called the traffic safety audit process. It is a specialized process conducted by a trained team with the expertise to evaluate traffic crashes. This team possesses the necessary engineering knowledge and experience to assess traffic safety factors. The analysis results vary from site to site depending on the nature of each location. **Figure (5)** shows the relationship between the severity of crashes and the speed percentile.

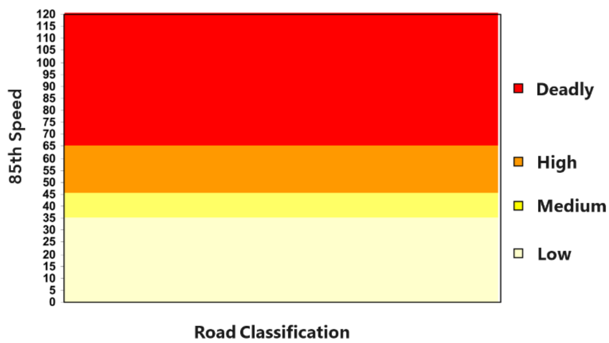


Figure 5. Relationship Between the Severity of Crashes and the Speed Percentile (*Riyadh Municipality, 2006*)

The hazard rating indicators mentioned above are utilized to assess the level of traffic risk at school sites as follows (*Riyadh Municipality, 2006*):

- High Hazard Area: the site has recorded five (5) or more traffic crashes within a single year, including at least one severe pedestrian run-over incident. Also, the 85th percentile speed is within the orange or red zone, as shown in the figure.
- Medium Hazard Area: the site has recorded five (5) or more traffic crashes within a single year, including at least one minor pedestrian run-over incident. Also, the 85th percentile speed is within the yellow zone, as shown in the figure.
- Low Hazard Area: the site has recorded two (2) or more traffic crashes within a single year, with no incidents involving pedestrian run-overs. Also, the 85th percentile speed is within the beige zone, as shown in the figure.

4. GLOBAL BEST PRACTICES & ENGINEERING STANDARDS

This section aims to identify and analyze key elements that contribute to the effectiveness of these strategies, including engineering solutions, policy frameworks, and community engagement initiatives. By benchmarking these practices, the goal is to extract valuable lessons and insights that can be adapted and applied to improve traffic safety in local contexts, ensuring the protection of vulnerable populations such as schoolchildren. The selection process for benchmarking best practices involved multiple steps. Initially, a long list was created based on traffic safety records, international rankings, and regional focus. The list was then narrowed down by applying specific criteria such as economic indicators, infrastructure and transportation metrics, population data, and traffic crash data. The final selection involved an in-depth analysis of implemented policies, innovations, and their effectiveness in improving school zone safety (**Figure 6**).

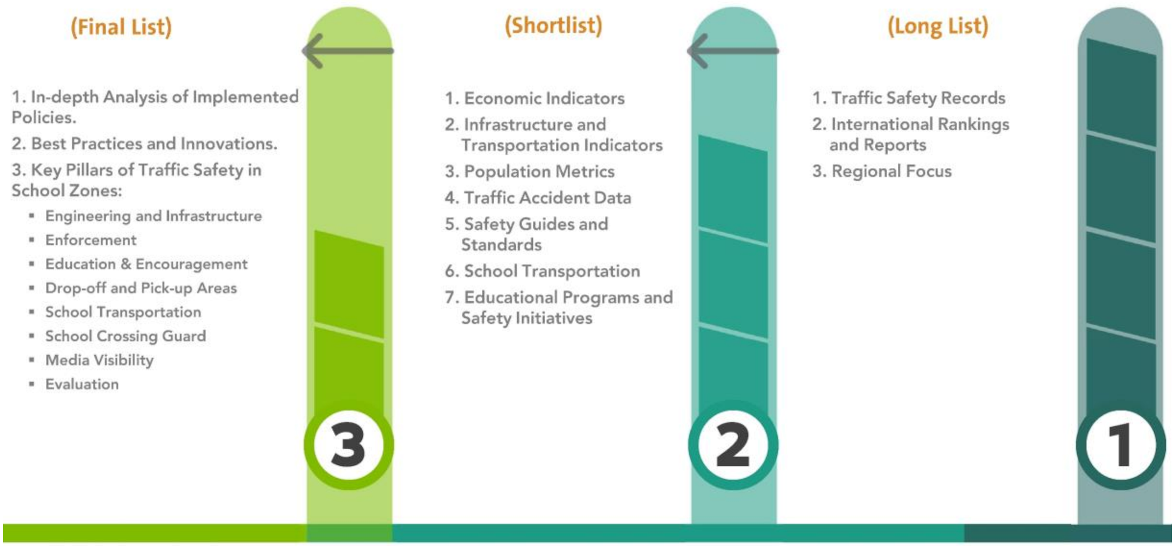


Figure 6. Benchmarking Selection Criteria (*Developed by the Authors*)

Based on the reviewed literature, the key pillars of traffic safety in school zones are fundamental areas that define effective school road safety programs. These pillars include Engineering and Infrastructure, Enforcement, Education & Encouragement, Drop-off and Pick-up Areas, School Transportation, School Crossing Guards, Media Visibility, and Evaluation. The most distinguished countries in promoting these safety aspects include:

1. Canada (*Parachute-Canada, 2022*; *BCAA Canada, 2022*; *Shared School Services, 2021*; *Tebinka et al., 2015*; *CGA, 2022*).

2. United States (*SRTS, 2024; CDOTm 2021; TxDOT, 2002; USDOT, 2023; FDOE, 2020*).
3. Australia (*Victoria Roads, 2021; RSEV, 2024; GACT, 2015; ADT & DOE, 2024; DOTMR, 2018*).
4. Sweden (*STA, 2013; Trafik och tillstånd, 2020*).
5. New Zealand (*LSA, 2011; NZTA, 2016; 2024*).
6. United Arab Emirates (*RTA, 2023, 2024; ADE, 2023; ADQCC, 2020; ADDOT, 2016; 2024*).
7. Ireland (*DCC, 2021; RSA, 2021; NTA, 2022*).
8. Spain (*Briz-Redón et al. 2019; SRA, 214*).
9. United Kingdom (*Rospa, 2020; UKDOE, 2024*).

These nations have excelled in implementing and promoting comprehensive strategies that align with these pillars, making them leaders in school zone traffic safety (**Figure 7**).

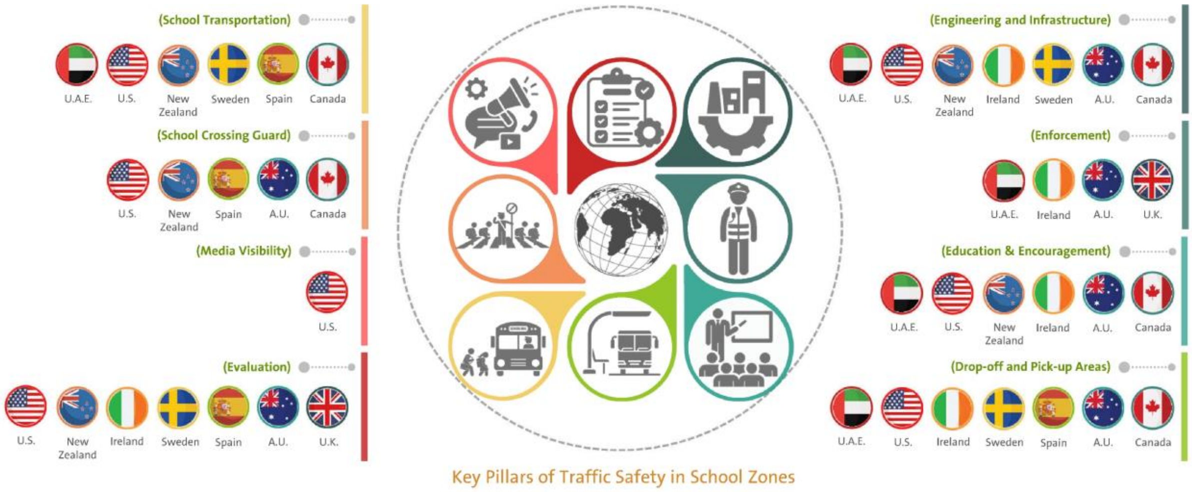


Figure 7. Key Pillars of Traffic Safety in School Zones (*Developed by the Authors*)

An ideal school zone layout, designed according to global best practices and engineering standards, should incorporate several key elements to ensure the safety and efficiency of the area, as shown in **Figure (8)**.

Figure 8. Comprehensive School Zone Design Incorporating Global Best Practices for Enhanced Safety and Traffic Efficiency (*Developed by the Authors*)

As shown in **Figure (8)**, first, off-street parking and dedicated drop-off lanes should be provided to minimize traffic congestion and enhance safety during peak hours. The road surfaces should feature colored asphalt and clear road markings to designate specific zones, such as the 30 km/h speed limit area, ensuring drivers are aware of speed restrictions. A one-way traffic system can be implemented to streamline traffic flow and reduce conflicts between vehicles. Pedestrian safety is essential, necessitating the installation of raised pedestrian crossings and handicap ramps, which not only slow down vehicles but also provide safe passage for all users, including those with mobility impairments. Additionally, pedestrian fences and well-landscaped areas serve to guide and protect pedestrians while adding aesthetic value to the environment. Stamped concrete can be used for sidewalks and pedestrian pathways, offering durability and visual contrast to vehicle lanes. Finally, including solar-powered traffic signals and clear signage further enhances visibility and safety, ensuring that drivers and pedestrians are well-informed and protected in the school zone.

5. STAKEHOLDER ALIGNMENT & ENGAGEMENT

The success of this study hinges on the development of a strong methodology and strategic framework that aligns with stakeholders through four key pillars (*Esmail, 2015*), each representing a step in the continuous improvement cycle for enhancing traffic safety around schools:

1. **Identification**: The first step in this study is to gather relevant legislation and input from key stakeholders. These stakeholders, including government agencies, private sector entities, community groups, and educational institutions, play a pivotal role in shaping the direction of this study and directly or indirectly impact traffic safety around schools.
2. **Engagement**: A comprehensive analysis and review are conducted to identify existing and proposed legislation and policies affecting traffic safety around schools. This phase also involves proposing amendments or new policies. Crucially, this is done with active stakeholder engagement, underscoring the participatory nature of this study and our commitment to enhancing traffic safety.
3. **Collaboration**: Implement procedures and foster collaboration among stakeholders to develop, implement, and support traffic safety measures around schools. This includes joint planning sessions, participation in traffic safety campaigns, and incorporating constructive feedback on infrastructure improvement studies and traffic solutions.
4. **Evaluation**: Analyzing outcomes and assessing the effectiveness of road safety initiatives and the stakeholder alignment process. This is achieved by evaluating traffic crash data, gathering feedback from stakeholders and the community, and assessing the impact of the implemented measures.

Moreover, the Stakeholder Matrix, also known as the Stakeholder Mapping and Analysis Matrix, is an essential tool for visualizing stakeholder engagement strategies and prioritizing future actions and communication approaches (*Slaba, 2016*). This matrix categorizes stakeholders into four distinct groups based on their influence and interest levels (**Figure 9**):

- **High Influence, High Interest**: These stakeholders possess significant influence over the study and demonstrate a high level of interest in its outcomes. It is essential to thoroughly gather their relevant inputs and references to ensure their needs are addressed and their influence is leveraged constructively. This list includes: Riyadh Municipality, Ministry of Education, Ministry of Municipal Rural Affairs and Housing, Ministry of Interior - Traffic Department, Transport General Authority, IRAP, Saudi Traffic Safety Society.

- **High Influence, Low Interest**: Stakeholders in this group have the potential to influence the study but may have a lower level of interest in its outcomes. The objective is to maintain their satisfaction by keeping them informed and supportive, without overwhelming them with the intricate details of the study. This list includes: Ministry of Health, Ministry of Transport and Logistic Services, General Directorate of Civil Defense, Roads General Authority, Green Riyadh/ Royal Commission for Riyadh City, Royal Commission for Riyadh City.

- **Low Influence, High Interest:** These stakeholders have a strong interest in the study but need more ability to influence its direction. It is important to keep them informed of the study's outcomes to sustain their support and leverage their potential to shape broader public opinion positively. This group includes: Saudi Red Crescent Authority, Najm, School safety and security management, World Bank, Saudi Council of Engineers, Academic Institutions, Engineering Consulting Firms and Expertise Houses.

- **Low Influence, Low Interest:** Stakeholders with low influence and interest may have minimal direct impact on the study; however, they should be monitored if their level of interest or influence changes. This group includes: Saudi Authority for Data and Artificial Intelligence, General Authority for Statistics, Saudi Census, Saudi Standards, Metrology and Quality Organization, Saudi Open Data portal.

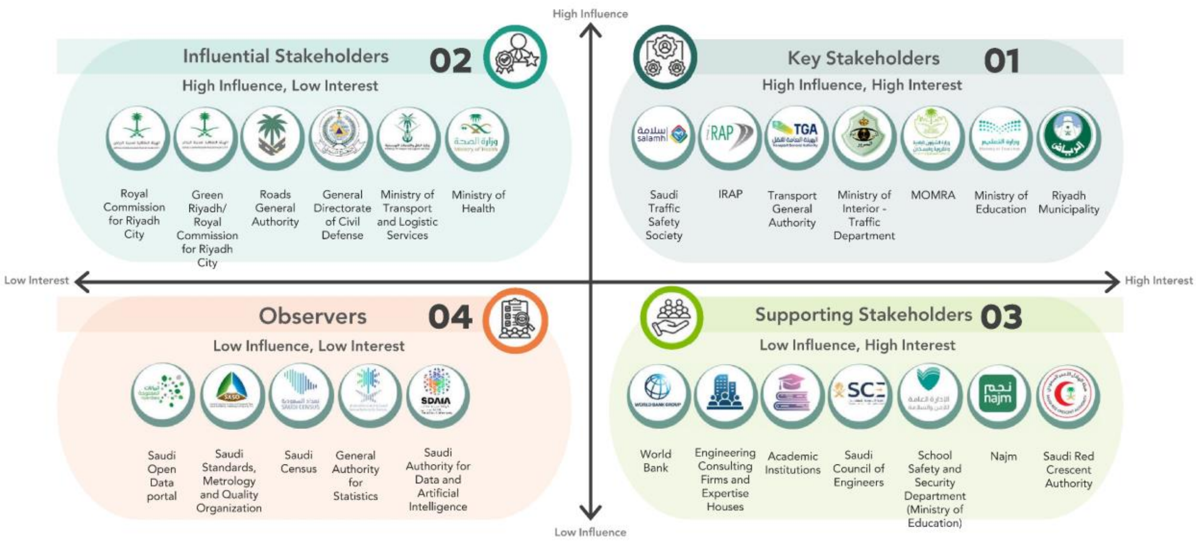


Figure 9. Stakeholder Mapping (*Developed by the Authors*)

The visual representation in the Stakeholder Matrix shown in **Figure 9** is crucial to the success of the study. It clarifies the roles and priorities of each stakeholder group and ensures that engagement strategies are tailored to maximize their influence and interest effectively. By categorizing stakeholders into distinct groups, the matrix allows for a strategic approach to collaboration, ensuring that high-influence stakeholders are engaged closely while maintaining clear communication with those who have significant interest but less influence. This alignment and engagement are crucial for driving the study forward, fostering collaboration, and ultimately achieving the goal of enhanced traffic safety around schools.

6. DETAILED SCOPE DEFINITION & CLASSIFICATION

The integration of the iRAP (*iRAP, 2024*) and SR4S (*SR4S, 2024*) System is critical, as it offers a globally recognized framework for analyzing available data and developing a criteria matrix for assessing road safety conditions around schools (**Figure 10**). The iRAP-SR4S methodology was utilized to analyze available data and develop a criteria matrix for over 5,000 school zones in Riyadh. This approach aimed to identify the schools with the highest priority for traffic safety improvements within the study scope (Phase-1) in Riyadh.

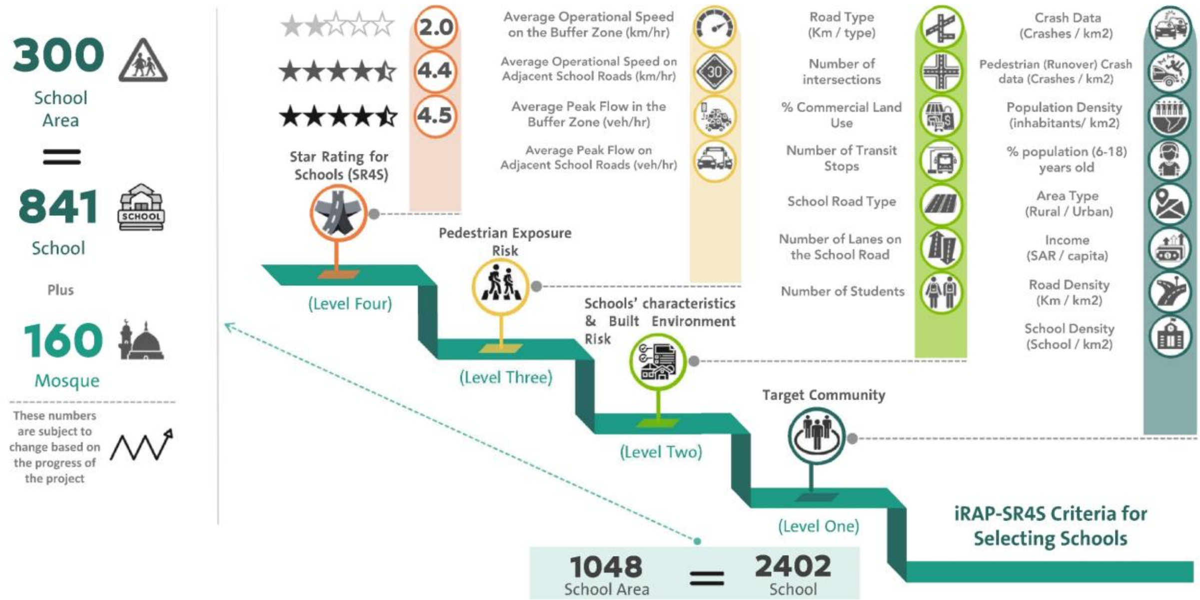


Figure 10. Stakeholder Mapping (*Developed by the Authors*)

Certain school areas were excluded from the analysis in the first phase of the study for various reasons, as follows:

- **Private Schools**: All private schools were excluded from the first phase, totaling 2,540 out of 5,416 schools.
- **Schools in Areas with Incomplete Data**: Schools located outside urban boundaries, where urban data was unavailable, were excluded. This category included 170 schools.
- **Special Use Areas**: The list of government schools included several located in special-use areas. The team excluded these schools as they were not prioritized, totaling 252 schools.
- **Inactive (Closed) Schools**: Several government schools were marked as closed. Consequently, 51 schools were excluded from the database used to define the study scope.
- **Non-Existent Schools**: One school found not to exist in reality was also excluded.

As a result, 2,402 schools, which are located within 1,048 school areas (as some schools are situated within the same area), will undergo the iRAP-SR4S school assessment and prioritization methodology. As shown in **Figure (10)**, the iRAP-SR4S methodology employs four fundamental levels of analysis (*SR4S, 2024*):

1. **Target community:** This level involves the analysis of various attributes to assess and enhance road safety around schools. This level is designed to identify and target high-priority communities by leveraging available data from census data, traffic analysis zones (TAZs), and neighborhood boundaries. Data include:

- Crash Data (Crashes / km^2).
- Pedestrian (Runover) Crash data (Crashes / km^2).
- Population Density (inhabitants/ km2).
- % population (6-18) years old.
- Area Type (Rural / Urban).
- Income (SAR / capita).
- Road Density (Km / km^2).
- School Density (School / km^2).

2. **Schools' Characteristics & Built Environment Risk:** This level focuses on evaluating the school environment, specifically the surrounding area known as the buffer zone. All potential entry routes for students must be considered for school road attributes. Additionally, this level addresses school characteristics, incorporating data related to the number of students and school operating hours.
   - Road Type (Km / type).
   - Number of Intersections.
   - % Commercial Land Use.
   - Number of Transit Stops.
   - School Road Type.
   - Number of Lanes on the School Road.
   - Number of Students.
3. **Pedestrian Exposure Risk:** At this level, the potential risks to pedestrians, particularly schoolchildren, are assessed by analyzing traffic flow and vehicle speeds in the vicinity of schools. The impact of vehicle speed on pedestrian safety is significant, as the chances of survival in the event of an crash decrease substantially with increasing speed (*Hussain, 2019*). Additionally, strong evidence indicates a strong correlation between vehicle flow, high traffic volumes, and the increased likelihood of pedestrian collisions (*Retting, 2003*).
   - Average Operational Speed on the Buffer Zone (km/hr).
   - Average Operational Speed on Adjacent School Roads (km/hr).
   - Average Peak Flow in the Buffer Zone (veh/hr).
   - Average Peak Flow on Adjacent School Roads (veh/hr).
4. **Star Rating for Schools (SR4S):** This fourth and final level of the evaluation methodology integrates the data and analysis results from the previous three levels along with additional specific factors that may impact each individual school.

The SR4S system evaluates the safety performance of roads surrounding schools and identifies risk factors contributing to road crashes and injuries. By applying this methodology, safety levels can be measured before and after improvements to the roads and surrounding areas, using star ratings that range from 1 star (least safe) to 5 stars (most safe). This star rating system enables a clear and objective comparison of safety conditions across different school zones, aiding in identifying areas most in need of intervention. To address the most vulnerable and high-risk environments, it is critical to select schools for road safety improvements. The iRAP methodology, particularly the SR4S system, provides a rigorous framework for this selection process.

The database was developed and organized using ArcGIS Pro (*Esri, 2024*) into five distinct categories, each representing specific data layers (**Figure 11**).

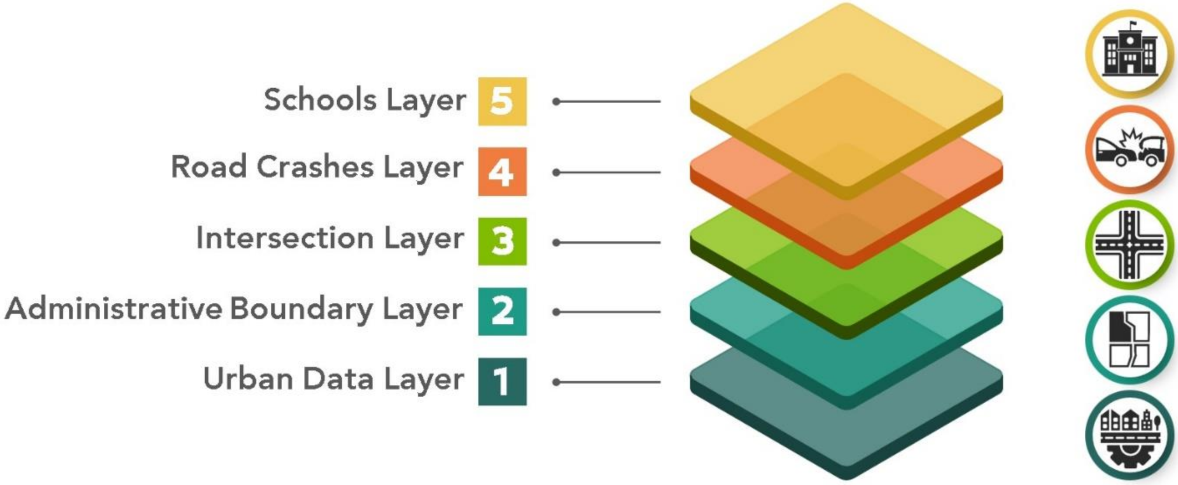


Figure 11. Study Data Layers on GIS (*Developed by the Authors*)

Geodatabases are structured to encompass multiple layers of data, each representing a distinct aspect of the urban environment, traffic, and infrastructure surrounding school areas. The process of constructing geodatabases involves the following stages:

1. **Defining the requirements for database development and designing the data model.**
   Setting clear objectives for the database entails identifying its specific data needs and ensuring that the included data is both suitable (relevant to the objectives) and sufficient (comprehensive enough to meet those objectives). Additionally, the structure of the data model must efficiently organize and relate the various data layers. A rich data model ensures that the database can handle the required data types and relationships, supports the intended analyses, and is scalable for future needs.
2. **Inputting and processing data according to the geodatabase construction plan.**
   Inputting spatial and descriptive data: including layers for administrative boundaries (district boundaries, sub-municipal boundaries, geographic sector boundaries), land parcels and land use, road networks, population data, as well as social and demographic characteristics.
3. **Calibrating, analyzing, and classifying the foundational data within the geodatabase.**
   Database evaluation and optimization: excluding irrelevant schools, defining school zones and impact areas, and aligning street layer data with local standards and guidelines.
4. **Generating descriptive information for the data and defining areas of influence.**
   Input road data, including speed limits, average daily traffic volumes, and street classifications. Populate the database with public transport routes and stations and identify schools with high crash densities and critical traffic intersections.
5. **Specifying the detailed scope of work.**
   The database encompasses information on iRAP criteria for school selection, outputs from the calibration and analysis process, and the ranking of schools based on all criteria. This data is used to generate a priority list for the 300 school zones targeted in the first phase of the study.

The concept of the school area encompasses the area directly adjacent to the school, including nearby streets and intersections. A school area may include more than one school, depending on the locations of the schools within its boundaries. The boundaries of the school area are determined by analyzing the adjacent streets closest to the school, which have the most significant impact on traffic safety, per the standards of the iRAP. The school buffer zone, or school zone, around each school was delineated using a polygon with specific distances, including both the early warning zone and the speed reduction zone. The designated impact zone extends between 200 and 300 meters from the school boundaries, representing the critical areas where safety measures must be implemented. Additionally, this zone includes relevant data within a 210-meter range from the school boundaries, as illustrated in **Figure (12)**.

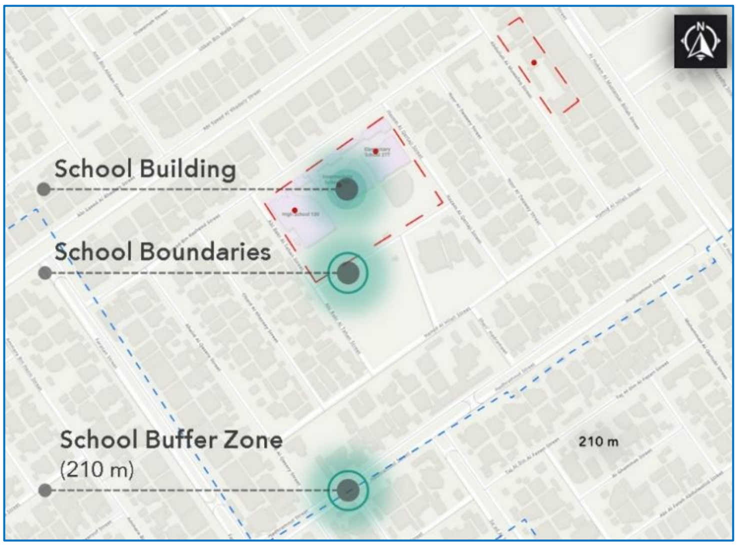


Figure 12. School Building, Boundaries, and School Buffer zone (*Developed by the Authors*)

In data analysis and modeling, managing different data types is a fundamental challenge, as data typically comes in two primary forms (*UA, 2024*), with additional subtypes, as summarized in **Figure 13**. The effective integration and analysis of these diverse data types are critical for deriving accurate and meaningful insights, especially when considering the nineteen (19) data variables within the evaluation criteria, according to the iRAP-SR4S methodology. The processes of data standardization and normalization play a pivotal role in this study.

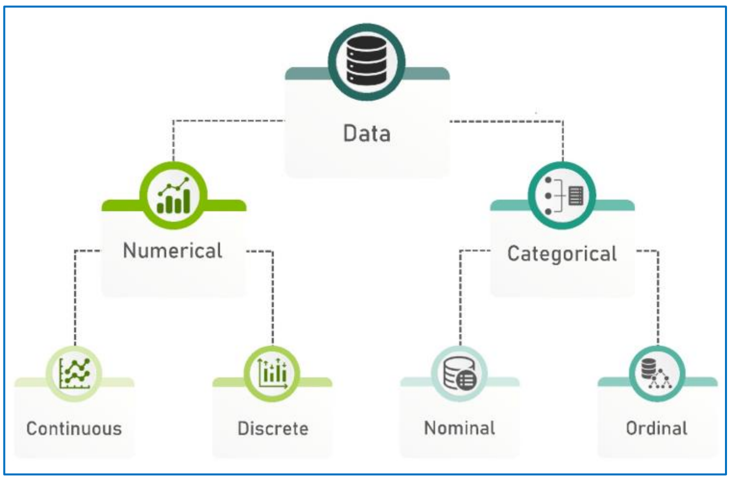


Figure 13. Types of Data (*Developed by the Authors*)

Data normalization is a statistical technique used to adjust values measured on different scales to a common scale, typically within the range of 0 to 1 (*Codecademy, 2024*). In this study, the data normalization process was performed using Min-Max scaling, one of the most widely used methods for data normalization. In this method, the minimum value for a given criterion is mapped to zero (0), the maximum value is mapped to one hundred (100), and all other values are scaled proportionally between the minimum (0) and maximum (100), as shown in Equation-1 (*Codecademy, 2024*).

$$\text{Normalized Value} = \frac{Actual\,Value - Min\,Value}{Max\,Value - Min\,Value} * 100 \qquad \textbf{(1)}$$

The formula in Equation-1 is employed to convert actual values to a uniform range between zero (0) and one hundred (100). In this context:

- **Actual Value** represents the value to be standardized.
- **Minimum Value** represents the lowest value in the dataset.
- **Maximum Value** represents the highest value in the dataset.

Figure 14 provides a clear visual representation of the ranking of school areas (Rank) on the x-axis. The iRAP Total Score, a key determinant of a district's priority, is represented on the y-axis. The lower the iRAP Total Score, the higher the priority, and vice versa.

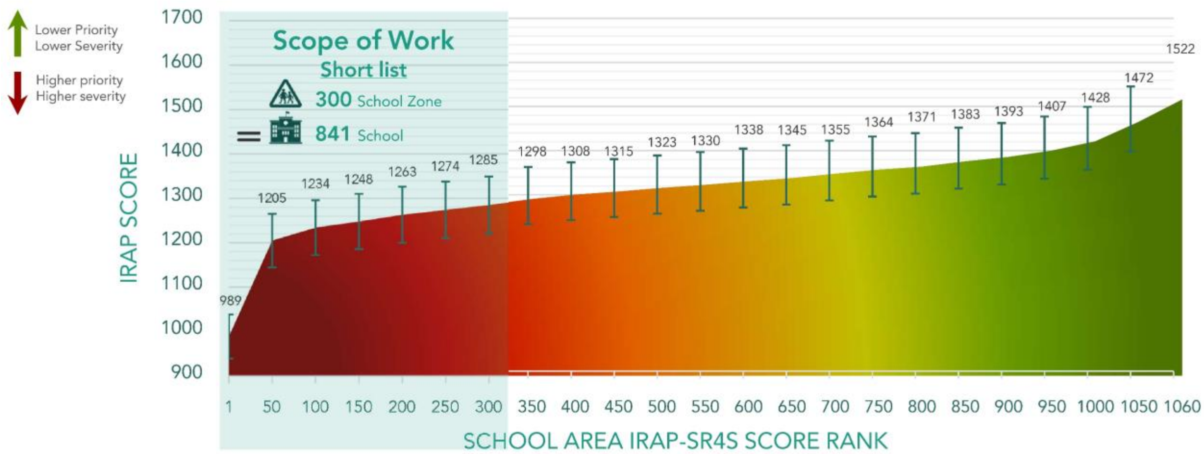


Figure 14. School Area iRAP-SR4S Score Rank (*Developed by the Authors*)

The iRAP-SR4S school, assessment and prioritization methodology, implemented in this study is a powerful and sustainable approach to enhancing traffic safety across Riyadh's schools. With 2,402 schools located within 1,048 school areas undergoing this rigorous evaluation, the study is meticulously structured to first address the most critical safety concerns. The methodology's strength lies in its ability to systematically rank and prioritize school zones based on a comprehensive set of criteria, ensuring that areas with the highest risk are targeted for immediate intervention.

The first phase of the study strategically focuses on the top 300 school areas, which include 841 schools and 160 mosques, as identified by their iRAP scores. This targeted approach ensures that efforts are concentrated on the zones where safety improvements will have the most significant impact. By prioritizing these areas, the study not only addresses urgent safety needs but also sets a precedent for continuous improvement in school zone safety throughout Riyadh City.

The graph in **Figure (14)** visually represents the prioritization process, clearly illustrating how school areas are ranked according to their risk levels. The graph highlights the gradient from high-priority, high-severity zones to lower-priority areas, ensuring that decision-makers can easily identify where interventions are most needed. This visual tool is crucial for maintaining transparency in the decision-making process and for communicating the rationale behind the prioritization to stakeholders and the broader community.

One of the key benefits of this methodology is its inherent sustainability. By establishing a full-bodied ranking and prioritization framework, the study enables ongoing assessments that can adapt to changing conditions over time. As new data becomes available, or as interventions are implemented, the ranking can be updated, ensuring that the prioritization remains relevant and effective. This dynamic process allows for the continuous monitoring and reassessment of school zones, promoting long-term safety and the efficient allocation of resources.

Moreover, the inclusion of 160 mosques within the same school areas underscores the holistic approach of the study. Recognizing that traffic safety concerns extend beyond school boundaries, the study incorporates these religious sites into the prioritization process, addressing the broader community's needs and ensuring that safety improvements benefit all road users, not just students.

In conclusion, the iRAP-SR4S methodology applied in this study exemplifies a forward-thinking approach to urban traffic safety. By focusing on data-driven prioritization, the study ensures that the most vulnerable and high-risk areas are addressed first, paving the way for sustainable and continuous improvements across Riyadh City. This methodology not only enhances the safety of school zones but also establishes a replicable model for other cities seeking to improve their road safety infrastructure. Through its structured, transparent, and adaptable approach, the study positions Riyadh as a leader in implementing effective and lasting traffic safety solutions.

7. COMPREHENSIVE TRAFFIC ASSESSMENT AND STRATEGIC PLANNING FOR SAFETY IMPROVEMENTS

As mentioned earlier, the first phase of the study strategically targets the top 300 school areas, encompassing 841 schools and 160 mosques, as prioritized by their iRAP scores. The next steps in this phase is guided by a comprehensive survey, traffic, and safety assessment methodology, structured into five key steps, and developed based on the iRAP and SR4S frameworks (**Figure 15**).

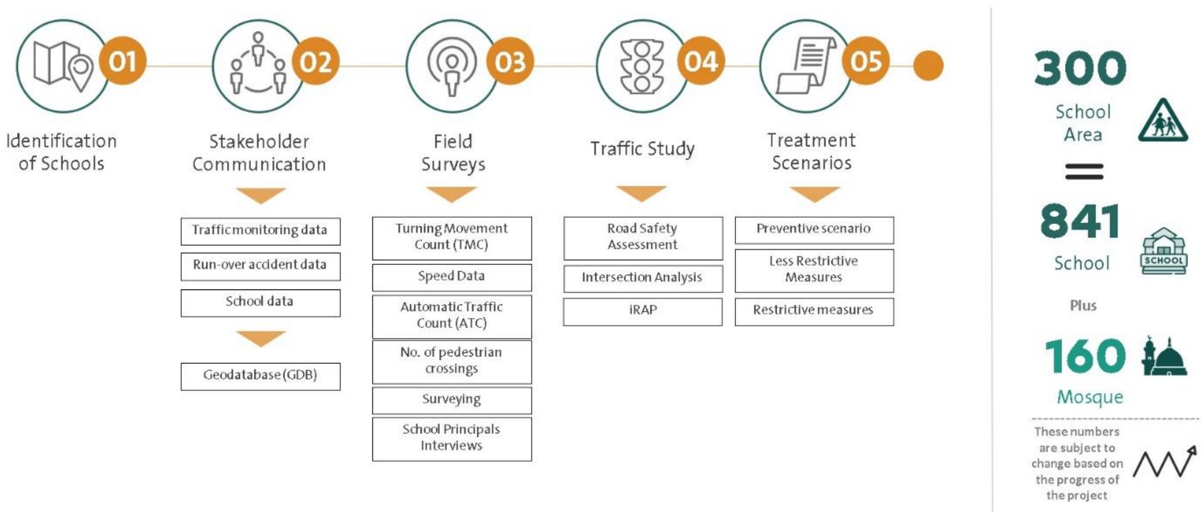


Figure 15. Key Steps After Schools Identifications (*Developed by the Authors*)

As shown in **Figure 15**, the first step involves identifying the schools and areas that require intervention, ensuring that the most critical zones are targeted. The second step focuses on engaging and aligning with stakeholders, collecting vital data such as traffic monitoring, run-over crash statistics, and specific school-related information, which is then integrated into a comprehensive geodatabase. The third step is conducting field surveys, which include time-motion studies, speed data collection, and pedestrian crossing assessments, alongside interviews with school principals to gain insights into local challenges. The fourth step entails a detailed traffic study, incorporating Road Safety Audits (RSA), intersection analysis, and the application of iRAP methodologies to evaluate current conditions and identify safety risks. The final step involves developing treatment scenarios, ranging from preventive measures to restrictive interventions, tailored to address the identified risks. This systematic approach, grounded in robust data and best practices, ensures that the study effectively engages key stakeholders and proposes context-sensitive solutions for improving traffic safety in school zones and around mosques.

7.1 Scope Survey and Comprehensive Traffic Inventory

In this study, the team conducted a topographic (Topo) survey of the school areas within the scope of influence, covering an approximate diameter of 500 meters or its equivalent in area, depending on the site's characteristics. This survey included all relevant features such as streets, pathways, sidewalks, traffic signs, traffic control devices, obstacles, surface utilities, trees, entrances, garages, and more.

The Topo Survey contained, but was not limited to, the following tasks:

- **Photography**: Comprehensive photographic documentation of the schools under study and all four sides of the study area (north, south, east, and west).
- **Three-Dimensional Photography using 360-Degree Technology**: Detailed 360-degree imaging of all four sides of the school area, allowing for a complete view of the study area from all angles.
- **Detailed Topographic Survey**: Includes all features within the school areas, such as medians, sidewalks, edges of sidewalks, adjacent buildings, intersections, building elevations, and their connections to the surrounding road network.
- **Point Cloud Technology**: Employed for comprehensive surveying of the school area, generating a large dataset of millions of points that accurately represent all area details.
- **Asphalt Boundaries and Surface Changes**: Documenting transitions in surface materials, such as from asphalt to tiles or interlock, to illustrate the intended uses of these spaces, whether for walking, parking, or vehicle passage.
- **Survey of Traffic Signs, Panels, and Control Devices**: Documentation of all types of signs, panels, and traffic lights, if present.
- **Survey of Infrastructure Service Openings**: Identification of all visible infrastructure elements, including drainage and utility holes, data or electricity access points, communication and water valves, lighting poles, trees, flower beds, and water wells.

Moreover, the team interviewed the school principals and leaders. They were engaging with school administrators to gather their insights, observations, and concerns regarding traffic safety. These interviews provide valuable information about traffic patterns, crash history, and specific safety issues affecting the school community within the district. Furthermore, the team conducted field surveys and comprehensive traffic counts in school areas during regular school hours, deliberately avoiding examination periods to ensure data accuracy. This approach was necessary because traffic volume patterns and peak hours—morning, afternoon, and evening—differ significantly during examination periods due to changes in school schedules.

Various field surveys and traffic counts were performed using advanced technologies, such as cameras equipped with Traffic Flow Data Collection systems and License Plate Recognition (LPR) systems. The key activities can be summarized as follows:

- **Automatic Traffic Counts (ATC)**: Conducted over three consecutive working days, with 24-hour data collection each day.
- **Classified Turning Movement Counts (TMC)**: Performed for all turning movements at intersections and road connections within the study area using TMC video cameras. Data was collected over one working day, with three hours during the morning school hours and three hours during the afternoon dismissal period.
- **Speed Survey**: Measurement of vehicle speeds on roads and streets surrounding the school area, carried out over three consecutive working days, with 24-hour data collection each day.
- **Parking Supply and Demand Analysis**: Determined by using video cameras to observe parking availability and usage around school areas over one working day, with three hours of observation during the morning school period and three hours during the afternoon dismissal period.
- **Drop-off Counts**: Monitoring of student drop-offs at school entrances and exits using video cameras over one working day, with three hours of observation during the morning school period and three hours during the afternoon dismissal period.

7.2 Traffic Analysis and Safety Element Audit

The study involves a comprehensive approach to traffic safety, starting with speed analysis and traffic calming techniques. Traffic data is analyzed to identify speed patterns, particularly in areas near school entrances and pedestrian crossings, comparing them with local and international standards to pinpoint deviations. Based on these findings, appropriate traffic calming measures, such as speed humps, raised crossings, and improved signage, are implemented through a carefully developed plan. The iRAP methodology is then applied to collect detailed data on road characteristics, traffic volumes, and crash history. Using the SR4S framework, safety within school zones is assessed, focusing on high-risk areas identified through iRAP risk maps, which are then prioritized for intervention. The study also includes general traffic analysis, evaluating traffic volumes, road capacity, and key intersections using delay and Level of Service (LOS) metrics. Pedestrian and bicycle traffic are assessed to ensure the safety of frequently used routes. Finally, design alternatives are developed based on three scenarios: a restrictive scenario involving comprehensive safety measures, a less restrictive scenario balancing safety and feasibility, and a preventive scenario focusing on proactive, low-cost interventions. This holistic approach ensures targeted and effective traffic safety improvements around schools.

7.3 Development of Detailed Executive Plans and the Submission of Final Study Deliverables and Recommendations

This final stage involves several key steps: first, preparing detailed geometric design plans that outline the engineering specifications for traffic safety improvements around schools. Next, landscape and site coordination plans are developed, integrating aesthetic and functional elements into the overall design. Comprehensive tables of quantities and tender documents are then prepared to guide the construction phases of the project. Finally, detailed executive plans are provided for each school, offering a clear roadmap for implementing the proposed improvements. Together, these steps ensure a well-coordinated and effective approach to enhancing school zone safety.

8. CONCLUSIONS

The study on improving traffic safety around schools and mosques in Riyadh has highlighted the critical need for targeted interventions in high-risk areas. Using the iRAP-SR4S methodology, this study successfully identified and prioritized 2,403 schools within 1,048 school areas, focusing first on the 300 most critical zones. The comprehensive approach, which included detailed data collection, traffic analysis, and the development of tailored safety interventions, has established a robust framework for enhancing traffic safety across the city.

The conclusions drawn from this study underscore the importance of a data-driven approach to traffic safety. The systematic analysis of speed, traffic volumes, and crash history clearly understood the most pressing safety issues in school zones. The application of traffic calming measures, such as speed humps and improved signage, was shown to be effective in reducing vehicle speeds and enhancing pedestrian safety, particularly around schools and mosques. Additionally, the involvement of stakeholders, including school administrators and community members, was crucial in ensuring the relevance and effectiveness of the proposed interventions.

However, the study also revealed several challenges that must be addressed in future phases. The need for continuous monitoring and adaptation of safety measures is paramount, given the dynamic nature of urban traffic environments. The integration of advanced technologies, such as real-time traffic monitoring systems and automated enforcement tools, is recommended to enhance the sustainability of the interventions. Furthermore, expanding the scope of the study to include private schools and areas with incomplete data will provide a more comprehensive assessment of traffic safety across Riyadh.

The following recommendations are proposed to ensure the ongoing success of traffic safety initiatives in Riyadh:

1. **Continuous Monitoring and Evaluation**: Implement a regular review process for traffic safety measures, utilizing real-time data to adjust interventions as needed.
2. **Expansion of Scope**: Include private schools and currently excluded areas in future assessments to ensure a comprehensive approach to city-wide traffic safety.
3. **Stakeholder Engagement**: Maintain and enhance collaboration with all relevant stakeholders, including government agencies, educational institutions, and community groups, to ensure the continued relevance and effectiveness of safety measures.
4. **Technology Integration**: Invest in advanced traffic monitoring and enforcement technologies to improve the efficiency and impact of traffic safety interventions.

By following these recommendations, Riyadh can continue to lead the implementation of effective, data-driven traffic safety solutions that protect vulnerable populations, particularly schoolchildren and worshippers, across the city. The methodology and approach outlined in this paper provide valuable insights and tools for stakeholders and decision-makers locally, regionally, and globally, serving as a model for enhancing traffic safety in diverse urban contexts.

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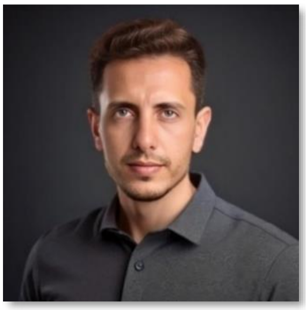

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Abstracts

Comparative Analysis: Determining the Best Fitted PV Technology and PV Cleaning Frequency – A Case Study in German University of Technology, Oman

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Abstract: The performance of a Photovoltaic (PV) module is a critical component that determines the effectiveness and success of a PV-based power system. The kind of PV technology chosen in relation to the local environmental conditions has a significant impact on the system's performance, thus, it is essential to choose the technology that will best capture the area's solar energy to supply and provide great efficiency throughout different seasons, while also being reasonably priced. The study analyses and compares three different silicon-based PV technologies: monocrystalline bifacial Passive Emitter and Rear Contact (PERC) technology, monocrystalline PERC technology, and multi-crystalline technology. In addition to studying how the considered technologies perform under different cleaning frequencies to determine the best-suited cleaning interval for Oman's climate. The optimum PV technology and cleaning frequency for the considered location were chosen based on two criteria: performance and cost. Jinko Monocrystalline PERC Module has the highest performance ratio comparing to others and it has low difference of efficiency within 8 weeks.

Keywords: Power, voltage, Current, Silicon-Based, Monocrystalline, Multi-Crystalline, Efficiency.

The influence of Adding Nanomaterials on Impact Strength of Epoxy Reinforced by E-Glass Chopped Fibers

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Abstract: Due to their high mechanical properties such as, light weight, high strength, relatively low cost, composite materials have attracted the interest of researchers to develop and improve new materials with cheaper cost to get better performance than the known alloys and individual materials. The effect of adding different nanomaterials with different weight percentage on the mechanical properties of chopped E-glass fibers reinforced epoxy composite has been studied. Mechanical properties, specifically (impact strength) are studied by the change in the nanomaterial content to study the behavior of the composite material when it is subjected an impact load. Three different weight fractions (0.5, 0.75, and 1wt.%) for the nanomaterials at 8wt.% of E-glass chopped fibers are studied in this research. Three types of nanomaterials were investigated (MWCNTs, GNP, and mixture of MWCNTs with GNP). Charpy impact test were done to the samples and results revealed that adding nanomaterials to the composite gives a significant enhancement for the impact strength. The best result achieved when adding a mixture of 0.5wt% MWCNTs and 0.5wt% of GNP that gave an enhancement of 407% compared to neat epoxy sample and a 244.7% compared to epoxy with 8wt.% chopped fibers.

Keywords: Epoxy; Composite; Chopped Fibers; Impact Strength; MWCNTs; GNP.

Design a Smart Thoracolumbosacral Orthosis Device

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Abstract—The Thoracolumbosacral Orthosis (TLSO) is essential in treating Degenerative Scoliosis, a condition characterized by twisting of the vertebral column. Treatment involves wearing the TLSO for at least 6 months. However, patients often experience muscle stiffness, necessitating frequent physical therapy sessions that are costly and time-consuming. The smart TLSO integrates a Neuromuscular Electrical Stimulation (NMES) device, controllable via a mobile application. This innovation aims to eliminate the dependency on therapy sessions, offering a more efficient and economical treatment option for patients. Moreover, the mobile application allows both patients and doctors to monitor treatment progress by collecting essential data, enhancing the overall management of the condition

Keywords— Scoliosis, TLSO, NMES, Mobile Application

Enhancing the Efficiency of Industrial Boilers and Burners Using Deep Learning Techniques

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Abstract: The process of boiler combustion is complicated, and the production environment is severe. The oxygen content in the flue gas is considered as a good indicator of boiler efficiency in any industrial process. Measuring the oxygen content in the flue gas need time, effort, and money. To overcome this, deep learning methods used effectively in the prediction of oxygen content of boiler flue gas. Moreover, many issues were encountered with the burners flame in industries. Hence, MATLAB and PYTHON techniques are that used widely to preform suitable models that can be used to solve this issue. They are considered as helpful tools to create mathematical model, test the machine, run automatic tests on equipment functions and design artificial intelligence algorithms for optimization purposes. In this research, deep learning tools were used to test the content of oxygen in the flue gas. Also, it investigates the ability of a deep learning methodologies in the segmentation of industrial burner flames based on example image data from a special waste incineration plant. Results shows that the model derived with the deep-belief algorithm produced better accuracy than the models generated by the other algorithms.

Key words: Boiler, Burner, Deep Learning Machine, Efficiency, Artificial Neural Network.

Feasibility Study of Using Produced Water from Oil and Gas Operations for Green Hydrogen Production

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Abstract: This research explores the feasibility of using water collected from oil and gas operations to create a green hydrogen manufacturing facility. By analysing the correlation between the efficiency of hydrogen generation and produced water quality parameters (pH, chemical oxygen demand, total hardness, and density), the research aims to optimize the electrolysis process. The project's main elements include creating a green hydrogen production prototype, rigorously testing and characterizing the electrolysis process, and conducting in-depth techno-economic evaluations to assess the technology's commercial potential.

Significant findings include identifying optimal parameters for maximizing the volumetric flow rate of hydrogen generation while maintaining a stable system temperature. A stable system temperature of 38.834°C was achieved with a volumetric flow rate of 594.152 ml/min, a pH of 6.7, COD of 426 mg/L, total hardness of 1.34 kg/m^3, and density of 1.153 g/cm^3. These conditions highlight the crucial role of pH in influencing temperature and volumetric flow rate, emphasizing the importance of balancing different water quality parameters to enhance system longevity and efficiency.

The research findings and methodologies underscore the potential of green hydrogen as a critical component of future energy systems, contributing to the broader agenda of sustainable development. By paving the way for the mainstream adoption of green hydrogen production through comprehensive analysis, this research aims to support environmental sustainability and address current energy challenges.

Key words: Optimization, Electrolysis, Volumetric Flow Rate, pH Levels, Techno-Economic Analysis.

Design and Modelling of Mechanical Systems for Hayat Mall in Hebron

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Abstract: This paper presents the comprehensive design of mechanical systems for the Hayat Mall, a large-scale commercial building currently under construction in Hebron, spanning eighteen floors and 68,191 square meters. The project focuses on optimizing HVAC, water supply, drainage, and firefighting systems to ensure a sustainable and efficient operation that meets the comfort needs of occupants. Using software such as Revit, Elite, and AutoCAD, the project covers thermal load calculations, material selection, and system design. The results indicate a significant reduction in energy consumption through modern HVAC solutions and compliance with safety and environmental standards for drainage and firefighting systems. The conclusions underscore the importance of integrated systems in achieving operational efficiency in commercial buildings.

Keywords: Mechanical Systems Design; HVAC; Firefighting Systems; Energy Efficiency; Revit Modeling.

GNSS/INS Navigation Solution for Autonomous Systems

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Abstract: In response to the rising demand for precise navigation across industries like autonomous vehicles, robotics, and unmanned aerial systems, the MARS Robotics team has developed a standard-precision solution integrating GNSS/INS technologies. Our system combines GNSS receivers with Inertial Navigation System (INS) technology, using advanced sensor fusion algorithms, including Kalman Filter, to achieve superior performance even in challenging environments. Rigorous testing has confirmed the system's reliability, offering Pitch and Roll accuracy of 0.5 degrees RMS, Yaw accuracy of 1 degree RMS static and 2 degrees RMS dynamic, and horizontal position accuracy of 2.6 meters RMS and velocity accuracy of 0.06 meters per second RMS. This places the solution in direct competition with industry leaders like XSENS and Inertial Sense. However, limitations in mitigating GNSS spoofing and jamming are addressed by an ongoing development of a Visual Navigation (VN) system to enhance performance in compromised environments.

Keywords: GNSS/INS; Spoofing; Jamming; Kalman Filter; Sensor Fusion

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Optimizing Pediatric Dental Clinic Operations: A Simulation-Based Analysis.

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Abstract: This report details a systems and industrial engineering project aimed at optimizing operations in group of private pediatric dental clinics in Kuwait using Arena Simulation Software by Rockwell Automation. The project focuses on identifying inefficiencies and proposing strategic improvements to enhance operational efficiency for clinic of 5 pediatric dental clinics. Key activities include developing a detailed simulation model to reflect real-life patient waiting time, dental work time and costs of operations by collecting data on patient flow and operations and engaging with stakeholders through interviews to understand challenges and build the simulation model. Various enhancement scenarios were evaluated through simulations to determine the most effective strategies for implementation. Simulation results show that reducing the pediatric clinics from five to four clinic reduced the cost by (3%) while increasing the profit by 1.5% per patient per day with increase in patient service time by 19%. In addition, it would be advised to consider a scenario of four pediatric clinics with extended work time to serve one extra patient with a 3% increase in profit per day compared to the four clinics with no extra working hours.

Keywords: *dental clinic, simulation model, ARENA Simulation Software, pediatric dental clinic*

Early Detection of Wildfire Using Convolutional Neural Network (CNN)

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Abstract: The level of Wildfire plays a critical role in recent years. the Detection of wildfires will be useful in avoiding their significant effects on agricultural activities and crop productivity due to soil dryness and the burning of crops in the fire-affected areas. Moreover, the primary purpose of this work is to enhance the use of deep learning methods to analyze and understand Wildfire. This paper presents a method for integrating data from wildfire UAVs with wildfire data from Jordan, focusing on image analysis through the VGG16 model. The approach involves employing Convolutional Neural Networks (CNNs) and deep learning techniques to accurately detect wildfires. The result showed that the system can classify Wildfire in approximately 98.05% of the 1,902 datasets. This contributes to advancements in algorithmic efficiency, computational infrastructure, and the scalability of climate modeling and analysis.

Keywords: Wildfire; Deep learning; CNN; VGG16

Performance assessment of photovoltaic thermal system: An overview

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Abstract: The escalating needs of contemporary society, the process of industrialization, and advancements in technology have substantially augmented the need for energy. Hence, the engineering industry is aggressively pursuing environmentally friendly and economically efficient energy solutions. One of the potential solutions to the issue is the photovoltaic thermal system (PVT), which seeks to harness both electrical and thermal energy from solar radiation. The purpose of this research is to examine computational and experimental studies that assess the thermal and electrical efficiency of solar energy systems. Additionally, the discussion includes the significance of incorporating PCM with nanoparticles in solar energy systems. During the evaluation process, it was clear that adding fins to the phase change material (PCM) made the electrical conversion efficiency much better, by 10.2% to 10.9%. Both computational and practical investigations have shown that using a hybrid cooling system, which includes water and PCM materials for temperature management, results in a superior performance enhancement of 18.5% compared to concentric solar cells that are only cooled by phase change material. The best cooling performance for solar cells was achieved with Al_2O_3/TiO_2 hybrid nanoparticles, which led to a 17.6% increase in electrical energy efficiency.

Keywords: Solar energy; Thermal energy; Electrical energy; PCM; Nanoparticles.

Modelling and Simulation of Bio-Hydrogen Production in a Sewage Treatment Plant: A Case Study in Oman

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Abstract: Simulating the production of hydrogen gas is a valuable tool for understanding and optimizing the underlying processes. In this study, Aspen-Plus is used as a versatile simulation software, to model and analyse biohydrogen gas production at standard temperature and pressure for a selected sewage treatment plant in Oman. The primary objective is to investigate the impact of varying temperature and pressure on the production rates of hydrogen, carbon dioxide, and acetic acid, with the aim of selecting optimal conditions for energy efficiency and product yield. The simulation findings reveal that temperature fluctuations have negligible effects on hydrogen and carbon dioxide production rates. However, acetic acid production is significantly hindered by elevated temperatures, leading to a decrease in its yield. To conserve energy and enhance acetic acid production for potential alternative uses, an operating temperature of 37°C is recommended. Regarding pressure, it is observed that alterations in pressure levels do not considerably affect hydrogen and acetic acid production rates. On the other hand, changing in the pressure affects the production rate of carbon dioxide. Therefore, the optimal operating pressure condition for mitigating the negative impact of carbon dioxide production is 101.325 kPa. By implementing these recommended temperature and pressure conditions, hydrogen gas production rates would range from approximately 84.76 kg H2/h to nearly 254.54 kg H2/h, depending on variations in the glucose input rate (ranging from 500 to 1,500 kg/h). This study demonstrates the efficacy of simulation-based approaches in optimizing biohydrogen gas production processes, offering insights that can lead to improved energy efficiency and increased yields of valuable byproducts like acetic acid.

Keywords: Bio-Hydrogen, Aspen-Plus, Sewage Treatment, Dark Fermentation, Sludge, Process optimization.

Intelligent Control Strategies for Permanent Magnet Synchronous Machines in Robotics and Automation

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Abstract: Permanent magnet synchronous machines (PMSMs) are of great interest in automation and robotics for their compact size, high efficiency, and low maintenance requirements. However, controlling their speed and position presents challenges, primarily due to the necessity for precise rotor position detection. This paper addresses the significance of accurate rotor position detection in such drive systems, along with strategies for controlling the operation of permanent magnet motors. Conventional controllers such as PID controllers are commonly employed but are often affected by changes in system dynamics, requiring periodic updates for controller parameters based on the precise mathematical model of the motor. This research aims to explore several intelligent control strategies that do not rely on the mathematical model of the PMSM. The performance of the PMSM drive system will be evaluated using various intelligent controllers, including a fuzzy logic controller, a neural network controller, an adaptive neuro-fuzzy inference system (ANFIS) controller, and a deep learning-based controller. The performance of these intelligent controllers will be compared against that of a PID controller, which relies on PMSM mathematical model to obtain optimal or suboptimal parameters of the controller. The results presented in this paper demonstrate the capability of the proposed smart controllers to effectively regulate the speed of PMSMs compared to a PID controller.

Keywords: PMSM, Rotor position detection, PID controller, Fuzzy control, Neural networks control, ANFIS controller, Deep learning controller, Brushless drive system.

Numerical Analysis of the effect of Upstream Obstacles on Aerodynamic Performance of NACA 65-421 Airfoil Using k-epsilon Model

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Abstract

This study presents a computational analysis of the aerodynamic performance of the NACA 65-421 airfoil in the presence of upstream obstacles, focusing on flow behavior and both lift and drag characteristics. The simulations were performed using ANSYS Fluent with the RNG k-ε turbulence model to capture the complex flow interactions and disturbances caused by obstacles. The analysis includes detailed evaluations of velocity magnitude contours and vectors, pressure distribution, velocity profiles, and lift and drag forces at key points on the airfoil, including the leading edge, trailing edge, and wake regions.

Despite the presence of upstream obstacles, which introduce flow disturbances, the airfoil maintained efficient aerodynamic performance. The velocity profiles at the leading edge reveal strong flow acceleration, generating significant lift, while the trailing edge and wake regions show moderate turbulence with quick velocity recovery, minimizing drag. The static pressure contours further validate the aerodynamic efficiency, with a high-pressure stagnation point at the leading edge and smooth pressure recovery towards the trailing edge. Overall, the study confirms the NACA 65-421 airfoil's robustness in maintaining low drag and steady lift, even under disturbed flow conditions, making it suitable for applications in environments with flow obstacles, such as urban wind energy systems or low-altitude flight. The results demonstrate a consistent lift coefficient of approximately 0.36 and a stable drag coefficient of around 0.006, both showing excellent agreement between experimental and numerical data. Also, it was found that the non-uniform inflow can cause localized fluctuations in pressure, particularly at the leading and trailing edges, which can affect the overall lift and drag.

Keywords: NACA 65-421, Airfoil, Obstacles, Aerodynamics, RNG k-ε, CFD

Low-Cost Fused Deposition Modeling (FDM) of Metallic Alloy

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Abstract: Additive manufacturing (AM) and its applications are growing and have the potential to revolutionize manufacturing as they can be used to create highly complex geometries with reduced lead, set-up, and production cycle times. In so doing, they could supplement, and potentially replace, traditional supply chains. However, metal AM has challenges including the availability and cost of powder production, the final price of the AM parts, and the quality of the part. Fused deposition modeling (FDM) is a low-cost AM technology due to the low equipment cost. With numerous parameters that affect the finished part, optimization of the parameters is conducted. The effect of the nozzle temperature, infill density, and sintering temperature on a 89% stainless steel 316L filament. Samples were printed in a hobbyist printed, then debinding and sintered in a normal atmosphere furnace. Results show the effect of nozzle temperature and infill density on the porosity of sintered samples. And the significant effect of heating rate in the debinding process on porosity. Results found that nozzle temperature, infill density, and heating rate affect porosity.

Keywords: Fused deposition modeling; Additive manufacturing; SS316L; Nozzle temperature; infill density; Sintering

Effect of Uniaxial Strain on Frequency Bandgaps of Lightweight Lattice Materials

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Abstract: Lattice-based materials, owing to their ability to deliver impressive structural properties at low weights, are used in composite sandwich structures designed for aerospace and naval applications. In these applications, the structural integrity of lattice materials needs to be assessed regularly and nondestructively. This work explores the potential for using low-frequency ultrasonic waves to detect damage in hexagonal lattices widely used as cores in sandwich structures. Damage is represented by superposing permanent strain fields on an otherwise perfect lattice. The effect of damage is detected by computationally determining the strain-induced changes in the lattice's acoustic properties, in particular, by detecting changes in its wave band gap characteristics. The effects of small and large strain fields are considered to determine the level of strains that can be detected using frequencies between 100kHz and 1000kHz. Results show that permanent strains significantly affect lattices' bandgaps and indicate that nondestructive evaluation techniques utilizing low to moderate ultrasonic frequency waves can be used to detect damage in lattice materials.

Keywords: aluminum honeycomb cores; nondestructive evaluation; acoustic characteristics; sandwich structures; finite element; bandgaps.

Investigation of Flexural Properties of Hybrid Copper-Aluminum Honeycomb Structures

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Abstract: Sandwich panel structures with aluminum honeycomb cores are renowned for their high stiffness and strength-to-weight ratios, making them ideal for diverse industrial applications. This study seeks to enhance the structural performance of these panels by improving the mechanical response of their honeycomb cores through the application of thin copper coatings. Finite Element Analysis (FEA) was conducted under three-point bending, following ASTM C393 standards, to assess the effects of coating thickness on the flexural and shear moduli of the hybrid copper-coated aluminum honeycombs. Commercially available aluminum honeycombs, fabricated from Al3003 alloy with a cell wall thickness of 0.07 mm, were used to ensure the relevance of the findings. Coating thicknesses of 10, 15, and 20 µm were modeled. Results demonstrate that copper coatings significantly improve the mechanical properties of aluminum honeycomb structures, enhancing the peak load by up to 37.68%.

Keywords: Finite Element Analysis, Hybrid coating, Honeycomb, Sandwich panels, three-point bending.

Experimental Investigation of the Performance of Bifacial Solar Panels Under Jordanian Climate Conditions

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ABSTRACT

In this study, a bifacial photovoltaic (PV) system, which is a dual-plate type of solar cell, is investigated for its performance under Jordanian climate conditions. Bifacial solar cells can produce more energy than monofacial solar cells by absorbing solar radiation on both sides—front and rear. This study focuses on the effect of varying the tilt angles (15º, 30º, and 45º) on the energy output of the bifacial PV system. Experiments were conducted in Amman, Jordan, during February, March, May, and June 2020. Measurements were taken at noon on sunny days to track irradiance and evaluate the performance of bifacial versus monofacial panels. The optimum tilt angle for the bifacial PV module was found to be 30º, yielding an efficiency of 19.9%, compared to the 14.7% efficiency of the monofacial panel.

Keywords: *Bifacial Solar Panels, Monofacial Solar Panels, Photovoltaic System, Tilt Angles, Energy Output, Jordanian Climate*

Innovative Cooling System of Raspberry Pi using Ultrasonic Resonant Device

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Abstract

This study explores the use of an ultrasonic resonant device (URD) as an innovative cooling system for a Raspberry Pi computer, typically utilized in vibration measurement devices. Traditional cooling fans, with known noise and vibration can interfere with sensitive measurements. Therefore, the project aims to employ a PZT (Piezoelectric) URD to generate airflow, minimizing the impact on measurement sensors.

The URD operates at a frequency of 34 kHz, significantly higher than the operational range of the measurement device, thereby eliminating interference.

The study includes a detailed computational fluid dynamics (CFD) analysis to evaluate the cooling performance of the URD. Initial conditions set the processor temperature at 60°C with a heat generation rate of 1W. The airflow, driven by the URD, enters at 25°C with a flow rate of Cubic meters per second (m3/s). The cooling system incorporates a heat sink made of pure aluminum, which aids in efficient heat dissipation.

Results from the CFD analysis indicate that the URD successfully reduces the processor temperature to a stable 33°C within a minute. The turbulence generated by the ultrasonic airflow enhances heat transfer, proving the system's efficacy over traditional fan-based cooling methods. The study also suggests potential improvements in the design of the enclosure and heat sink for better performance.

Thus, the ultrasonic resonant device presents a viable alternative to conventional cooling fans, offering noise-free and efficient cooling for sensitive electronic measurement applications. Further experimentation with different heat sink designs is planned to optimize the system's performance.

Keywords: Ultrasonic Resonant Device, Piezoelectric (PZT), Computational Fluid Dynamics (CFD), Noise Control, Vibration, Natural Frequency, Cooling System

The Impact of Energy Subsidies on Renewable Energy Competitiveness In Arab States

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Abstract:

This study examines the intricate relationships between fuel subsidies as a percentage of GDP (S/GDP) and the share of renewable energy in total final energy consumption (REN%) across various economic contexts. Using a Fixed Effects Vector Autoregression (FE-VAR) model with one lag, the research explores the temporal interactions and impacts of these variables on each other. The findings reveal that both S/GDP and REN% exhibit mean-reverting tendencies, where changes in one period are followed by adjustments in the next. A notable positive correlation is observed between past fuel subsidies and current renewable energy consumption, suggesting that higher past subsidies are linked to increased present renewable energy use. This unexpected result may reflect broader energy policy efforts to promote both conventional and renewable energy sources. Additionally, the study identifies a direct correlation between fuel subsidies and renewable energy usage, with variations across countries shaped by national policies, economic conditions, and energy plans.

Keywords: fuel subsidies; renewable energy; Fixed Effects Vector Autoregression; energy policy; sustainable energy transition

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Pre-design of a Hydroelectric Energy Storage System (HESS) at Wadi Mujib Dam, Jordan

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Abstract: This study presents a pre-design analysis for integrating a 1 MW solar power station with a Pumped Hydro Energy Storage (PHES) system at Wadi Mujib Dam, Jordan. The project aims to assess the feasibility of storing excess solar energy to enhance grid reliability and manage energy variability. The Wadi Mujib location offers suitable elevation and a natural reservoir, making it an ideal location for PHES. The methodology includes simulation-based energy analysis using Python and PVSyst, examining the efficiency of power generation and energy storage. The economic feasibility is evaluated based on capital costs, operational expenses, and expected revenue generation. Initial findings suggest that integrating a PHES system at Wadi Mujib can significantly enhance renewable energy utilization and offer a sustainable solution to energy storage challenges in Jordan. Environmental and social considerations are also reviewed to ensure compliance with local regulations.

Keywords: Solar energy, Pumped hydro storage, Energy storage, Feasibility analysis, Wadi Mujib Dam, Jordan.

Autopilot Triple Modular Redundancy Approach for Unmanned Aerial Vehicles

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Abstract: Tactical or MALE UAVs have a very high price components and any failure could lead to catastrophic consequences. By improving fault tolerance and reliability, this project aims to maintain safe navigation and mission continuity even in challenging conditions. The Triple Modular Redundancy (TMR) for UAV autopilot ensures reliable operation despite potential autopilot failures. The current phase of the autopilot TMR project focuses on autopilot outputs only, excluding redundancy for other components, such as sensors. TMR utilizes three parallel autopilot systems, with a voter that work based on a logic to determine the correct output by comparing the autopilots output and eliminating any deviating signals. This system ensures continuous functionality in complex environments and avoids risks associated with malfunctions. The voter logic employs a majority principle to manage differences among autopilot outputs, ensuring that any faulty output is excluded from the control process. Currently, the ground station connects to the TMR system via external transceiver, while autopilots communicate internally with the voter through a CAN bus. Data from each autopilot is compared in the voter system based on control surfaces deflections. The system checks for Variances, values outside the normal behavior, and noise. A scoring system is included to prioritize reliable autopilots.

Keywords: Triple Modular Redundancy; Reliability; Fault Tolerance; Fault Detection.

Experimental Study of Enhancement the Piezoelectric Energy Harvesting from Raindrop Impact by Employing Bioinspired Membrane

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Abstract: Energy harvesting devices are gaining popularity due to their potential as a clean and sustainable energy source. Low-power systems may function in remote locations without the need for battery replacement or other related maintenance once raindrop impact energy can be captured. The primary factor that renders conventional raindrop energy harvesters (REH) ineffective or impractical is their inadequate power output. To overcome this limitation, a bioinspired surface copying snake scale, created by using the kirigami tool is proposed in this research. The bioinspired surface acts as a membrane that can enhance the electricity production of REH by transferring more stretchability and stress deformation to the piezoelectric (PVDF). When the substrate was subjected to raindrop pressure, the power enhancement indicated by the transferred stress deformation to the PVDF of the bioinspired surface was examined and contrasted with its corresponding conventional harvester involving a plain surface. In this study, utilization of the fractal cut kirigami method to create cutting membrane level 2, level 3 alpha (α), and level 3 beta (β) patterns is conducted in this research. The level of the pattern indicates the density of the cutting. From the experiment, obtained that the level 3 alpha which also mentioned as kirigami type B can provide better performance with 0.0558 V at the maximum distance of the burette to the harvester surface (40 cm) which is almost 3 times better than the plain membrane. The whole kirigami will be combined together with the sequence kirigami C+B+A to give more stretchability. The result is that combination can perform better which can supply energy 0.001578 V/s to the capacitor and requires 79.2 seconds to flash bulb. This research will provide insight that the electricity generated by the piezoelectric raindrop energy harvester (PREH) system can be enhanced and used in regions with high rainfall intensity for different public facilities such as tents, umbrellas, awnings, temporary roofs, coverings, and tarps to provide power for sensing, lighting, signage, digital displays, etc.

Keywords: Raindrop Energy Harvester, Piezoelectric, Kirigami, Fractal Cut Pattern, Stretchability

AI in Supply Chain Risk Management: Identifying, Assessing, and Mitigating Risks

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Abstract: This literature review explores the changing landscape of supply chain risk management in the complex and dynamic global market of the present time. It discusses a variety of existing research on the topic and underlines the importance of managing supply chain risks effectively. It also highlights the role of (AI) and the significance of managing supply chain risks effectively. It also discusses the theories of resilience and continuity as responses to risks. Lastly, the review focuses on the development of advanced risk prediction models using AI and machine learning, the blending of AI algorithms for fraud detection, and real-time data analytics to manage supply chains. We argue that (AI) mitigates many known risks and therefore improvements in supply chain management rest heavily on its effectiveness. The main points are that AI enhances predictive accuracy, hones mitigation strategies, decreases operational disruption and advances decision-making informed by data. We hope to promote a shift towards using AI-enhanced applications of supply chain risk management to achieve a wider range of risk management goals, all the while maintaining a level of adaptability to manage high levels of complexity and rapid changes in the market and environmental externalities through a keen anticipation of risk.

Keywords: AI risk prediction; supply chain fraud detection; supply chain resilience; AI in supply chain management; risk mitigation; operational continuity

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Process Design of Sulphur Recovery from Hydrogen Sulphide (H2S) through Claus Process

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Abstract: The recovery of sulfur from hydrogen sulfide (H_2S)-containing gas streams is essential in industries like natural gas processing. The widely used Claus process is detailed in the research for extracting elemental sulfur from H_2S-rich gases. The study explores process design and optimization, aiming for efficient sulfur recovery and compliance with environmental regulations. The Claus process consists of thermal and catalytic sections, with thermal production accounting for 64% of the total elemental sulfur. The research involved simulation using the SULSIM package in HYSYS V.11, resulting in an overall efficiency of the Sulfur Recovery Unit (SRU) at 94.53%. Sensitivity analysis indicated that H_2S and SO_2 flare emissions were within acceptable limits, and the produced sulfur had high purity. Optimizing the process through simulation modeling, adjusting operating conditions, and including a Tail Gas Treatment (TGT) unit in the ASPEN HYSYS system can lead to significant improvements in efficiency and profitability.

Key words: Aspen HYSYS, Claus Process, CrystaSulf Process, Hydrogen Sulphide, Natural Gas, Pure Sulphur, Recovery Process, Sulphur Dioxide.

Industrial Energy Efficiency and Sustainability Using Phase Change Material

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Abstract: Phase change materials (PCMs) are substances which can store and release large amounts of energy at constant temperature during phase transition. They are broadly classified into three groups: organics, inorganics, and eutectics. Phase change materials have been utilized in all aspects of engineering, such as chemical, mechanical, material, civil, biomedical, industrial, and electrical engineering. The applications have been extended to the thermal management of solar panels, vehicles, building materials, lithium-ion batteries, electrical appliances, electronics, textiles, and biomedical applications. In this study a series of experimental runs have been performed under different conditions to evaluate a household refrigerator's performance utilizing Phase Change Materials (PCMs). The PCMs have been placed on the backside of the wire and tube condenser with cascade arrangement to absorb excessive heat from the condenser to reduce the surface temperature and enhance efficiency. All experimental runs have been conducted in standard room in Philver Company in Tehran, Iran. The objective of the research was to increase the off time of the compressor for reduction of electrical energy consumption. The results indicated that for the novel refrigerator, the condenser surface temperature was reduced significantly which led to coefficient of performance increase. The experimental results for the household refrigerator also prove that integration of PCMs on the condenser surface decreases the work time percentage from 32.7% to 27.6% and the energy consumption was reduced by 13%.

Keywords: Phase Change Materials, Refrigerator, Cascade, Eutectic, Energy management

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Mechanical Properties of PLA-CF Composites via FDM: Characterization and Optimization

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Abstract: The process of additive manufacturing (AM) involves depositing layers of material layer by layer to create 3D parts with complex geometries. There have been numerous engineering applications that have successfully utilized this process. FDM (fused deposition modeling) is a promising and widely used additive manufacturing technology, based on material extrusion. In addition to producing thermoplastic parts for functional applications, and simplifies material conversion by reducing waste, reducing costs. FDM-generated thermoplastic parts require improved mechanical properties, which are accomplished by enhancing pure thermoplastic mechanical performance. The thermoplastic matrix can be reinforced with reinforcement materials such as carbon fiber-reinforced polymer composites for applications in the engineering field. A study has been conducted to examine the effects of the FDM process parameters on the tensile and flexural properties of specimens. The material's mechanical properties were optimized using an experimental setup based on Taguchi L9. Following this, a desire-function analysis (DFA) was conducted. After extensive analysis, it has been determined that 0.3mm layer height, 210°C nozzle temperature, and 100% infill density are the optimal combination. This resulted in a tensile strength and modulus, the percentage of elongation, flexural stress, and modulus were determined to be 62.49052 MPa, 2796.05 MPa, 8.079%, 94.7249 MPa, and 3995.77 MPa respectively. To increase PLA's mechanical properties, this study investigated the possibility of adding CF. Results showed a significant increase in tensile and flexural strength and modulus. This paper presents a framework for investigating the mechanical properties and optimizing the process parameters of PLA-CF 3D-printed parts.

Keywords: FDM; Optimization; PLA-CF; Additive manufacturing; DFA

Digital Excellence in Supply Chain: Utilizing Lean Six Sigma for Integrated and Automated Solutions

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Abstract: Supply chain management (SCM) is vital for organizational sustainability amid evolving market dynamics influenced by health, lifestyle, and technological advancements, which all force supply chain (SC) members to re-evaluate their effectiveness individually and as a whole. A major evolution in quality management (QM) is Lean Six Sigma (LSS), which is a structured approach and a continuous improvement (CI) methodology that aims at customer satisfaction and waste reduction. SCM can utilize the LSS tools and CI principles to achieve high levels of customer satisfaction regarding cost, quality and delivery. This research builds on existing literature by providing a case study on LSS implementation in SCM, demonstrating the effectiveness of value stream mapping (VSM) in fostering SC improvements. VSM approach enables teams to reassess the existing system of processes from a broader perspective, identifying various challenges and opportunities across the value stream including physical operations, IT systems, and virtual customer service platforms, promoting stakeholder interaction and process simplification. Robotic process automation (RPA) automates repetitive manual tasks like invoice creation through computer programming. Outcomes include automated manual tasks, reduced cycle and lead times, minimized idle operator time, enhanced stakeholder communication, resulting in financial savings in the order of Millions of Dollars annually.

Keywords: Lean Six Sigma; Supply Chain Management; Value Stream Mapping, Robotic Process Automation.

Prediction of Stratified Flow Temperature Profiles in a Fully Insulated Environment

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Abstract

Thermal stratification is encountered in many situations. The flow of contaminants and hydrocarbons in environment often get stratified. The prediction of temperature profiles and flow characteristics are essential for HVAC applications, environment and energy management. The present paper presents a simple analytical model to predict the temperature profiles. The temperature profiles in the stratified region are successfully obtained, in terms of flow-operating functions. The analytical model agrees well with the published experimental data as well as the related closed-form solutions, which is helpful for HVAC applications. The model will be further developed and incorporated within a numerical model in order to investigate the flow field characteristics and establish correlations for a wide range of parameters.

Effects of Adding Nanofillers on the Tensile Properties of Epoxy and Hybrid Composites

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Abstract: Researchers are interested in developing and improving new materials with high mechanical properties, such as light weight, high strength, and cost-effectiveness. Composite materials have emerged as a promising solution, offering better performance than traditional alloys and individual materials. This study focuses on studying the effect of adding different nanomaterials with varying weight ratios on the mechanical properties of epoxy composites reinforced with chopped E-glass fibers. Specifically, the study examines changes in tensile and flexural stiffness based on nanomaterial content. Three different weight fractions (0.5, 0.75, and 1 wt.%) of nanomaterials were added to the composites containing 8 wt.% chopped glass fibers. Three types of nanomaterials were studied: MWCNTs, GNPs, and mixtures of MWCNTs with GNPs. Tensile and flexural tests were done to the samples and the results revealed that adding nanomaterials to the composite gives a significant enhancement for the mechanical properties. The results revealed that the optimal tensile strength achieved by combining 0.25GNP + 0.25MWCNTs, resulting in 51.4% reinforcement. In addition, the most significant improvement in flexural stiffness was observed by blending the epoxy with 8 wt.% CGF + 1 wt.% GNP, resulting in an overall increase of 176.4%. also, a numerical investigation was done using the software program (ANSYS APDL 17.2) to model the flexural samples and the results were in good agreement with the experimental results.

Keywords: Epoxy; Composite; Chopped Fibers; Tensile Properties; MWCNTs; GNP.

Numerical Analysis of the Aerodynamic Performance of NACA 65-421 Airfoil Using k-epsilon Turbulence Model

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Abstract
This study presents a computational analysis of the aerodynamic performance of the NACA 65-421 airfoil in the presence of upstream obstacles, focusing on flow behaviour and both lift and drag characteristics. The simulations were performed using ANSYS Fluent with the RNG k-epsilon turbulence model to capture the complex flow interactions and disturbances caused by obstacles. The analysis includes detailed evaluations of velocity magnitude, pressure distribution, and velocity profiles at key points on the airfoil, including the leading edge, trailing edge, and wake regions.

Despite the presence of upstream obstacles, which introduce flow disturbances, the airfoil maintained efficient aerodynamic performance. The velocity profiles at the leading edge reveal strong flow acceleration, generating significant lift, while the trailing edge and wake regions show moderate turbulence with quick velocity recovery, minimizing drag. The static pressure contours further validate the aerodynamic efficiency, with a high-pressure stagnation point at the leading edge and smooth pressure recovery towards the trailing edge. Overall, the study confirms the NACA 65-421 airfoil's robustness in maintaining low drag and steady lift, even under disturbed flow conditions, making it suitable for applications in environments with flow obstacles, such as urban wind energy systems or low-altitude flight. The results demonstrate a consistent lift coefficient of approximately 0.36 and a stable drag coefficient around 0.006, both showing excellent agreement between experimental and numerical data.

Keywords:NACA 65-421, Airfoil, Obstacles, Aerodynamics, RNG k-epsilon, CFD

Financial Innovations and Their Impact on Modern Supply Chain Operations

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Abstract: This research investigates how financial innovations, particularly FinTech, are reshaping supply chain management (SCM) by improving efficiency, transparency, and security. Technologies like blockchain and digital payments are central to this transformation, offering streamlined processes and enhanced traceability. The study aims to analyze the impact of FinTech on SCM efficiency, assessing cost reductions and operational improvements. It also evaluates transparency enhancements through blockchain, ensuring accurate and accountable transactions across supply chains. Furthermore, the research scrutinizes the security of financial transactions within SCM, focusing on the robustness of digital payment systems against cyber threats. Reviewing existing literature reveals consistent findings on the positive influence of FinTech on SCM, highlighting efficiency gains, increased transparency, and strengthened security measures. However, challenges such as initial adoption costs and integration complexities remain significant barriers. Looking forward, advancements in artificial intelligence and data analytics present opportunities for predictive insights and sustainable practices in global supply chains. Collaborative efforts among stakeholders and investments in technology infrastructure will be crucial to maximizing the potential of these innovations. Ultimately, this study contributes to understanding how financial innovations can optimize supply chain operations amidst evolving global demands and technological advancements.

Keywords: FinTech; AI in Supply Chain Management; Blockchain; Digital Payments; Transparency; Security

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Comparison of third order Euler's method with fourth order Runge-Kutta method for solving engineering problems

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Abstract

Obtaining the exact solution of some ordinary differential equations (ODEs) may have some mathematical difficulties. For these equations, we prefer to solve them numerically. In this paper, we use the third order Euler's numerical method to solve ordinary differential equations and compare the total absolute error obtained by this method. We then solve the same example using the fourth-order Runge-Kutta numerical method and found that the fourth-order Runge-Kutta method yields the smallest absolute error.

Submission Guidelines

1. Paper Requirements

The paper should start with the title, followed by the author's name, title, and e-mail address.

2. Originality of the Paper

It should not have been published earlier in any form.

The author must not send the pre-print manuscript to any other journal before a publishing decision is made.

3. Author's Responsibility

The author is fully responsible for all information included in their paper.

4. Summary Guidelines

The summary should not exceed 200 words.

Expected Formatting

Paper size: A4

Layout: One column, 2 cm margins

Font: Times New Roman

14 pt bold for the main title

12 pt bold for subtitles

12 pt regular for text and page numbering

11 pt regular for tables and graphs

9 pt for summary and references

Line spacing: 1.25

5. Images and Illustrations

Images and illustrations must be of high quality and comply with copyright laws.

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7. References

References should follow the ALA style, ensuring that all information is documented according to scientific standards.

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