Fayoum University Faculty of Engineering, 2024, Vol: 7(3), 144-159
https://fuje.journals.ekb.eg/
ISSN Online: 2537-0634
ISSN Print: 2537-0626

Balancing Economics and Performance for Building Design

Riham S. Hassan[1,*], Ramadan Abdel-Maksoud Ali[2], Riham Nady Faragallah[1]

[1] Architectural Engineering Department, Faculty of Engineering, Pharos University, Alexandria, Egypt
[2] Architectural Engineering Department, Faculty of Engineering, Alexandria University, Alexandria, Egypt
*Corresponding author: Riham S. Hassan (riham.sherif@pua.edu.eg).

How to cite this paper: Hassan, R.S., Ali, R.A-M & Faragallah, R.N. (2024). Balancing Economics and Performance for Building Design, *Fayoum University Journal of Engineering, Vol: 7(3), 144-159*
https://dx.doi.org/10.21608/FUJE.2024.285869.1074

Abstract

Design economics of buildings is significant for successful construction projects, involving analyzing costs and benefits of design choices to make informed decisions within budget constraints. Factors influence design economics, include policy attributes, location, building shape, area, floor height, building height, openings, construction methods, finishing systems, materials, labor and running cost. The scope of a construction project directly impacts its design economics, with larger projects requiring more resources and specialized materials. Traditional construction methods may be readily available, but they can be time-consuming and labor-intensive. However, innovative construction techniques can offer faster construction times, reduce labor costs and improve quality control. The study emphasizes the issues of project delays and increased costs, which could keep stakeholders from establishing new initiatives. The research aims to identify key factors influencing cost reduction in projects, including efficiency, life cycle, cost analysis, standardization, technology innovation, to optimize design economics and improve project performance with lowest cost. It presents a methodology for dealing with these factors that evaluate factors that manage project cost reduction is essential during architectural design phases, aiming to improve project performance and achieve the lowest facility cost with the highest performance. The housing design economics depend on the state's policy, market conditions, economic and social conditions. Understanding these factors is essential for architects, engineers and project managers to optimize design decisions and ensure economic viability by standards which provide a glimpse into the complex interplay of factors affecting design economics and highlights the importance of reaching the highest performance with lowest cost.

Keywords

Construction methods; Design economics; High performance; Low cost.

1.Introduction

Design economics is a field that examines the factors that influence the economic viability, cost-effectiveness and success of design projects. It emphasizes the need to understand and address these factors to achieve optimal design outcomes while balancing performance objectives with cost considerations. Factors influencing design projects include material selection, energy efficiency, construction methods and lifecycle considerations. Balancing these factors is a complex task.

The challenges of delaying project implementation and increasing actual costs is a significant issue, causing traders to hesitate to invest in new projects due to disruptions in investments, inflation of loan interest and delays in project operation and expected return. The study presents an approach to identify and address these factors, resulting in principles and standards. The economics of housing design depend on state policies, market conditions, economic and social conditions. By considering market conditions, policy regulations, social dynamics and design economics, architects and developers can achieve optimal performance in housing building projects. Understanding these factors is important for creating cost-effective and well-designed living spaces that cater to evolving needs.

The research aims optimize design economics by identifying key factors that contribute to cost reduction in projects. During architectural design phases, it's necessary to identify and address key factors that influence project cost reduction. This helps improve overall project performance and achieve the optimal balance between facility performance and the lowest possible construction and life-cycle costs. These include efficiency, value engineering, life cycle cost analysis, standardization and modularization, technology and innovation, risk management and collaboration. Efficiency involves optimizing space utilization, energy consumption and resource allocation to reduce waste and improve productivity. Value engineering involves analyzing design to identify cost savings without compromising performance. Life cycle cost analysis assesses the total cost of owning, operating and maintaining a design over its lifespan. Standardization and modularization can reduce costs and improve performance. Risk management strategies can mitigate potential risks early in the design process. Effective collaboration among project stakeholders is important for identifying and implementing cost-saving opportunities.

In this study, the key element is to determine the effectiveness of these factors on the project's cost and how they shape the economics of housing design. The study is divided into three parts. The first part is the theoretical study that provides a foundational understanding of the key determinants that architects must respect and consider in design economics through the policy factors and economic effect and factors affecting on site economics. The second part is the analytical study delves deeper into specific design considerations and their relationship to the structural systems of a building. By investigating the "relative coefficient for perimeter-to-area," this analytical approach helps identify optimal design solutions that achieve the highest performance standards while minimizing construction costs. The combination of theoretical and analytical studies enables architects to make decisions that lead to the most economically and structurally efficient building designs, ultimately benefiting both stakeholders and architects that leads to the third part are the Findings and Results, Conclusion, Recommendations and Limitations of the study **"Figure 1"**.

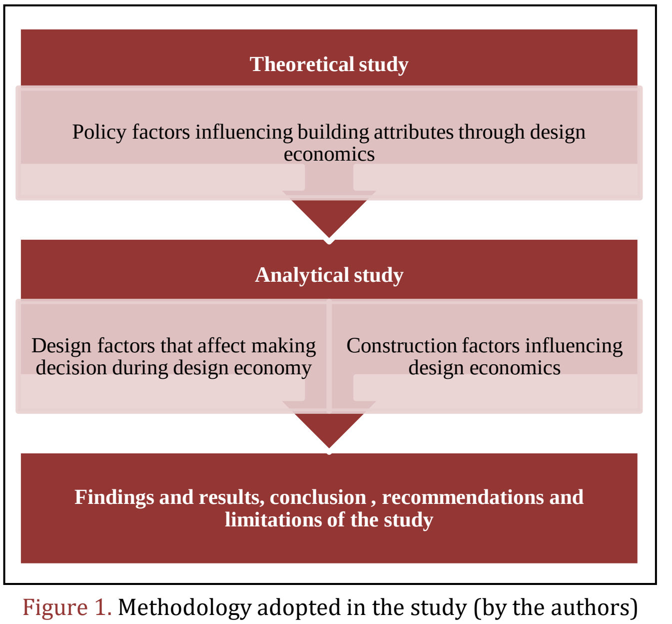


Figure 1. Methodology adopted in the study (by the authors)

2. Policy factors influencing building attributes through design economics

Egypt's housing and urban sectors have evolved since the 1950s, causing resource inefficiency. To address this, an integrated housing strategy focusing on social, economic and urban goals is needed, while identifying factors affecting buildability in the construction industry is aimed at optimizing resource use **"Figure 2"** (Sims & Abdel-Fattah, 2020).

2.1. Policy Factors and Economic Effect

Egypt's housing and urban industries have encountered obstacles stemming from policies leading to inefficiencies in resource management and discrepancies in accessibility. A comprehensive strategy is essential to provide cohesive solutions to address these issues (Sims & Abdel-Fattah, 2020).

- **Housing, History, Geography and Economy:** Egypt's Housing history is rich with modern and social housing dating back to European architectural styles. The economy was centralized from 1952-1970s, with a large agricultural sector and foreign investments. Post-2011 reform, foreign exchange reserves fell and inflation rose, indicating a modest economic recovery (Sims & Abdel-Fattah, 2016).
- **Housing as an economic sector and economic stimulus:** Housing and construction often linked to construction and real estate, significantly impacted the economy, contributing to 5.1% of factor cost in 2010-2013 and 25.5% of total employment in 2013. The sector's impact on employment and the economy is debated, with some arguing it's an end consumer good (Sims & Abdel-Fattah, 2016).

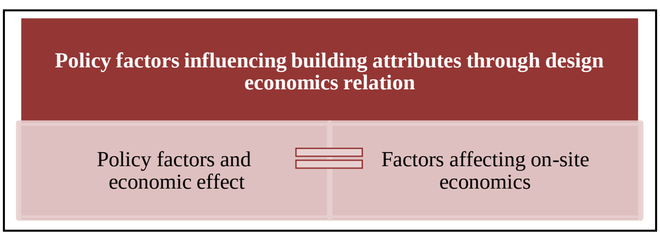


Figure 2. The relation between policy factors and building attributes through design economics (by the authors)

- **Government public housing 1952-1981:** Egypt has a long history of government-provided subsided public and cooperative housing since the 1950s aiming at lower-income households. Over the years, 1.1 million units of government housing were built, with an average annual rate of 37,790 units. In 1981, the subsidized rental system was changed to ownership allowing beneficiaries to own their units after 30-40 years (Sims & Abdel-Fattah, 2016).
- **Government housing production 1982- 2011:** Egypt's government housing programs from 1982-2005 produced 1.26 million units, with an average annual production of 54,700 units. However, target beneficiaries were not based on income or wealth thresholds and state subsidies were large, with 68% of every pound invested never recovering. Most government housing were located in new towns or on desert lands, making it difficult for beneficiaries to pursue normal livelihoods (Sims & Abdel-Fattah, 2016).
- **Housing policies in post 2011 in Egypt:** Since the 2011 revolution in Egypt, housing policies have primarily focused on government-financed and affordable housing. In 2013, the Social Housing Program was introduced, representing subsidized social housing in Egypt. Administered by the Ministry of Housing, Utilities and Urban Communities, it received funding from central budget allocations and the UAE Government (Sims & Abdel-Fattah, 2016).

Respecting policies are essential to leverage the impact of political factors on the characteristics of buildings. These policies are often outside the architect's control but play a significant role in shaping the fundamentals of design considerations. By adhering to relevant regulations and guidelines, architects can navigate the influence of political factors effectively. Incorporating these policies into the design process ensures compliance with legal requirements and promotes socially responsible architectural solutions. By embracing political factors and integrating policy considerations, architects can create buildings that not only meet regulatory standards but also contribute positively to the broader societal and environmental context.

2.2. Factors affecting on-site economics

This section aims to determine the buildability attributes of design appraisal by consulting literature on both buildability and constructability at the design stage.

- **Building law:** Egypt has implemented stringent building codes and standards to uphold safety and quality in construction endeavors, encompassing aspects such as structural design, fire safety and accessibility. Adherence to these regulations is compulsory for all construction ventures, guaranteeing the structural robustness and safety of residential structures. By enforcing these codes, Egypt aims to mitigate risks, enhance construction quality and safeguard the well-being of individuals residing in these buildings (Wong et al., 2006).
- **Site-specific factor topography and soil type:** Buildability is significantly influenced by the site's choice and type, with land value, location, soil quality and topography all playing significant roles. The choice of foundations, construction system and cost of implementation are all influenced by factors such as topography, including contour lines, main features, drainage patterns and natural landmarks can influence the number of floors and construction costs (Wong et al., 2006).
- **Site layout, access service, transportation and environment:** Designers address builder issues like access, layout, material storage and distribution during construction, especially in congested areas. Protective measures and efficient temporary work locations are major for good buildability while transportation impacts time and cost (Wong et al., 2006).
- **Infrastructure:** Project cost depends on minimizing underground construction time, ensuring safety and considering services and infrastructure elements. Distance and suitable locations can reduce paths and costs (Wong et al., 2006).
- **Weather:** Designs facilitate the enclosure of building at the earliest possible stage to exclude hindrance and damage because of bad weather (Wong et al., 2006).
- **Innovations and dealing with availability of implementation labor, tools, plant and equipment:** Innovative construction methods can reduce labor use and increase productivity by simplifying design details and standardizing tolerance specifications. Factors like labor availability, location and access to materials and equipment are essential for project economics, ensuring suitable skills and minimizing labor intensity (Wong et al., 2006).

3. Design Factors that affect making decision during design economy

Building costs are influenced by factors like shape, area, height, floor height and openings, requiring a balance between needs, expectations and resources, with cost and time constraints limiting standards and quality "**Figure 3**" (Cunningham, 2013).

3.1. Building Shape

The shape of a building determines the overall costs, with shape classification reflecting cost discrepancies resulting in variations of building outlines, a factor that varies across different building types. Building shapes can exhibit significant diversity, necessitating the reporting of base building costs for various shapes. The layout of a building is influenced by site constraints and functional needs, allowing for adjustments to accommodate irregular plots. Irregularly shaped buildings may incur higher costs due to factors such as increased external walls, excavation, drainage requirements, additional brickwork and roofing complexities. These cost implications underscore the importance of thoughtful consideration and planning in shaping buildings to optimize function and cost-efficiency (Cunningham, 2013).

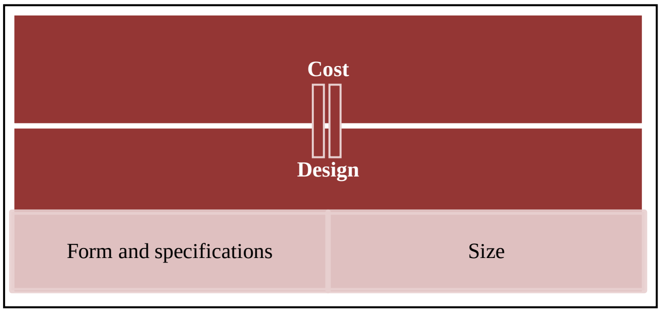


Figure 3. The relationship between design and cost (by the authors)

To calculate the cost of outer shape and by assuming that the height of the unit is 3m with y/m. Then,

$$\text{The cost/m}^2 = P*H*y/A. \quad (1)$$

"Equation (1)" could be defined as follows (Seeley, 1996):
P: Perimeter,
H: Height,
y: Assumption factor,
A: Area.

The shapes are divided into regular and irregular shapes, whereas the regular shapes classified into square, circular and rectangular shapes.

- **Regular Shapes:** Large, simple, rectangular buildings are more cost-effective due to economies of scale and efficient construction methods. Square-shaped buildings are simpler but may face challenges in internal lay-out planning. Circular buildings, despite their shorter perimeter can be costlier due to foundation construction issues, increasing costs by 20-30% "**Figure 4**" (S. Ibrahim et al., 2015).
- **Irregular Shapes:** The exterior wall system is most affected by changes in building plan layout, as indicated by the perimeter-to-floor ratio. The use of this ratio has been validated as a predictor of the effect of building shape on unit construction cost. Generally, larger buildings have lower unit construction costs due to economies of scale and reduced proportion of fixed costs. High-rise buildings may have a cost advantage due to the efficiency of serving a larger floor area and accommodating more occupants **"Figure 4"** (Ahmed Doko Ibrahim, 2003; A. Ibrahim, 2008).

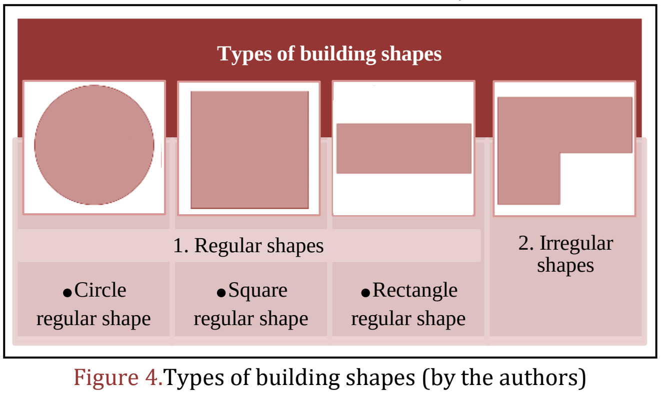


Figure 4.Types of building shapes (by the authors)

The shape of a building directly impacts its construction cost, causing increased costs for materials, services and finishings. Factors like longer services, waste pipes and additional costs for finishing and decoration also contribute to higher costs. The total construction cost increases with building height without affecting floor area. Increased irregularity in a building plan leads to higher unit construction and total project costs, making understanding these cost implications important for construction cost professionals (S. Ibrahim et al., 2015; A. Ibrahim, 2008).

3.2. Area

The cost per square meter of floor area is a unit-cost estimate for construction costs, measuring the total floor area of all storeys between external walls, but has drawbacks like determining the appropriate rate and imprecision in allowances (Ahmed Doko Ibrahim, 2003).

- **Gross Area:** Gross area is the total area of all floors of a building, including exterior walls, vertical penetration areas and shaft areas, excluding areas with less than 1.5m clear ceiling height unless a separate structure is met. To Calculate the Gross Area (Cyros & Korb, 2006).

$$\text{Gross Area} = N.A + S.S. \quad (2)$$

"Equation (2)" could be defined as follows:
N.A: Net Area,
S.S: Structural Space.

- **Net Area:** The net assignable area is the total floor area assigned to an occupant or specific use, calculated by physically measuring or scaling surfaces, excluding areas with less than 1.5m clear ceiling height. To Calculate the Net Area (Cyros & Korb, 2006).

$$\text{Net Area} = \text{Sum of areas designed.} \quad (3)$$

- **Perimeter-to-Floor Area:** The wall/floor ratio measures a building's planning efficiency. Circular buildings having the best ratio, but wall savings are usually offset by a 20-30% reduction in output. To Calculate the Perimeter-to-Floor Area and by assuming that the high of the unit is 3m (Ahmed Doko Ibrahim, 2003).

$$\text{Perimeter-to-Floor Area} = P*H/T.F.A. \quad (4)$$

"Equation (4)" could be defined as follows:
P: Perimeter,
H: Height,
T.F.A: Total Floor Area.

3.3. Floor Height

Floor height significantly impacts construction costs, with high-rise buildings being considered more expensive than low-rise ones. Storey heights also affect building costs, making it difficult to estimate costs using the cubic method due to the significant differences between buildings. Variations in storey heights can increase cooling volume, longer pipes, roof costs, stair-cases, lifts, ceiling finishing and potentially more expensive foundations (Ahmed Doko Ibrahim, 2003; Blackman & Picken, 2010).

3.4. Building Height

Building height is important in determining the best development project when considering future maintenance costs, property value and adjacent properties. Developers use the project profitability criterion to evaluate the ratio between development costs and income. Factors like permitted height, local area character, streetscape character, street views, potential overshadowing, local microclimate and taller elements influence decision-making. The unit building cost increases moderately with the height (Ahmed Doko Ibrahim, 2003; Żelazowski, 2015).

3.5. Openings

Building openings, forming 70%-80% of window area, significantly impact thermal and lighting comfort, natural daylighting and heat transfer. Costs vary based on frame and glazing types, materials, number of openings, area, wall ratio, shape, climatic factors and orientation (Walid Yehia AbdelHAdy El-Eshmawy et al., 2021).

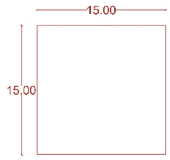
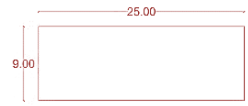
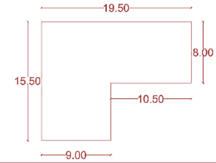
- **Materials used in the openings:** Understanding building windows and ventilation systems is crucial for energy efficiency, durability, aesthetics and cost effectiveness. Opening frames, glazing and visual transmittance affect performance, aesthetics and temperature (Forrest, 2012; Walid Yehia AbdelHAdy El-Eshmawy et al., 2021).
- **Window- to- Wall Ratio (WWR):** Window to wall ratio (WWR) significantly impacts energy performance in a building, affecting heating and cooling demand. Window size, affecting natural lighting has a 10% optimal WWR, with south windows having the worst impact (Eljojo, 2017; Muhaisen & Dabboor, 2015; Sayadi et al., 2021).
- **Window Orientation:** Window orientation affects natural ventilation and energy performance. Proper design, ensuring windows are parallel or less than 30º to inlet opening planes, can improve indoor air flow and reduce building costs (Eljojo, 2017; Idowu et al., 2018).

3.6. Methods and Assumption

This study explores the impact of building shape and reveals that complex building shapes are more expensive per square meter of floor area. Shape classification considers cost differences from variations in building outline and basic building costs are given for several shapes. The study focuses on four housing units connected to a staircase in a 7-story building with a height of 3.00m and no basements.

The buildings were differentiated based on their plan shapes, which could be square, rectangle, circle, or irregular shape. The residential units have the same area, characteristics and window areas. By considering the fixed design considerations, the following table can describe which building shape optimize to achieve highest performance through the relative coefficient value to lead to the estimated lowest cost **"Table 1"**.

Table 1. Factors that affect making decision during design economy to get the highest performance shape (by the authors).

	Shapes	Regular shapes			Irregular shape
		Circle shape	Square shape	Rectangular shape	Rectangular shape
					
Design Considerations	**Number of storyes**	**7**	**7**	**7**	**7**
	Floor Height	**3 m**	**3 m**	**3 m**	**3 m**
	Area	$\pi*r^2$= π*8.46 ^{2} =	*L*W*= 15*15 =	*L*W*= 25*9 =	$(L_1*W_1) + (L_2*W_2)$ = (9*15.5) + (8*10.5) =
		225 m²	**225 m²**	**225 m²**	**225 m²**
	Total Floor Area	$\pi*r^2$*No. of storyes= π*8.46^2*7 =	*L*W**No. of storyes= 15*15*7 =	*L*W**No. of storyes= 25*9*7 =	$((L_1*W_1) + (L_2*W_2))$ *No. of storyes= ((9*15.5) + (8*10.5)) *7 =
		1575 m²	**1575 m²**	**1575 m²**	**1575 m²**
	Perimeter	*2*π*r*= 2*π*8.46 =	*(L+W) *2*= (15+15) *2 =	*(L+W) *2*= (25+9) *2 =	(L_1+W_1) *2 + (L_2+W_2) *2 = (9+15.5) *2 + (8+10.5) *2 =
		53.17 m	**60 m**	**68 m**	**70 m**
	Perimeter-to-Floor Area Ratio	*P*H/T.F. A*= 53.17*3/1575 =	*P*H/T.F. A*= 60*3/1575 =	*P*H/T.F. A*= 68*3/1575 =	*P*H /T.F. A*= 70*3/1575 =
		0.64	**0.51**	**0.82**	**0.84**
	Volume (m3)	$\pi*r^2*H$*No. of storyes= π*8.46^2*3*7 =	*L*W*H**No. of storyes= 15*15*3*7 =	*L*W*H**No. of storyes= 25*9*3*7 =	$((L_1*W_1) + (L_2*W_2))$ *H**No. of storyes= ((9*15.5) + (8*10.5)) *3*7 =
		4725 m³	**4725 m³**	**4725 m³**	**4725 m³**
	Openings area (m2)	**22.5 m²**	**22.5 m²**	**22.5 m²**	**22.5 m²**
	Openings area (%)	**10%**	**10%**	**10%**	**10%**
	Estimated cost	Assuming y= 100/m²			
		*P*H*y/A*= 60*3*100/225=	*P*H*y/A*= 53.17*3*100/225=	*P*H*y/A*= 68*3*100/225=	*P*H*y/A*= 60*3*100/225=
		80/m²	**70.9/m²**	**90.6/m²**	**93.3/m²**
	The relative Coefficient Value	$P^2/F. A$= 53.17^2/225 =	$P^2/F. A$= 60^2/225 =	$P^2/F. A$= 68^2/225 =	$P^2/F. A$= 70^2/225 =
		12.56	**16**	**20.55**	**21.77**

To get the relative coefficient for perimeter-to-area, it is considered that the perimeter unit is m and the area unit is m², so the relation between the perimeter and area can be shown as Perimeter²: Area= m²/m² to be compared with the same units.

$$\text{The relative Coefficient Value} = P^2/A = 16. \qquad (5)$$

"Equation (5)" could be defined as follows:

P: Perimeter,

A: Area.

Circular buildings offer the best ratio, but their higher cost offsets the savings. Therefore, the best choice is square shape to get highest performance with lowest cost according to achieving the relative coefficient value.

4. Construction factors influencing design economics

Construction project changes are influenced by various factors, with design being the most influential. Construction project changes are influenced by design, material, location, quality, quantity, demand, stock availability, delivery time and transportation costs. Design changes lead to the greatest deviation in construction costs, requiring identification and evaluation for cost reduction (Yana et al., 2015).

4.1. Construction Systems

The evolution of construction systems has been shaped by various factors such as climate, location, soil conditions, culture and economics. Industrialization and the increasing societal emphasis on quality control have significantly impacted the characteristics of materials used and the structural performance of buildings. Construction systems are classified into two primary categories: the design of construction systems which encompasses traditional and semi-developed systems and the execution construction system which includes developed and prefabricated systems. These categorizations reflect the diverse approaches and methodologies employed in the construction industry to address the complex interplay of environmental, cultural and economic considerations in building design and implementation **"Figure 5"** (Tavares et al., 2014).

4.1.1. Traditional Systems

Traditional construction methods are based on human energy and vary across locations and countries. They are primordial and traditional, having been known since the beginning of man. These methods have evolved through trial and error, resulting in their current form. No strategy will quickly resemble another, but they share a common origin.

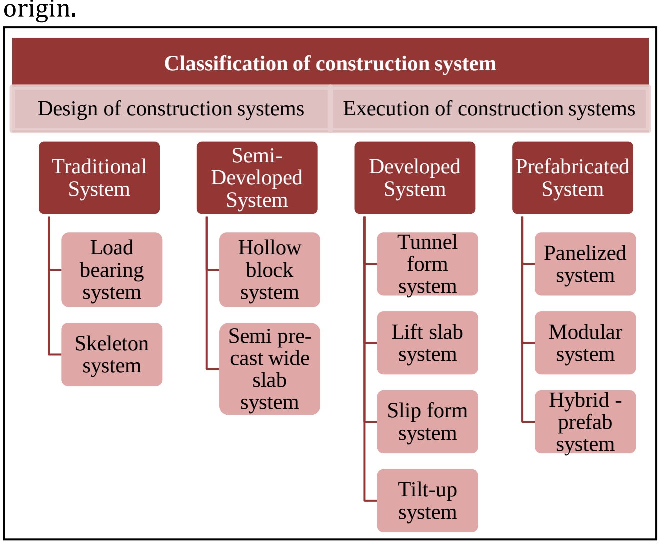


Figure 5. The classification of construction systems (by the authors).

- **Loadbearing System:** Load-bearing walls are increasingly popular in developed countries for large span buildings in factories, commercial premises and sports centers. These walls move the load vertically downward through the structure, from slabs to walls and foundation, supporting structural members like beams, slabs and walls on above floors **"Figure 6.a"**. Load-bearing structures are uneconomical as they require thicker walls and increased stress on the foundation as the building's height increases. They are suitable for low-rise buildings, residences and buildings with less than three floors due to lower brick prices and a foundation depth of 1.2m to 1.5m. However, they are not suitable for large structures, cantilever elements or large spans (Abdullah et al., 2015; Ramli, Abdullah, & Mohd Nawi, 2014; Ramli, Abdullah, & Nawi, 2014; Wahane et al., 2022).
- **Skeleton System:** The skeleton system is a construction method that uses columns to distribute roof loads, allowing for rapid building erection and flexible interior floor layouts. *The column and beam system* distribute loads in two directions, transferring floor, wall and slab weight to beams, columns, foundations and soil **"Figure 6.b"**. *Flat Slabs System* transfers load to columns without beams, suitable for long distances and 10m lengths, expanding when connected to the slab **"Figure 6.c"**. The skeleton system is a high-speed, easy-to-build method for tall multi-story buildings, allowing architectural design changes and sound insulation, but has disadvantages like varying loads, high costs and weak resistance to horizontal forces (Alprogrammer, 2008; Skeleton Frame - Designing Buildings, 2020).

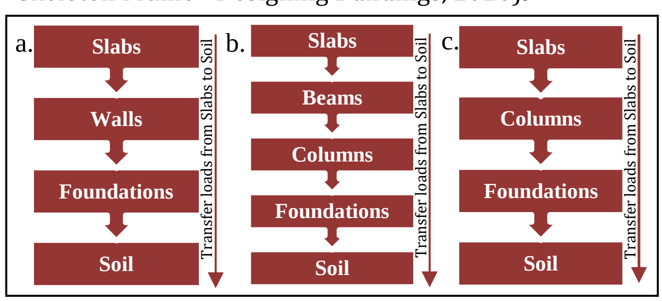


Figure 6.a. Load transform for load bearing system.
Figure 6.b. Load transformation for colomns and beams.
Figure 6.c. Load transformation for flat slab (by the authors).

4.1.2. Semi- Developed Systems

The construction system, similar to traditional Dubach buildings, uses precast nerves instead of concrete slabs, supported by walls and hollow forms and a concrete cover is poured over them, eliminating the need for wooden formwork.

- **Hollow block system:** The hollow block slab is a ceiling design method that combines cast-in-place and pre-cast systems. It involves lifting pre-cast ribs on columns with wide distances, placing blocks between them to form a top reinforcing mesh **"Figure 7"**. Steel cushions are constructed and a 5-iron mesh is laid over the blocks. Hollow blocks are made from materials like red blocks, cement blocks and blue styrene or cybersex. This technique is ideal for residential houses but has higher costs in small spaces and requires additional steelwork (Agrama et al., 2014; Alprogrammer, 2008).
- **Semi pre-cast wide slab system:** Its elements are: footing, column or bearing brick walls and pre-cast wide slabs. The foundation is isolated footing for cast-in-place columns and strip footing for bearing walls. The pre-cast slab is lifted by a crane to complete the skeleton. Slabs are used in various constructions, including solid units, hollow units, units box and T-shaped double units **"Figure 7"**. Solid units are suitable for ceiling tiles or walls but have high weight. Semi pre-cast wide slabs offer speedy implementation and wall preparation with various finishes, but require numerous connections and trained workers (Agrama et al., 2014).

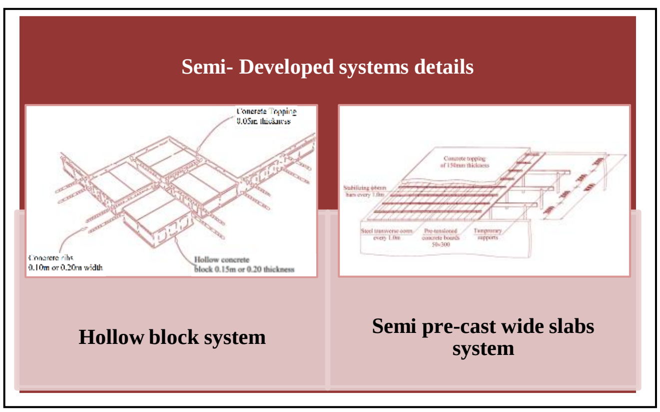


Figure 7. Semi- Developed systems details (adapted by the authors)(Paultre et al., 2013; Szydlowski & Szreniawa, 2017).

4.1.3. Developed Systems

Technological advancements in the 20th century have revolutionized construction requiring architects and professionals to create diverse building types, adapting architectural styles to specific purposes and materials (Alprogrammer, 2008).

- **Tunnel form system:** Tunnel form is a cost-effective, efficient formwork system for in-site concrete structures, suitable for high, medium or low-rise housing projects. It enhances productivity and reduces earthquake risks **"Figure 8"**. The design and construction of tunnel form projects depend on site layout, location and boundary conditions. It requires a 5m clearance for lifting 18 cm wall thickness form-work modules and requires workforce attention for quality. However, it's not suitable for small projects, high equipment costs and supplier dependency (Brooker & Hennessy, 2008; Chaudhary, 2017; Ilerisoy & Tuna, 2013; Miranda & Kodre, 2018; Tavafoghi & Eshghi, 2013).
- **Lift slab system:** Lift slab system is a cost-effective concrete construction method used in office buildings, apartments, parking garages and hotels. It involves casting floor and roof slabs and can save up to 20% in time and cost **"Figure 8".** This method offers advantages like minimal formwork, monolithic cast slabs, cantilevering and simplicity for isolated point block buildings, but requires special equipment for lifting and moving (Emmitt & Gorse, 2014; Randal, 1986; Zallen & Peraza, 2004; George et al., 2017).

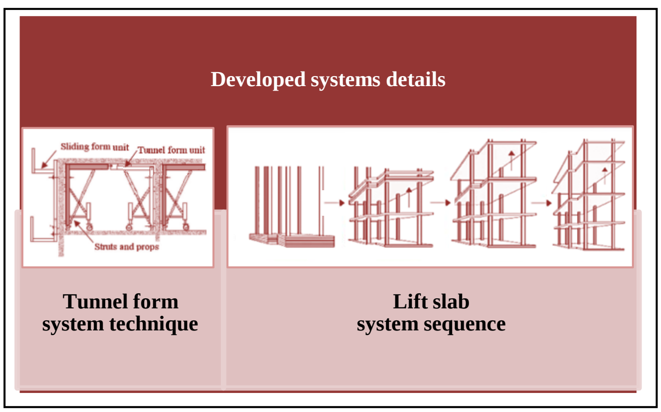


Figure 8. Developed systems details (adapted by the authors) (El- Agamy, 2012; Jha, 2019).

- **Slip form system:** The slip form technique is a cost-effective construction method that involves pouring concrete into vertically raised formwork, allowing it to harden before being freed. It is used for structures like chimneys, cooling towers, building cores, bridge piers and roads. Slip form-work techniques are rapid, economical and accurate construction methods used for over 16 m height structures **"Figure 9".** It requires less labor force and automation erection techniques. Benefits include simultaneous construction, high progress rate, standardization, material reuse, cost effectiveness, offsite pre-fabrication, quicker project completion and reduced craneage (Global, 2020; Hasselqvist & Gegrfelt, 201 C.E.)
- **Tilt-up system:** Tilt-up is a cost-effective, efficient and quick method of precast concrete construction used in various settings such as correctional facilities, schools, office buildings, industrial projects, recreational facilities, churches and housing developments. It involves panel prefabrication, lifting, bracing, crane time and skill in erection sequences. Tilt-up differs from typical steel structures as it uses panel locations and requires a reputable contractor for panel forming. It offers advantages such as economy, speed, durability, fire resistance, low maintenance costs, lower insurance rates, architectural attractiveness, low heating/cooling costs, expansion, security and value appreciation. However, it requires more coordination, site size limitations and a knowledgeable design team **"Figure 9"** (Ward et al., 2016; Klock, 2005).

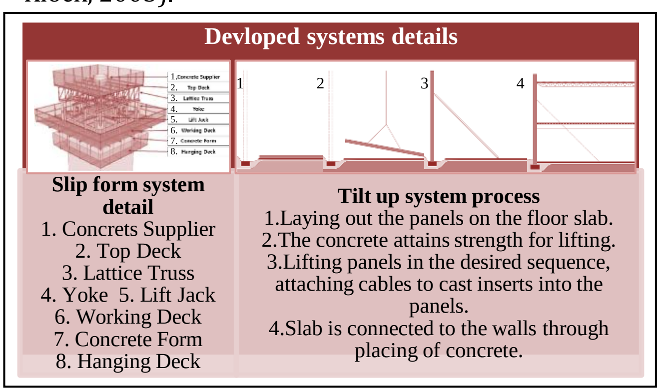


Figure 9. Developed systems details (adapted by the authors) (Kim et al., 2013).

4.1.4. Prefabricated Systems

Prefabricated buildings are built using self-sustaining volumetric modules or panels, combining modern construction methods and offsite manufacturing for a holistic solution with innovative connection systems.

- **Panelized system** is load-bearing structural systems in buildings that transfer gravity loads to modules, providing resistance against racking and are ideal for low-rise applications. Corner-supported systems transfer floor loads to columns, resisting horizontal loads (Gunawardena & Mendis, 2022).
- **Modular system** involves pre-engineered, factory-fabricated three-dimensional structures transported for site assembly. These parts are assembled, transported and installed with dry-point connections and can be reused for various building types (Gassel & Roders, 2006).
- **Hybrid-prefab system** combines panelized and modular methods with compact modular units (pods) used in highly serviced areas like kitchens and bathrooms and panels or modules for the rest of the building **"Figure 10"** (Gunawardena & Mendis, 2022).

Prefabricated buildings, made from steel, timber or concrete, are utilized in residential, commercial and public infrastructure sectors for thermal insulation, water resistance, fireproofing and structural integrity, reducing on-site congestion, waste and pollution (Dhawade, 2015; Gunawardena & Mendis, 2022).

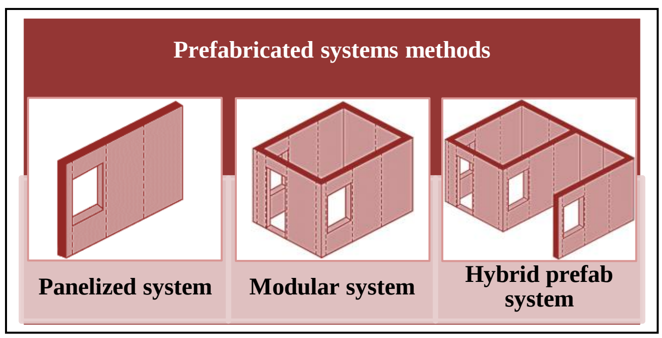


Figure 10. Prefabricated systems methods (by the authors).

4.2. Finishing Systems

The initial cost estimation is symbolic in the project team's decision-making process, determining whether to start work procedures and formulating implementation strategies. It impacts the success and quality of construction projects, ensuring satisfaction for all involved parties. The process is integral to feasibility studies and pivotal in the design and construction process, occurring early in the project's design phase. The unit area or volume method is used in construction projects to estimate costs, especially during feasibility studies. It uses information from similar projects to determine the cost per unit area or volume. The method accounts for price changes and operating conditions. The relationship between finishing work costs and building area consider the significant percentage of finishing work costs (Moneer Gad, 2020).

4.3. Material and Labor

The cost of a project is influenced by materials, construction details, speed and duration. Technical decisions directly impact the final cost and prefabrication or standardization can streamline the process (Cunningham, 2013). Labor productivity is important for project performance. There are ten factors affecting it in the Egyptian construction projects which include payment delay, skill, gap of experienced labor, lack of supervision, motivation, working over-time, lack of leadership, high humidity, technical specification clarity and high/low temperature. Labor productivity is essential for economic success and a challenge in the construction industry (M. Hafez, 2014).

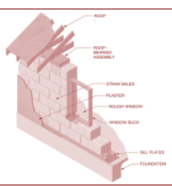
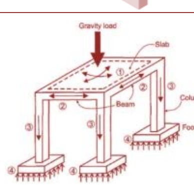
4.4. Running Cost

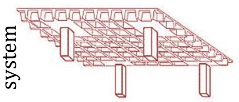
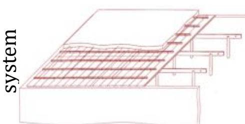
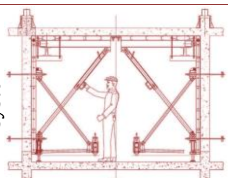
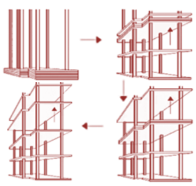
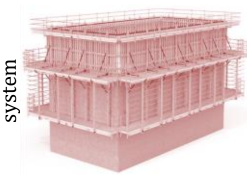
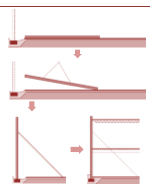
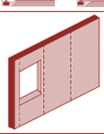
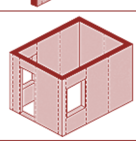
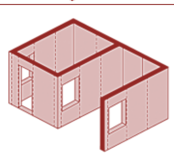
The success of a project is often determined by its economic efficiency which is measured by the overall project cost from inception to completion. Cost predictability is consequential as it ensures the final cost which aligns with the initial estimate. Cost overruns, often criticized as cost growth, can negatively impact a project's success. Factors such as profit rate, design cost, material waste rate, variation orders and rework cost can affect these costs (Olusola et al., 2016).

4.5. Analytical comparison of construction systems

When embarking on a construction project, one of the initial and most critical decisions that the designing engineer should take into consideration is the selection of the construction system. This decision sets the foundation for the entire project, aiming to achieve the highest performance with the lowest cost. The following analytical comparison of construction systems typically revolves around four main directions: the traditional system, semi-developed system, developed system and prefabricated system. Each of these systems offers unique advantages, challenges and careful consideration which should be given to factors such as efficiency and cost-effectiveness. By conducting a thorough analysis of these construction systems, designers can make informed decisions that align with the project's objectives and ultimately lead to a successful completion of the building project **"Table 2".**

Table 2. Analytical comparison of construction systems (by the authors).

Construction system				Design considerations	Advantages	Disadvantages
Traditional System	Load bearing system		Load-bearing structures transfer load vertically through walls, suitable for constructions with up to 3 floors.	•Transfers loads from roof to foundation through walls. •Thickness determined by roof load. •Suitable materials.	•Low-priced bricks. •Minimum foundation depth: 1.2m-1.5m. •Economic depends on availability and competitive pricing. •Labor availability.	•Limited storeys. •Difficulty in cantilever elements. •Thick walls. •The active area depends on the internal area. •Raise time.
	Skeleton system		Structural constructions focus on columns, transferring roof loads from beams to columns to foundation to suitable soil layers.	• Load transfer to beams, columns, foundations and soil. • Building height linked to column size for space preservation. •Flexibility in design	• Speed and efficiency. • Design changes and ease extension for walls. • Good sound insulation. • Facade formations. •Labor availability.	•Varying loads. •High costs compared to load-bearing wall systems. •High usage of steel

Construction system				Design considerations	Advantages	Disadvantages
Semi developed System	Hollow block system		Cast-in-place method and pre-cast system, lift pre-cast ribs on columns, place blocks between ribs and complete the top reinforcing mesh of the poured concrete slab.	•Alterable unit partitions and walls. •Hollow block in slab reduces roof weight. •Transfers loads to foundations.	•Low cost for large areas. •Sound insulation. •Hidden beams. •Reduce time. •Reduce labor. •Less framework.	•High accuracy in construction •Higher costs in smaller spaces. •The active area depends on the area of internal units.
Semi developed System	Semi precast system		Pre-cast wide slabs consists of footing, column or bearing brick walls, with isolated footing for cast-in-place columns and strip footing for bearing walls.	•Installing columns, beams and slabs •Grouting or welding elements. •Pouring concrete. •Erecting walls and facades.	•Improved quality control. •Reduced on-site formwork. •Worker safety. •Potential cost savings.	•Limited flexibility. • Higher initial costs. •Transportation challenges. •Potential construction delays.
Developed System	Tunnel form system		Tunnel form is a formwork system for cellular structures using in-situ concrete in walls and slabs, enhancing productivity and cost savings.	• Supports slabs up to 0.35m thick, variable with modulation walls based on structure. •Strengthened for deeper slabs.	•1-day repeat casting cycle and reduce labor. •Removes joint leakage •Design flexibility •Provides smooth walls and easy finishing. •Early cost recovery.	•Restricted design due to internal walls. •Variable designs. •High equipment and initial costs. •Large wall thickness.
Developed System	Lift slab system		Lift slab construction is an economical method for multi-story building construction, where flat roof and floor slabs are cast around columns or cores and jacks pull them up.	•Casting slabs and optimizing construction sequence. •Lifting slabs using hydraulic jacks. • Careful lifting point placement.	•Minimal formwork. •Simple pouring slabs •Continuous slab span. •Cantilevering for balconies. •The work is under supervision •Reduce time.	•Damage during transport can disturb connections. •Requires special equipment for lifting and moving.
Developed System	Slip form system		Slip form technique is a method that saves costs compared to conventional formwork, particularly for regular structures with four or more storeys.	•Continuous vertical and horizontal reinforcement construction. •Pours concrete onto moving formwork. •Stops when required casting length is reached.	•Reduce time. •Offsite prefabrication. •Rapid site installation. •Greater speed. •Uniform wall sections. •Reduced labor costs.	•Extensive planning and supervision. •Requires heavy equipment and skilled labor. •Continuous operation in all weathers.
Developed System	Tilt up system		Tilt-up used for one and multi-story structures. It involves prefabricating panels, lifting and bracing into the structure, utilizing time and skill in sequences.	•Panel locations determine tilt-up workflows. •Distribution facility can cast panels on slabs. ••Coordinating lifting and erection sequences.	•Low maintenance •Fire-resistant. •Cost-effective. •Offers expansion, security, value appreciation.	•Requires coordination and costly design changes, sufficient space for construction. •Require suitable Labors.
Prefabricated Systems	Panelized system		Prefabricated buildings are offsite-manufactured and assembled onsite using self-sustained modules or panels. Columns are fixed in the foundations then beams then slabs. Modern methods of construction integrate technology into a holistic solution, transforming traditional site-based construction methods.	•Utilizes object tree, guideline, ranking system. •Provides structured system description and analysis. •Aesthetic flexibility. •Optimized transportation. •Site-specific adaptability.	•Reduced Labor. •Reduced Material. •Reduced time. •Machine-Friendly Production. •Improved Product Quality.	•Increasing transportation costs. •Heavy crane requirements. Require professional labor.
Prefabricated Systems	Modular system					
Prefabricated Systems	Hybrid-prefab system					

6. Findings and Results

In the realm of architecture and construction, every type of building presents unique design challenges that must be carefully navigated to achieve optimal performance based on the relative coefficient value. This entails a meticulous analysis of the specific requirements and functions of the building in question, considering factors such as load-bearing capacity, structural integrity and aesthetic appeal. By understanding the inherent design considerations associated with different building types, architects and engineers can make informed decisions when selecting the most suitable structural system.

The ultimate goal is to strike a harmonious balance between performance and cost efficiency, ensuring that the chosen structure not only meets the functional needs of the building but also aligns with budgetary constraints. This strategic approach to design consideration not only enhances the overall performance of the building but also contributes to long-term operational efficiency. By prioritizing both performance and cost-effectiveness in the design process, architects can create buildings that deliver exceptional functionality and durability while optimizing resources and minimizing expenses.

7. Conclusion

Design economics is a field that examines the interplay between economic feasibility, cost-effectiveness and success of design projects. It emphasizes the need to understand and address these factors to achieve optimal design outcomes while balancing performance objectives with cost considerations. The study emphasizes the significance of identifying and evaluating factors affecting project cost reduction, especially during architectural design phases to improve project performance and achieve the lowest facility cost. It uses a deductive method to analyze factors affecting residential buildings' economics, focusing on state policies, market conditions and the country's economic and social conditions.

Understanding these factors is crucial for creating cost-effective living environments and optimizing design economics, aiding architects, engineers and project managers in making informed decisions.

Factors influencing design projects include material selection, energy efficiency, construction methods and lifecycle considerations. The study highlights the challenges of delayed project implementation and escalating costs, which can deter investors and lead to inflated loan interest and delayed project operations. It proposes a methodology to identify and address these factors, establishing pillars and standards.

The criteria can help designers and architects to achieve the highest performance with the lowest cost and this was achieved through analyzing 3 building types to another for example: apartment, dorm and hotel. The policy factors are fixed considerations that must be respected, while the structure system that achieves the highest performance in the design factors is determined according to the type of housing building.

Policy factors enhance residential building performance by ensuring safety, efficiency and environmental impact, while optimizing space utilization, accessibility and usability to create diverse living spaces for inhabitants.

Building design optimization is a critical process that enhances the performance and functionality of housing buildings by comparing and integrating various factors, thereby creating efficient living spaces.

Building design's construction system is influenced by architectural, environmental and structural factors, with residential performance significantly influenced by building codes, zoning regulations and environmental policies. The construction system chosen is based on design contributions, varying from building type to type and collaborating with design considerations.

8. Recommendations

The study emphasizes the importance of design economics in achieving high performance with the lowest cost. It calls for a comprehensive approach to design decision-making, balancing performance objectives with cost.

Future research could explore the integration of advanced technologies and the evolving design practices to contribute to the evolution of design economics and achieve higher performance outcomes with lower costs.

The selection of the construction system is a critical decision for designing engineers, setting the foundation for the entire project. Analyzing traditional, semi-developed, developed and prefabricated systems offers unique advantages and challenges, requiring careful consideration of efficiency and cost-effectiveness to achieve highest performance with **lowest** cost. By conducting a thorough analysis, designers can make informed decisions that align with the project's objectives and lead to successful building project completion.

For the architects: they should adopt a holistic design approach, integrating economic considerations into the design process from the beginning and regularly engage with clients and stakeholders to ensure alignment on project goals and economic feasibility. They should also use data-driven decision-making tools, such as cost estimation and energy modeling, to inform design decisions. They should also collaborate with research institutions and industry partners to stay informed about design economics advancements.

Architects should actively explore and experiment with emerging design methodologies, construction systems and technologies to enhance economic viability. They should engage in continuous professional development and participate in professional organizations to stay informed.

Lastly, architects should advocate for design economics education, integrating design economics principles into architectural curricula, encouraging the development of interdisciplinary programs and mentoring the next generation of architects to develop a comprehensive understanding of the economic dimensions of building design.

For the stakeholders: it suggests fostering open communication and collaboration among all parties involved, facilitating decision-making processes and promoting cross-disciplinary teamwork. It also suggests prioritizing life-cycle cost analysis to evaluate the long-term economic viability of design solutions, considering not only initial construction costs but also operational, maintenance and future modifications or demolition costs. It encourages stakeholders to make investment decisions based on this comprehensive assessment. It also suggests incentivizing sustainable and innovative practices, such as implementing policies and financial mechanisms, exploring public-private partnerships, government subsidies, or tax incentives and recognizing successful design projects that demonstrate excellence in both design and economic aspects.

By implementing these recommendations, architects and stakeholders can work together to create a more suitable, economically viable and high-performing built environment that meets the evolving needs of society achieving highest performance with lowest cost

9. Limitations of the study

It is important to highlight the limitations encountered during the study, such as constraints in data availability, the complexity of evaluating the long-term impact of certain factors and changing the housing polices as the time pass. Whereas, the policy factors influencing building attributes through design economics should be respected and adhered by the designer because these factors are fixed considerations that must be taken through design.

References

Abdullah, C. S., Bahaudin, A. Y., Nawi, M. N. M., Baluch, N. H., Kamaruddeen, A. M., Mohtar, S., Mohamed Udin, Z., Zulhumadi, F., & Abu Bakar, Z. (2015). Implications of technology transfer in the design and construction of load-bearing masonry buildings. *Jurnal Teknologi*, *77*(5). doi.org/10.11113/jt.v77.6128

Agrama, F., Al-Nemr, M., & Abdo, M. (2014). Value Engineering for Low-Cost Housing in Egyptian Expansion Urban. *Advanced Research in Engineering Sciences "ARES"*, *2*.

Ahmed Doko Ibrahim. (2003). *Cost implementation of architectural design variables* [MSc. Thesis]. King Fahd University of Petroleum and Minerals.

Alprogrammer. (2008). 📖 *"كتاب تقنية معمارية إنشاء معماري"* — *الإدارة العامة لتصميم وتطوير المناهج*📖. المؤسسة العامة للتدريب التقني والمهني الادارة العامة لتصميم وتطوير المناهج كتاب نظم الانشاءات.

Blackman, I. Q., & Picken, D. H. (2010). Height and Construction Costs of Residential High-Rise Buildings in

Shanghai. *Journal of Construction Engineering and Management*, *136*(11). doi.org/10.1061/(asce)co.1943-7862.0000226

Brooker, O., & Hennessy, R. (2008). *Residential Cellular Concrete Buildings: A Guide for the design and specification of concrete buildings using tunnel form, crosswalk or twin wall systems* (O. Brooker & R. Hennessy, Eds.). The Concrete Centre.

Chaudhary, Ms. A. D. (2017). Study of Tunnel Formwork System & Comparative Analysis with Conventional Formwork. *International Journal of Scientific & Engineering Research*, *8*(5). doi.org/10.14299/ijser.2017.05.009

Cunningham, T. (2013). Factors Affecting The Cost of Building Work - An Overview. *Dublin Institute of Technology*.

Cyros, K., & Korb, R. (2006). *Postsecondary Education Facilities Inventory and Classification Manual (FICM): 2006 edition* (K. Cyros & R. Korb, Eds.). U.S. Department of Education Institute of Education Sciences.

El- Agamy, H. E. (2012). *Lateral Deformations in Shear Walls with Openings* [Thesis]. Mansoura University.

Eljojo, A. (2017). Effect of Windows Size, Position and Orientation on the Amount of Energy Needed for Winter Heating and Summer Cooling. *JOURNAL OF ENGINEERING RESEARCH AND TECHNOLOGY*, *1*(1).

Emmitt, S., & Gorse, C. (2014). BARRY'S ADVANCED CONSTRUCTION OF BUILDINGS Third edition. In *John Wiley & Sons, Ltd* (Vol. 28, Issue 3).

Forrest, D. (2012, September). *Window and Fenestration Systems Selection*. (Accessed: 7-12-2022) https://continuingeducation.bnpmedia.com/article_print.php?c=930.

Gassel, F. Van, & Roders, M. (2006). A Modular Construction System: How to design its Production Process. *Adaptables 2006*, *July*.

Global, S. (2020). *Slipform Construction, Reducing construction time utilising slipform.* SRG Global. (Accessed: 10-1-2023) https://www.srgglobal.com.au/wp-content/uploads/2020/05/srgg-slipform_2020-05_e.pdf

Gunawardena, T., & Mendis, P. (2022). Prefabricated Building Systems—Design and Construction. *Encyclopedia*, *2*(1). doi.org/10.3390/encyclopedia2010006

Hasselqvist, A., & Gegrfelt, E. (201 C.E.). *Concrete in vertical slipforms, A process for determining a suitable concrete composition.* [Thesis]. Royal Institute of Technology (KTH).

Ibrahim, A. (2008). Effect of Changes in Layout Shape on Unit Construction Cost of Residential Buildings. *Samaru Journal of Information Studies*, *7*(1). doi.org/10.4314/sjis.v7i1.40600

Ibrahim, S., Olaku, A., Abdulmumin, A. A., & Ola-awo, W. (2015). Assessment of the Effect of Plan Shapes on Cost of Institutional Buildings in Nigeria. *International Refereed Journal of Engineering and Science (IRJES)* , *4*(3), 39–50.

Idowu, O., Marafa, U., Gwandi, S., & Humphrey, S. (2018). EFFECT OF ORIENTATION AND OPENING SIZE ON NATURAL VENTILATION IN OFFICE BUILDINGS SURROUNDING A PENTAGONAL OPEN SPACE . *Ethiopian Journal of Environmental Studies & Management*, 634–643.

Ilerisoy, Z. Y., & Tuna, M. E. (2013). Construction costs of tunnel form buildings. *Gradjevinar*, *65*(2). doi.org/10.14256/jce.854.2011

Jagtap, A. D., & Dhawade, S. M. (2015). Benefits of Prefabricated Building Material Over on Site Construction-A Review. *International Journal of Research in Engineering, Science and Technologies (IJRESTs), Civil Engineering*, *1*(8).

Jha, S. (2019, September 2). *BCM Lift Slab*. (Accessed: 8-10-2022) https://www.scribd.com/document/424093592/bcm-lift-slab.

Kim, H. S., Kim, Y. J., Chin, W. J., & Yoon, H. (2013). Development of Highly Efficient Construction Technologies for Super Long Span Bridge. *Engineering*, *05*(08). doi.org/10.4236/eng.2013.58075

M. Hafez, S. (2014). Critical Factors Affecting Construction Labor Productivity in Egypt. *American Journal of Civil Engineering*, *2*(2). doi.org/10.11648/j.ajce.20140202.14

Miranda, R., & Kodre, A. (2018). Advanced Tunnel Form Construction Technique, Case Study of "Rohan-Abhilasha, Wagholi." *International Journal of Scientific Engineering and Science*, *2*(3), 54–57.

Moneer Gad, M. (2020). دراسة مدى تأثير زيادة المساحة على تكاليف أعمال التشطيبات. *Engineering Research Journal*, *167*(0). doi.org/10.21608/erj.2020.145842

Muhaisen, A. S., & Dabboor, H. R. (2015). Studying the Impact of Orientation, Size, and Glass Material of Windows on Heating and Cooling Energy Demand of the Gaza Strip Buildings. *Journal of Architecture and Planning*, *27*(1).

Olusola, S., Ayodeji Emmanuel, O., Douglas Omoregie, O., & Adeyemi, S. (2016). Effect of Construction Project Performance on Economic Development of Nigeria. *Issn*, *7*(12).

Paultre, P., Calais, É., Proulx, J., Prépetit, C., & Ambroise, S. (2013). Damage to engineered structures during the 12 January 2010, Haiti (Léogâne) earthquake. *Canadian Journal of Civil Engineering*, *40*(8). doi.org/10.1139/cjce-2012-0247

Ramli, N. A., Abdullah, C. S., & Mohd Nawi, M. N. (2014). A study of potential load bearing masonry (LBM) system in Malaysia construction industry. *MATEC Web of Conferences*, *15*. doi.org/10.1051/matecconf/20141501011

Ramli, N. A., Abdullah, C. S., & Nawi, M. N. M. (2014). Definition and new directions of IBS Load bearing masonry (LBM) system in construction industry. *Advances in Environmental Biology*, *8*(5).

Randal, F. (1986, February). *New developments in lift slab construction| concrete construction.* (Accessed: 28-8-2022) https://www.concreteconstruction.net/products/gen-eral-construc-tion-equipment/new-developments-in-lift-slab-construction_o.

Sayadi, S., Hayati, A., & Salmanzadeh, M. (2021). Optimization of window-to-wall ratio for buildings located in different climates: An IDA-indoor climate and energy simulation study. *Energies*, *14*(7). doi.org/10.3390/en14071974

Seeley, I. (1996). *Building economics* (I. Seeley, Ed.; 4th ed.). Red Globe Press.

Sims, D., & Abdel-Fattah, H. (2016). *Egypt Housing Profile* (D. Sims & H. Abdel-Fattah, Eds.). United Nations for Human Settlements, UN-Habitat 2020. (Accessed: 10-1-2024) https://unhabitat.org/sites/default/files/download-manager-files/1525977522wpdm_Egypt%20housing%20EN

Szydlowski, R., & Szreniawa, M. (2017). New Concept of Semi-precast Concrete Slab on Pre-tensioned Boards. *IOP Conference Series: Materials Science and Engineering*, *245*(2). doi.org/10.1088/1757-899X/245/2/022090

Tavares, A., D'Ayala, D., Costa, A., & Varum, H. (2014). Construction Systems. In A. Tavares, D. D'Ayala, A. Costa, & H. Varum (Eds.), *Structural Rehabilitation of Old Buildings* (pp. 1–35). Springer Berlin Heidelberg. doi.org/10.1007/978-3-642-39686-1_1

Walid Yehia AbdelHAdy El-Eshmawy, A., Atef El Dessoqy Faggal, A., & Mohamed Mustafa Eissa, A. (2021). Conventional and Advanced Glazing Technologies for Enhancing Thermal and Lighting Performance. *Engineering Research Journal*, *171*(0). doi.org/10.21608/erj.2021.193260

Ward, W., Lindsay, L., Stadler, C., Peebles, M., & Carr, K. (2016). *The Construction of tilt-up* (W. Ward, L. Lindsay, C. Stadler, M. Peebles, & K. Carr, Eds.; 1st ed.). Tilt-Up Concrete Association. (Accessed: 28-1-2023) https://issuu.com/evaarchitects/docs/ctu-final-web

Wong, F. W. H., Lam, P. T. I., Chan, E. H. W., & Wong, F. K. W. (2006). Factors affecting buildability of building designs. *Canadian Journal of Civil Engineering*, *33*(7). doi.org/10.1139/L06-022

Yana, A. A. G. A., Rusdhi, H. A., & Wibowo, M. A. (2015). Analysis of factors affecting design changes in construction project with Partial Least Square (PLS). *Procedia Engineering*, *125*. doi.org/10.1016/j.proeng.2015.11.007

Zallen, R. M., & Peraza, D. B. (2004). Engineering Considerations for Lift-Slab Construction. In *Engineering Considerations for Lift-Slab Construction*. doi.org/10.1061/9780784407059

Żelazowski, K. (2015). Optimal Height of Land Development - An Economic Perspective. In *Real Estate Management and Valuation* (Vol. 23, Issue 1). doi.org/10.1515/remav-2015-0002