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Enhancing building maintainability through early supplier involvement in the design process

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Abstract: The post-construction phase represents a critical milestone in the project lifecycle. This is because design errors and omissions as well as construction defects are examined during this phase. The traditional procurement approaches that are commonly adopted in construction projects separate design from construction, which inhibits contractors, suppliers and other parties from providing the design team with constructive comments and feedback to improve the project design. Consequently, lack of considering maintainability aspects during the design process results in increasing maintenance and operation costs as well as reducing building performance. This research aims to investigate the role of early supplier involvement (ESI) in the design process as an approach for enhancing building maintainability. To achieve this aim, a research methodology consisted of literature review, case studies and survey questionnaire was designed to accomplish four objectives. Firstly, literature review was used to examine the concepts of building maintenance, maintainability, the design process and ESI. Secondly, three case studies were presented and analysed to investigate the role of ESI towards enhancing building maintainability during the design process. Thirdly, a survey questionnaire was conducted with a representative sample of architectural design firms (ADFs) in Egypt to investigate their perception and application of ESI towards enhancing building maintainability during the design process. Finally, the research developed a framework to facilitate ESI during the design process in ADFs in Egypt. Data analysis showed that 'Difficulty of trusting external parties and sharing information with transparency' was ranked the highest challenge of ESI in ADFs in Egypt.

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1 Introduction

The construction industry is concerned with delivering projects that meet clients' requirements, fulfil their objectives and offer the best value for money (Barrett and Stanley 1999; Watson and Asher 1999). This principle should be implemented throughout the project's life cycle. The post-construction phase is the one in which design errors and omissions as well as construction flaws are investigated. Although many people regard maintenance as one of the most unpleasant aspects of the construction industry (Son and Yuen 1993; Jones 1995), it is essential in retaining or restoring the constructed building to a state where it can perform its intended function in the most cost-effective manner. Despite the fact that maintenance costs constitute a considerable amount of the building's operating budget, it has yet to be completely considered during the design phase. The failure to integrate maintainability concerns during the early phases, which raises the eventual expenses of building operation and maintenance, is a major source of difficulties in building maintenance. Up to 50% of maintenance difficulties may be avoided if problematic designs were changed during the design process, since architects have greater flexibility to make modifications that enhance building maintainability, improve safety standards, minimise maintenance downtime and expense, and assure improved accessibility. Integrating maintainability considerations into the design process may result in fewer building components that require maintenance, decreasing the need for specialist resources and thus lowering later maintenance and operating costs (Kanniyapan et al. 2015; Sofi et al. 2016). Traditional procurement approaches that are frequently employed in construction projects, on the other hand, separate design from construction and subsequent phases of the project. This separation hinders other construction and maintenance experts from offering constructive feedback and recommendations to the design team that improve the project's design and maintainability. Furthermore, traditional procurement approaches are significant sources of waste, disagreements and time wasting (Kamara et al. 1999). Furthermore, failure to integrate and involve contractors, suppliers and other stakeholders during the design process increases maintenance costs, waste and rework (Katunzi 2011). Without incorporating suppliers early in the design phase, the opportunity to fine-tune components and their requirements is lost, and the project misses out on the important supplier's experience in the project development process. Accordingly, the purpose of this paper is to investigate the role of early supplier involvement (ESI) in the design process as an approach for enhancing building maintainability.

2 Literature review

2.1 Building maintenance

The British Standard BS EN 13306 (BSI 2001) defined maintenance as 'The combination of all technical, administrative and managerial actions during the life cycle of an item intended to retain it in, or restore it to, a state in which it can perform the required function'. The process of decay and deterioration of a building's fabric and services begins the moment it is completed and occupied (Williamson et al. 2010). Building maintenance is the art and process of successfully and efficiently retaining the performance of buildings and equipment at their peak levels in the most cost-effective manner possible (Chew et al. 2018). This aims to allow building occupants and users to continue to use it to the fullest with minimal deterioration throughout its life cycle. The dimension of building maintenance is a major focus that most countries have in order to ensure that buildings perform properly. To optimise the performance of any type of facilitates or buildings, specific standards must be met as well as a certain level of design quality must be maintained. Meeting standards and planning a quality design are critical and more effective when applied during the design stage, and these enable the building to achieve its intended purpose (Rocha and Rodrigues 2017).

2.1.1 Types of maintenance

Maintenance could be classified into several types, see Figure 1.

(i) ***Preventive maintenance:*** It is a maintenance programme that aims to decrease the likelihood of malfunctioning or deteriorating functional elements. It is utilised to have a systematic character, which means that the parts are checked even if they have not shown any indicators of having a problem.

(ii) ***Corrective maintenance:*** It refers to maintenance performed after a failure to return an object to a state in which it can perform its needed function.

(iii) ***Condition-based maintenance:*** It detects when maintenance is necessary by analysing the state of the facility or equipment while it is in operation and recognising indicators of degradation or potential failures. Under severe economic conditions, condition-based maintenance is a common strategy for maintaining big, complex facilities. It prevents system failures and catastrophic breakdowns while enhancing reliability and availability at a low cost.

(iv) ***Deferred maintenance:*** It denotes repair work that has been postponed after the prescribed service time has elapsed. Deferred maintenance will result in greater expenses or failure than if regular maintenance was performed. When conventional maintenance management fails to conduct essential repair, maintenance and renewal, deferred maintenance occurs.

(v) ***Building repairs/breakdown maintenance:*** These are the maintenance operations that are completed when building components are damaged. It is not scheduled maintenance, but rather repair. Treatment repair, corrective repairs and emergency repairs are the three categories with the purpose of recovering damages (Levitt 2013).

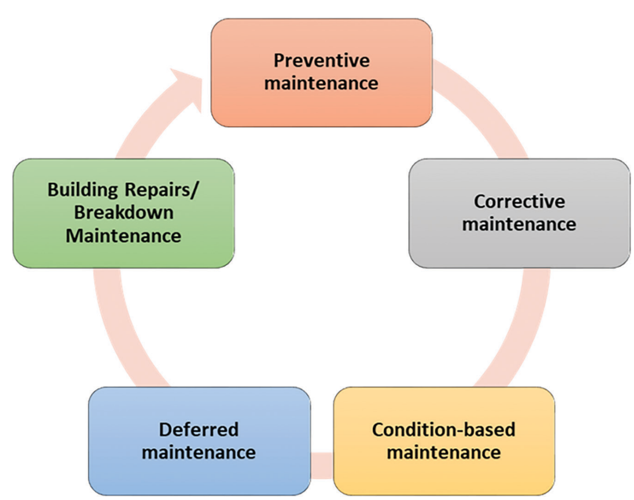

Fig. 1: Types of maintenance (developed by the authors).

2.1.2 Factors affecting building maintenance

There are three factors that affect building maintenance effectiveness, as follows (Talib et al. 2014).

(i) ***Human and culture related factors*****:** These factors are related to the human and cultural behaviour of building client, end-users and maintenance team. These factors include poor attitude of clients and wrong behaviour of occupants towards building maintenance, a shortage of skilled appointed maintenance personnel and lack of training and skills among the maintenance crew (De Silva et al. 2012). In addition, a lack of knowledge of the importance of maintenance work as well as communication between the client, maintenance contractor, end-users and the design team, leads to disregarding maintenance considerations during the design process (Othman 2007). Moreover, low concern of future maintenance of existing maintenance team, insufficient building maintenance efforts and poor-quality control during construction and maintenance hinder appropriate building maintenance (Talib et al. 2014; Akasah and Alriwaimi 2015).

(ii) ***Fiscal and building materials related factors*****:** These factors are related to the financial and selection of building materials. They include specifying poor-quality building materials, applying defective materials during maintenance works (De Silva et al. 2012), insufficient funds to maintain the buildings, shortage of available services and maintenance centres, and changes in material types and specifications during maintenance (Ogunmakinde et al. 2013; Akasah and Alriwaimi 2015).

(iii) ***Environmental factors*****:** The environmental factors that obstruct the maintenance process include weather conditions such as moisture, wind or atmospheric gases which, if not attended to properly, may lead to incidents of leakage. Environmental conditions are not always in favour of sporadic maintenance efforts (Ofori et al. 2015). In addition, ageing of building is always positively related to the required maintenance efforts' frequency. Overlooked site conditions (Akasah and Alriwaimi 2015) and unexpected problems may exist on the surrounding area (Abisuga et al. 2017).

2.2 Maintainability

Maintainability, as described by Khan (2013), is the ease with which a product may be maintained in order to allow future maintenance or to cope with a continually changing environment. Design is distinguished by its ability to be maintained. According to Lau and Ho (2010), maintainability is a property of equipment design and installation that is described in terms of convenience and economy of maintenance, equipment availability, safety and accuracy in maintenance activities. It is the major design aspect that relates to the precision, convenience, cost effectiveness and safety of maintenance tasks. The concept of maintainability was initially created because organisations were seeking for a solution to rising maintenance expenses as well as concerns with constructing environments that were not maintenance friendly (John and Jeffrey 2000).

2.2.1 Design for maintainability (DfM)

DfM can be defined as the reduction of the probability of occurrence of building defects to a minimum, while simultaneously reducing the materials required and the expected maintenance labour hours, through adapting specific measures in order to fulfil the maintenance requirements during the building life cycle, all of which is done in the initial design and planning stage (Chew et al. 2018). The Building and Construction Authority (BCA) in Singapore introduced the concept of maintainability in 2017, when a DfM checklist (Building and Construction Authority, 2014) was provided to address the importance of maintainability, which includes the release of DfM framework throughout the building life cycle. The framework checklist is organised around the major components of a building. The following three critical maintainability design factors are then applied to each building component.

(i) ***Building area:*** The appropriate use of materials can minimise the frequency of cleaning, repair and replacement. These areas include facades and external walls, roof areas, common areas, lift lobbies and corridors, parking areas and other building areas e.g. washrooms, facilities for cleaners.

(ii) ***Mechanical and electrical (M&E) facilities:*** Access provisions must be designed to be safe and provide sufficient circulation and working space for maintenance vehicles or personnel carrying tools, equipment and component parts. These facilities include plant, machinery and fixed equipment, security and piping and exposed services.

(iii) ***Landscape and outdoor areas:*** The main concerns include having careful detailing to prevent staining, water penetration and premature deterioration, as well as to enable simple maintenance methods and replacement of elements. These areas include planting and turf, water features and other landscaped areas e.g. outdoor furniture, footpaths.

2.3 The design process

The typical project life cycle consists of seven stages, according to the Royal Institute of British Architects (RIBA 2020) plan of work update. Each stage has its own definition, scope of work, and participants. This paper will concentrate on the pre-construction stages. This is due to the fact that pre-construction is the foundation for any successful construction project. Before breaking ground, the project team should develop a communication strategy and thoroughly examine all aspects of the project. The project scope, programme requirements and site constraints are frequently used to develop the feasibility study and constructability exercise. Additionally, as the initial vision evolves into final documents, the budget implications of design decisions are evaluated. Collaboration between the design team and the construction manager helps to ensure that the systems and components chosen will perform as expected and optimise building performance (Barrie and Paulson 1992).

2.3.1 Preparation and briefing

The primary tasks completed during this stage include preparing the project brief, developing project outcomes and sustainability outcomes; undertaking feasibility studies; agreeing on project budget; sourcing site information and surveys; and preparing project programme and execution plan (RIBA 2020).

2.3.2 Concept design

The concept design stage is concerned with developing an architecture concept that incorporates strategic engineering requirements and is aligned with the cost plan, project strategies and outline specification. It also focusses on agreeing on project brief components, conducting design reviews with clients and project stakeholders, and developing a stage design programme (RIBA 2020).

2.3.3 Spatial coordination

The primary tasks of the spatial coordination stage are to conduct design studies, engineering analyses and cost exercises to test architecture concepts, resulting in spatially coordinated designs that are aligned with updated cost plans, project strategies and outline specifications. Furthermore, it focuses on initiating change control procedures and preparing a stage design programme (RIBA 2020).

2.3.4 Technical design

The technical design stage is concerned with the development of architecture and engineering technical design; preparing and coordinating design team building systems information; preparing and integrating specialist subcontractor building systems information; and preparing a stage design programme (RIBA 2020).

2.4 Early supplier involvement

2.4.1 Background and importance

In general, a supplier is a person or organisation that offers a good or service to another organisation. Providing top-notch goods from a manufacturer at a competitive price to a distributor or retailer for resale is the responsibility of a supplier in a business. The supplier serves as a liaison between the manufacturer and the store, making sure that information is forthcoming and that the inventory is of appropriate quality (Oberlo 2021). Suppliers in the construction industry were previously thought of as businesses that were hired to deliver tangible supplies, such as items, materials, plants, etc., either directly to the client or to the contractor or subcontractors. However, as the construction sector and supply chain became more complex, concomitant with the emergence of new techniques such as offsite fabrication, suppliers were required to provide services for the project, such as creating the project brief, providing architectural and engineering services, providing construction management services or providing goods for the project, such as constructed assets (PAS 1192-2 2019).

2.4.2 Benefits of ESI

Supplier participation in the design process provides knowledge and expertise for new ideas and technologies. Potential issues may also be recognised early on, which enhances the overall quality of the design. Furthermore, it avoids rework, decreases costs, provides techniques for outsourcing that can minimise project inner complexity, and give extra resources that can reduce the project's critical path. ESI can also increase information flow and collaboration, resulting in fewer delays and on-time completion of the project. When suppliers understand all aspects of the project, it leads to a better connection between the supplier and the customer on future projects. As a result, the most major advantage of ESI is that suppliers participate to the development of a better solution by offering access to their technology resources, capabilities and design ideas (McIvor 2004). Furthermore, ESI has an essential role in increasing building maintainability (Kamal et al. 2019) and minimising construction waste throughout the project life cycle, notably at the design stage (El-Saeidy and Othman 2021). Northey (2018) stated that ESI helps simplifying the project logistics delivered to the site in a timely manner and with minimal impact on the surrounding community as well as developing long and fruitful collaborative business relationship.

2.4.3 Challenges of ESI

Despite the advantages of ESI, integrating suppliers into the design process poses several challenges. Cooperation with suppliers can sometimes result in a slew of new ideas, which suppliers can then take and sell to competitors. Furthermore, suppliers' offerings are sometimes limited, and they will frequently choose their untested products, which lowers competitiveness and limits prospective options. In addition, the goals of the contractors, designers and suppliers are not always coinciding, which results in unwillingness in sharing accurate information (Wynstra 1998; Johnsen 2009). Effective ESI can be negatively affected by the excessive interventions by customers exercising their power in the relationship. It is unlikely that enough resources would be dedicated to the joint work with key suppliers to reach the full benefits of ESI. Another cultural challenge is present in the resistance of the design team to include suppliers in the design phase as it is difficult of trusting external parties and sharing information with transparency (Chen 2010) and the unwillingness of clients to accommodate the idea of ESI (Saghatforoush 2014). Furthermore, it is not easy to coerce suppliers to provide additional levels of support. ESI is still shrouded in mystery as no clear guidelines, policies or legal framework have emerged to govern this type of involvement. Furthermore, ESI is not a common practice in the design process and supplier remuneration is insufficient to involve in design phase (Chavhan et al. 2012).

2.4.4 ESI in design process

ESI is regarded as one of the most important project development endeavours. This is due to the high levels of rivalry between organisations both domestically and internationally, as well as the fast-paced marketplaces, which necessitated the development of better, smarter and more inventive projects. ESI will assist in taking rapid and critical steps to avoid delays, waste and poor building performance (Basi 2015). There are numerous prerequisites for integrating suppliers early in the project life cycle. These primarily include the ongoing need to improve design, incorporate sustainability factors, decrease waste, improve building maintenance, meet quality standards, and boost levels of flexibility and efficiency during the construction process (Othman et al. 2004; Kamal et al. 2019; El-Saeidy and Othman 2021). In addition, these prerequisites include also the rate at which key materials and technologies are developed, as well as gaps in the field's market structure. As a result, there will be greater cooperation and transparency between suppliers and clients. Furthermore, it is vital to share ideas and data, to work closely together and to have open dialogues between suppliers and clients throughout the early stages of a project. Furthermore, project enhancement and innovation may be added responsibilities for supplier work throughout construction. Suppliers are also informed about the cost, efficiency, storage, standards and transportation of supplies and equipment. As a consequence, this information will improve the final design and eliminate redesign and modification, allowing the supplier to provide the most appropriate material and equipment at the greatest price, eliminating rework and waste during construction (Johnsen 2009).

2.4.5 Levels of supplier involvement in the design process

There are four levels of supplier involvement in the design process and each level implies certain responsibilities towards the project design. The first level is 'None' where the supplier is not involved in the design development. The second level is the 'White Box' where the supplier is involved informally as a consultant to provide advice to the design team when needed. The third level is 'Grey Box' which includes formalised supplier involvement, where the supplier provides expertise, makes suggestions and conducts joint development activities such as joint design, prototype development and testing. However, the supplier typically will not assume sole responsibility for design development. Finally, the 'Black Box' level can be mentioned, in which the design is primarily supplier-driven. The supplier is formally empowered to design the different components of the project based on the required performance specifications. In this level, a high degree of trust typically exists between the client and the supplier, as the client relies on the supplier's capabilities to design and accordingly, the supplier assumes almost complete responsibility for the designed components (Koufteros et al. 2007; Zhao et al. 2014).

3 Research methodology

Achieving the research aim called for a research strategy that could gather data sufficiently rich to investigate the role of ESI towards enhancing building maintainability during the design process. Two approaches, namely, theoretical (literature review) and practical (field studies), were used to achieve four objectives:

- First, literature review was used to build a comprehensive background about the research topic through reviewing the concepts of building maintenance, maintainability, the design process and ESI.
- Second, three case studies were presented and analysed to investigate the role of ESI towards enhancing building maintainability during the design process.
- Third, a survey questionnaire conducted with a representative sample of architectural design firms (ADFs) in Egypt was analysed to examine their perception and application of ESI towards enhancing building maintainability during the design process.
- Final, to develop a framework to facilitate the early involvement of suppliers during the design process as an approach for enhancing building maintainability, see Figure 2.

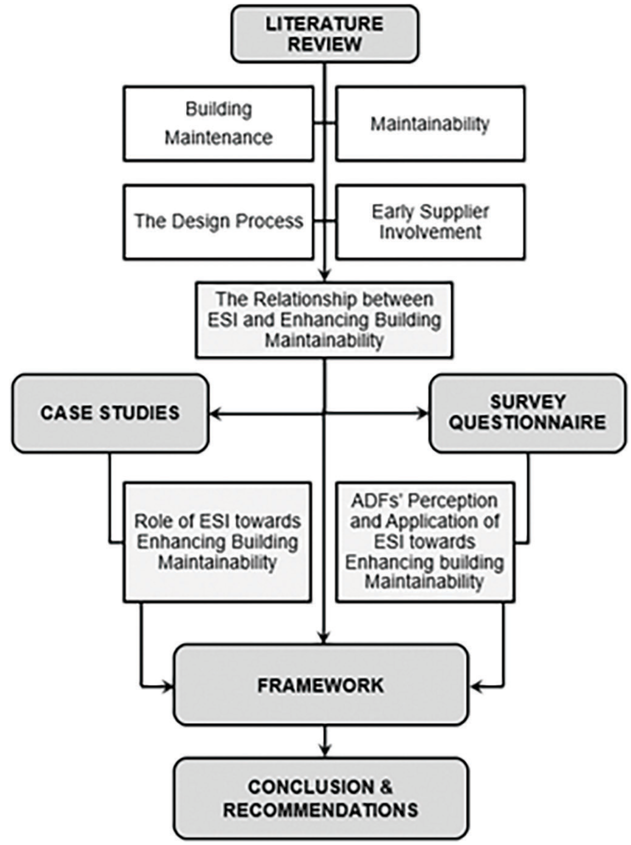

Fig. 2: Research methodology (developed by the authors). ADFs, architectural design firms; ESI, early supplier involvement.

3.1 Population and sampling

3.1.1 Questionnaire survey sample

The sampling plan using a random probability sampling method was applied to the population size, which was 44 ADFs registered in the Egyptian Engineers Syndicate (EES 2019). This sampling plan ensures that each unit had an equal opportunity of being encompassed in the sample (Hannagan 1997). Consequently, the sample would be representative and not biased with regard to the task of investigating the perception and application of ADFs towards ESI in enhancing building maintainability during the design process. To develop a representative sample size that can support the research findings, two equations were used. With Eq. (1) was calculated the sample size with a distribution of 50% that indicates no bias for measuring the extent to which information is misrepresented, a confidence level score of 1.96 that corresponds to a confidence level of 95% referring to the required accuracy and lastly a 5% margin of error. With Eq. (2) was computed the True Sample Size (Freedman et al. 2007; FluidSurveys Team 2014).

$$\text{Sample size} = \frac{\text{Distribution of } 50\%}{\left[\text{Margin of error}\% \big/ \text{Confidence Level Score}\right]^2} \quad (1)$$

$$\text{True Sample} = \frac{\text{Sample Size} \times \text{Population}}{\text{Sample Size} + \text{Population} - 1} \quad (2)$$

These figures are most commonly used in scientific research because they ensure that the research is 95% certain that the results contain the actual mean value of the total population.

$$\text{Sample Size} = \frac{0.5 \times (1 - 0.5)}{\left[0.05 \big/ 1.96\right]^2} = 384.16$$

$$\text{True Sample} = \frac{384.16 \times 44}{384.16 + 44 - 1} = 39.57 \sim 40$$

However, since the true sample size is only different from the population size by 4, the population size would be considered entirely for the survey questionnaire. It worth mentioning that the names of these design firms were suppressed for the purpose of security according to their request.

4 Case studies

4.1 Definition and selection criteria

A case study is a research method that is used to describe and analyse an individual matter, phenomenon, event or project in order to identify variables, structures, forms and orders of interaction between the participants in the situation or to evaluate work performance or development progress (Sturman 1997). Three case studies from Saudi Arabia and Singapore were selected for this study. The case study selection criteria were based on the nature of the selected project, data availability, degree of success, location and region. All of the case studies featured construction projects of varying scope that were successful in varying degrees in involving suppliers early in the design process to improve building maintainability. Since ESI is a new concept, there were few published case studies addressing the discussed topic; therefore, data availability was a major factor in selecting case studies. Although the field study was conducted in Egypt, the case studies were selected from other countries due to a lack of cases in Egypt.

4.2 Case study (1) – HVAC system concealed ducted indoor (fan coil), administrative building, Saudi Arabia

The first case study relates to the typical bidding process where a bill of quantities (BOQ) with certain specifications is required for a contracting job involving Heating, ventilation, and air conditioning (HVAC) operations. It was left for the bidding contractors to study and price the specifications accordingly and choose a suitable supplier. As intended by the BOQ, a handful of suppliers could execute the required HVAC design with its proper specifications, which amounted to only three. The selected supplier then analysed the specifications and the design regarding the allotted spaces, ducts and dimensions and it was found out that the older versions of the required model would be executed without a problem. The solutions proposed by the supplier would require variations in the offered prices since it would involve work beyond the specifications. However, due to the nature of the project being a public endeavour, a variation and change order would be exceedingly difficult. The team then decided to make as little changes as possible due to the many conflicts with the design and the specifications and a list of the solutions to the problem was proposed. The focus would revolve around the fact that the supplier identified a problem with the specifications that immediately required many additional costs, whether it was during the installation or during future maintenance operations. The main conclusion of this study was that such problems due to improper specifications could have been averted if the supplier was involved earlier in the design process (Kamal et al. 2019).

4.3 Case study (2) – Exposed roofing system, warehouses project, Saudi Arabia

In the second case, a project to restore some old warehouses and replace them with new warehouses included rooftop waterproofing. The BOQ included specifications for the entire waterproofing process, and a supplier was selected based on his expertise in the field. The contractor installed the system in accordance with the project specifications and industry standards. Owing to the high temperatures in the area, the supplied materials are more heat resistant. Since the overlap joints lacked the extra heat coating layer, the installation went smoothly. However, the end lap joints were coated, which resisted torching and expanded more after being exposed to sunlight Ultraviolet (UV) emissions. The input of a manufacturer/supplier is critical to the development of specifications included in the BOQ, and this problem could have been avoided if the supplier had been involved early in specifying the material and procedures involved. Warehouses that were waterproofed according to industry standards rather than manufacturer recommendations failed and required rework. In addition to the reworking costs, doubling the number of membranes would be required to complete the job according to the original specifications, resulting in additional costs (Kamal et al. 2019).

4.4 Case study (3) – Prefabricated bathroom units (PBU), public housing projects, Singapore

In most residential units, bathrooms and toiletries take up the least amount of space. However, for this small space to function properly and without problems, different trades must collaborate. It is also obvious that this small space has the most failures and issues after handover and requires maintenance on a regular basis, which is often a difficult task. Since November 2014, Singapore's BCA has mandated the use of PBUs in all public housing projects commissioned by the Housing and Development Board (HDB). The prefabricated systems have high-quality finishes, solid M&E design and execution, and, most importantly, are repair- and maintenance-ready. These PBUs are built offsite with all of the mechanical, electrical, waterproofing and even finishing with accessories completed and ready to be installed when the time comes. Such an endeavour necessitates extremely early collaboration between the manufacturer/supplier and the design team in order to realise the design, meet the end-user needs and meet the PBU's requirements before production begins. PBUs have several advantages over traditional bathroom units, including lower failure rates and higher quality execution; however, the main advantage is the unit's improved maintainability after installation. The units are designed with maintainability in mind, and clients are given a catalogue that describes every maintenance action that would be required with procedures, as well as having the manufacturer's information added to the PBU in case the client needs to communicate with them for any reason. The ESI demonstrates that the involvement not only helps to reduce costs but also improves the maintainability of the bathroom unit. The involvement of suppliers and manufacturers aided in the modification of the design to allow for easier access to the shaft for repair and maintenance (Building and Construction Authority 2014).

5 Data analysis

This section presents and analyses the results of a survey questionnaire administered to a representative sample of ADFs in Egypt to investigate their perception and application of ESI as a method for improving building maintainability during the design process.

5.1 Response rate and respondents' profile

Only 34 out of 44 ADFs invited to participate in the study responded to the survey questionnaire, which represents 77.3%. Twenty-seven firms are sole proprietors and the rest are partnerships. The number of years of experience of these firms in the construction industry ranges from 5 years to 50 years. Among the respondents, 65% are involved in both private and public projects. In addition, these firms are regularly invited to design projects in countries worldwide, which was beneficial for the study in that the addition of different perspectives was enabled. The size of these firms ranges from 10 to 50 employees with architecture, engineering and construction backgrounds.

5.1.1 Awareness of DfM

Respondents confirmed their perception of the concept of DfM, which indicates the maturity of the surveyed ADFs.

- Among the respondents, 55% stated that including building maintenance concept during the design process will help making future building operability efficient and less costly. Respondents indicated that the considerations of DfM are due to the need to utilise knowledge of material characteristics and maintenance needs (63.75%), meet client needs (55%), follow design firm's requirements and practice (50%) and reduce project budget (37%).
- On a scale of 1–5, respondents ranked the issues that affect the building maintenance during the design process. Results showed that 'Improper prioritisation of design maintainability' was the highest issue with an average of (4/5), followed by 'Lack of material and/or product availability in the market' with an average of (3.5/5), then 'Lack of material and/or product specification' with an average of (3/5) and finally 'Poor product user's feedback and evaluation' with an average of (2.8/5), see Figure 3.
- Among the respondents, 77% indicated that the majority of the feedback regarding building maintenance was received from the client, while 70% received from operation or facility manager and 50% received from building occupants.

5.1.2 Perception of ESI during the design process

Among the respondents, 87.5% agreed that involving external professionals (e.g. material and product suppliers) would help enhance building maintainability. However, the rest of the respondents stated that the involvement of suppliers during the design process depends on the nature of the adopted project procurement approach and client desire. On a scale of 1–5, respondents rated the role that suppliers can play towards enhancing building maintainability during the design process. Results showed that

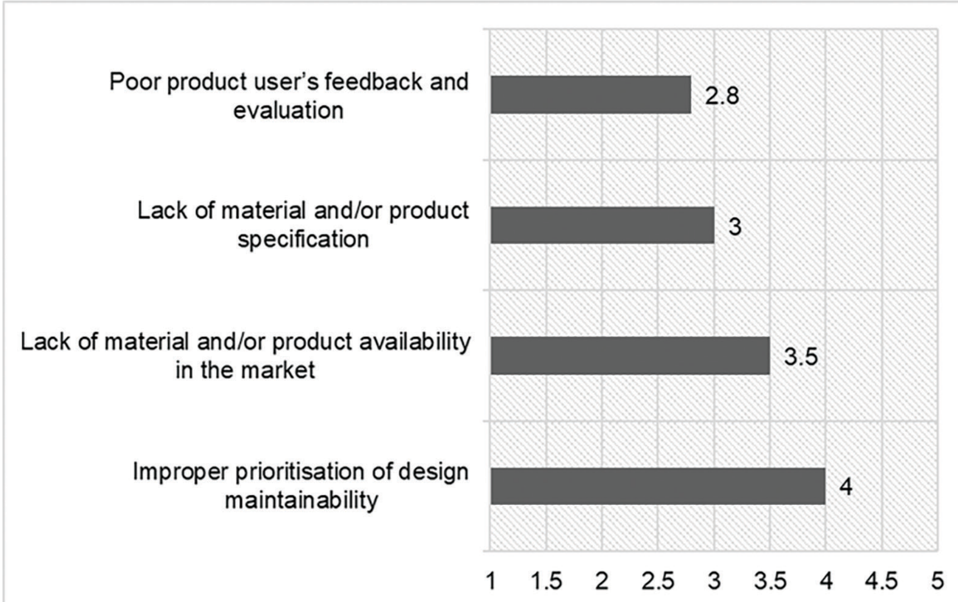

Fig. 3: Respondents' ranking of the issues that affect the building maintenance during the design process (developed by the authors).

'Better estimation for operation and maintenance costs' was ranked the highest contribution with an average of (3.56/5), followed by 'Reduce the number of operation and maintenance problems or reworks' (3.53/5), 'Using new and innovative operation and maintenance ideas' (3.47/5), 'Providing information about equipment and capabilities for the design and construction' and 'Added knowledge of properties and applications of new materials' (3.46/5), 'ESI can help project managers to solve logistical challenges' and 'Increase knowledge of designers for fast technological advances' (3.44/5) and finally 'Overall quality improvement' (3.06/5), see Figure 4. Among the respondents, 55% stated that they encourage and involve suppliers during the design process using the white box approach, where suppliers are involved informally as a consultant, in order to provide the design team with advice and suggestions.

5.1.3 Challenges of ESI during the design process

On a scale of 1–5, respondents ranked the challenges that may affect the ESI in the design process in ADFs in Egypt. Results showed that 'Difficulty in trusting suppliers and sharing information with transparency' was ranked the highest challenge with an average of (3.83/5), followed by 'Legal competitive advantage restrictions' (3.76/5) and 'Designer's goals and the supplier's goals may be different' (3.71/5), followed by 'Lack of legal framework to integrate supplier in design' (3.62/5), while 'Not common practice in the design process' was ranked the lowest challenge with an average of (2.53/5), see Figure 5. These results are in line with a previous study conducted by El-Saeidy and Othman (2021). This highlighted the need to overcome these challenges to enable ESI in the design process in ADFs towards enhancing building maintainability.

5.1.4 Supplier's selection criteria and forms of remuneration

On a scale of 1–5, respondents rated the criteria to be followed in order to identify and involve the right supplier to join the design team. According to the results, 'Innovation, technical expertise, and competence' was ranked the highest criteria with an average of (4.12/5), followed by 'Supplier willingness and ability to share information' (3.9/5), followed by 'Technical support and the ability to provide future materials and product spare parts' (3.75/5), followed by 'supplier commitment, trust, and view of partnership' (3.6/5), 'Senior management culture' (3.55/5) and 'Involvement cost and quality'. These findings are consistent with the ones drawn by Kannan and Tan (2002) and Petersen et al. (2003). According to 40% of respondents, they intend to compensate participating suppliers by paying consultation fees for offering advice and recommendations to the design team. On the other side, 26% of respondents suggested that suppliers share cost savings with the client, and 18% indicated that fees could be added to the price of materials and goods provided by suppliers during the procurement process.

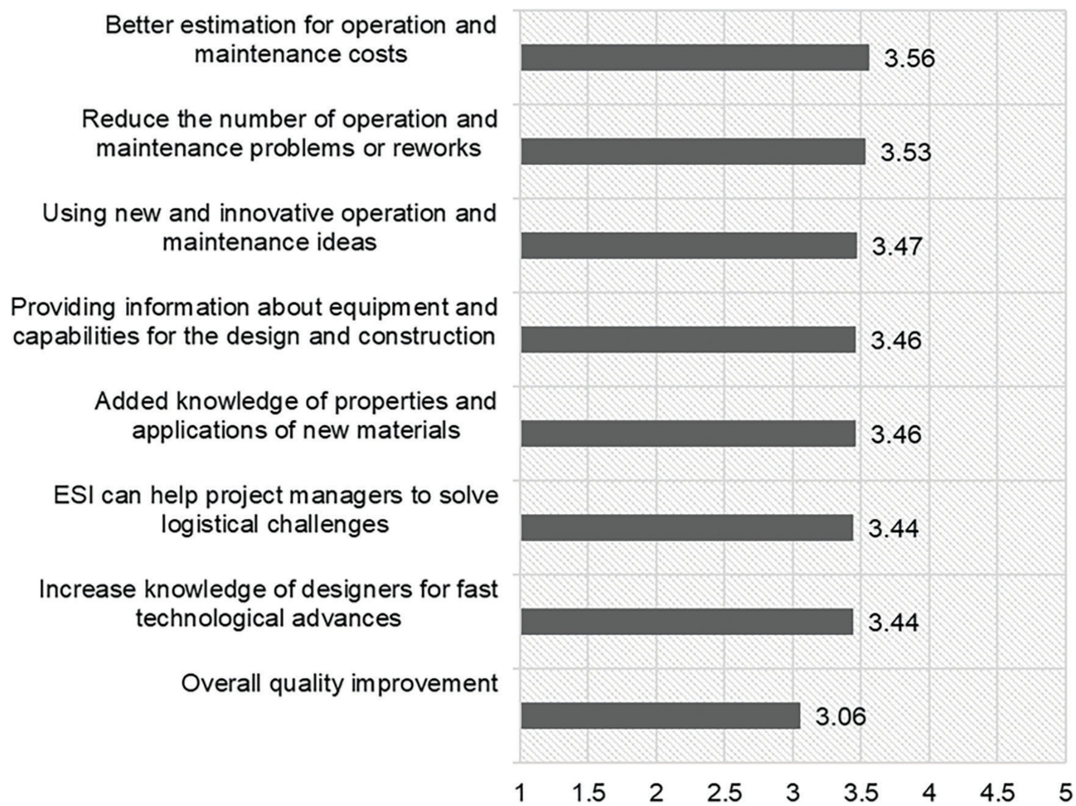

Fig. 4: Respondents' ranking of the benefits of ESI towards enhancing building maintainability during the design process (developed by the authors). ESI, early supplier involvement.

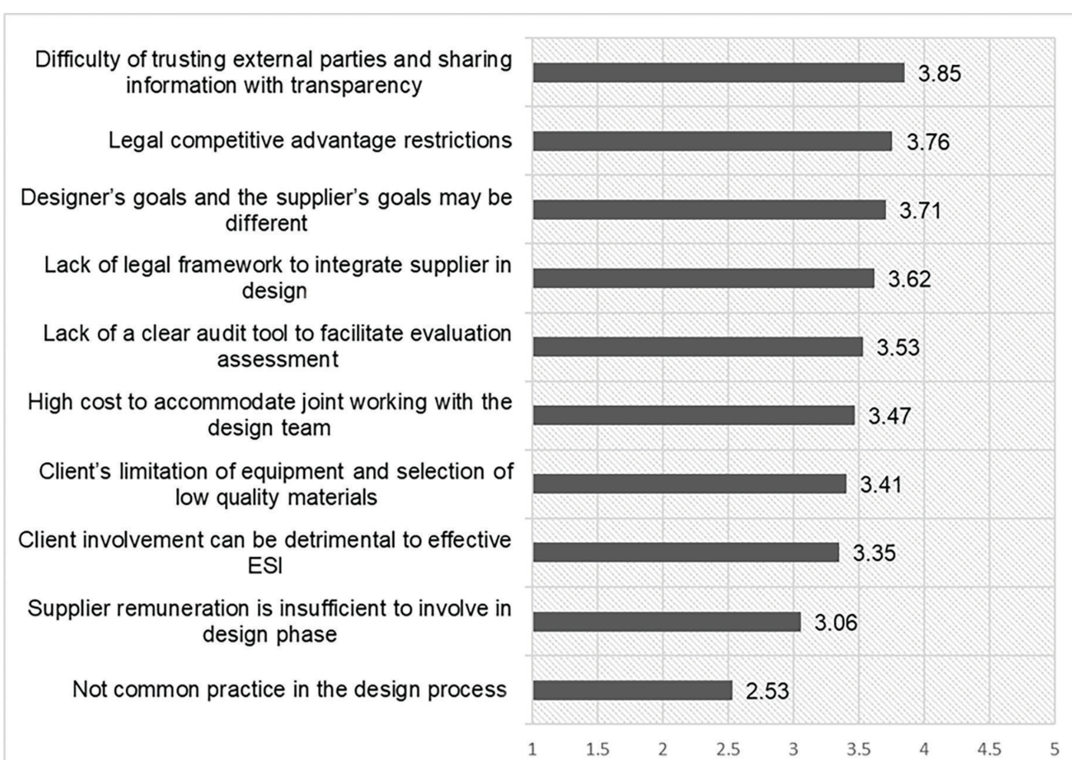

Fig. 5: Respondents' ranking of challenges that obstruct ESI in the design process in ADFs towards enhancing building maintainability (developed by the authors). ADFs, architectural design firms; ESI, early supplier involvement.

6 A proposed ESI framework for enhancing building maintainability during the design process

6.1 Definition and background

A framework is defined as a set of notions, techniques and tools in a planned outline to complete a product, process and design (EDMS 2010). The ESI framework is a proposed framework developed by this research to facilitate supplier involvement during the design process to enhance building maintainability during the design process.

6.2 The need for the framework

The framework is required to provide a structured plan for senior management in ADFs to address the constraints that hinder supplier engagement during the design phase in ADFs in Egypt. The need for this framework is derived from the need for utilising the knowledge and skills of suppliers to assist the design team in improving building maintainability during the design process.

6.3 Development of the framework

The development of the framework was based on the results gleaned from the literature review, case studies and survey questionnaire, see Figure 6.

6.4 Aim of the framework

This framework is an innovative conceptual business improvement tool developed to facilitate the involvement of suppliers during the design process as an approach towards enhancing building maintainability during the design process.

6.5 The conceptual description of the framework

The framework consists of five functions, namely:

- Enhancing communication between project participants
- Developing legal and financial procedures
- Developing a shared project vision between project participants
- Changing organisational culture
- Encouraging senior management involvement, see Figure 7.

6.5.1 Enhancing communication between project participants

Communication is an essential tool in construction for ensuring a smooth building process from start to finish. Furthermore, it is critical in achieving organisational and project objectives. Communication not only leads to more successful outcomes but also breaks down barriers between project team members, improves teamwork abilities, fosters good cooperation and leads to an optimistic project journey for the client. Communication enables project participants to share their knowledge and expertise in order to improve building performance and maintainability (Othman and El-Saeidy 2022). One of the most common reasons that suppliers are not integrated into the design process is a lack of communication among project participants. As a result, improving communication among project participants will aid in overcoming the difficulty of trusting external members of the design process (such as materials and product suppliers) and transparently sharing project information with them. Allowing project participants to participate effectively in planning, collecting, creating, distributing, storing, retrieving, managing, controlling, monitoring and disposing of project information could result in effective communications (PMBok 2021).

6.5.2 Developing legal and financial procedures

One of the challenges that obstructs supplier involvement and the use of their knowledge and experience in improving project design is a lack of legal and financial procedures. As a result, developing legal procedures will aid in clarifying business relationships, agreements and the rights and obligations of involved parties, as well as overcoming legal competitive advantage constraints. Furthermore, legal procedures will aid in the avoidance of potential disputes and litigation, as well as the protection of the project's intellectual property. Furthermore, in the design process, the developing financial framework will define a sufficient and agreed-upon remuneration package for ESI. This remuneration package will be proportional to the level and nature of supplier involvement in the design process, ranging from 'None' where the supplier is not involved in the project design to 'Black Box' where the

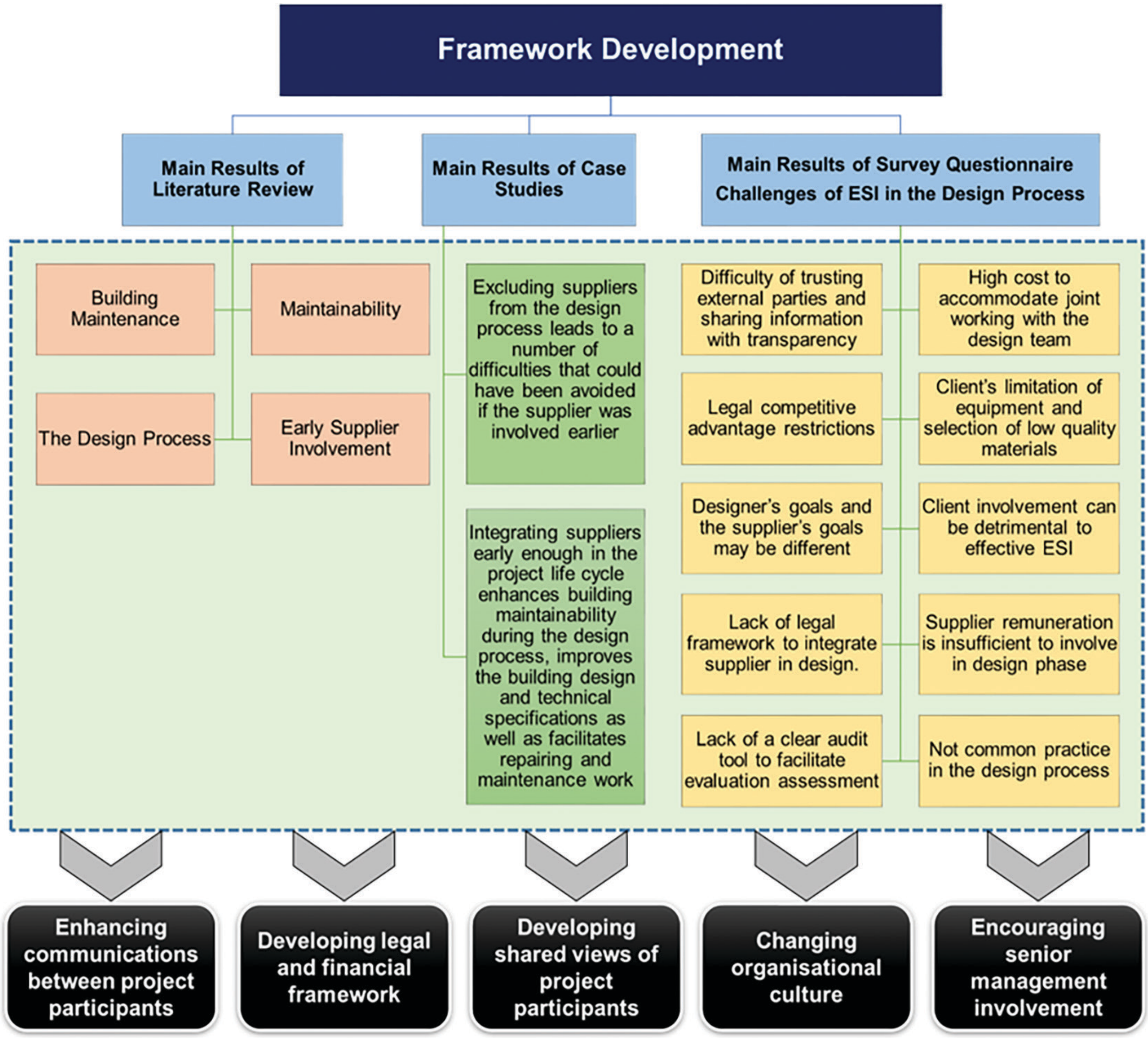

Fig. 6: Framework development (developed by the authors). ESI, early supplier involvement.

design is primarily driven by the supplier. Setting legal and financial procedures will encourage suppliers to participate in design development and overcome the cost challenge of allowing joint working with the design team.

6.5.3 Developing a shared project vision between project participants

The project vision is the team's or project's overarching goal. A clear project vision is essential for project success. It gives direction, establishes goals and may even prevent problems from occurring. The participation of project team members enables the sharing of a common understanding and involvement in the design decision-making process for the project. Furthermore, participation results in empowerment and shared ownership of the project. This will help both the designer and the supplier overcome the obstacles of having distinct goals. Creating a shared project vision among project participants must begin with consultation, progress to negotiations, and conclude with a shared vision and mutual decisions. Participation by project team members helps to ensure that project plans reflect real needs and priorities, fosters trust by allowing all participants' voices to be heard and issues to be addressed, and holds the project accountable to project participants. Furthermore, having a shared vision encourages openness in project activities, fosters project ownership and encourages project participants to sponsor the project, all of which contribute to the effective realisation of project objectives.

Fig. 7: ESI framework (developed by the authors). ESI, early supplier involvement.

6.5.4 Changing organisational culture

Organisational culture is the set of shared values, beliefs, behaviours, goals, attitudes and practises that define a company, organisation, community or group. From a business standpoint, culture is the sum of people's behaviours regarding how they complete their tasks. Employees attribute their ability or inability to achieve something to their organisation's culture. The organisational culture either facilitates or inhibits change or opposition (Mann 2005). Changing organisational culture aims to influence employees' attitudes, behaviours, abilities or performance in ADFs. One of the cultural challenges that must be overcome in ADFs is involving suppliers in the design process. This is because the design team's resistance to include suppliers in the design process prevents the project design from leveraging supplier experience to improve building maintainability. Furthermore, despite the importance of client involvement in project design, the culture of client power exercise must be changed because it may be detrimental to effective ESI. Finally, the notion that ESI is not a common practise in the design process must be reconsidered in light of Integrated Project Delivery (IPD), which encourages it. The involvement of various project participants (for example, suppliers) is becoming more common in the United States and other parts of the world. Its use in the Middle East and Egypt has yet to begin (Barrett et al. 1996; Othman and Youssef 2020; Rached et al. 2014).

6.5.5 Encouraging senior management involvement

A committed senior management is required for a firm's daily operations, the creation of goals and strategies, as well as for strong involvement, commitment and trust (Martensson 2000). Leaders are crucial in developing business strategies that enhance an organisation's performance and boost its competitive advantage in the dynamic business world of today. To enhance building performance and maintainability, these strategies entail defining an organisation's vision, goal and objectives. According to Storey and Barnett (2000), senior management involvement should be ongoing and provided in a realistic manner. This will assist in overcoming challenges such as the client's equipment limitations and choice of low-quality materials, as well as the absence of a clear audit tool to allow ESI evaluation assessment. Raising senior management's awareness of the advantages of enhancing building maintainability, boosting competitiveness, establishing formal legal and financial processes to support ESI, and boosting top management confidence by showcasing the effectiveness of the DfM idea will all help to encourage senior management participation. Senior management must frequently communicate with team members to both assess their performance and inspire them to focus their efforts on achieving organisational objectives and enhancing building maintainability.

6.6 Benefits and limitations of the framework

In the early stages of the project life cycle, the framework provides organised procedures for integrating providers. This framework enhances the design process's quality while simultaneously enhancing the ability to sustain a structure after construction. The framework can improve designers' comprehension of the importance of the ESI notion. The practical application of the framework, however, largely depends on the willingness and cooperation of senior management of ADFs to adopt the framework in order to enhance building maintainability throughout the design phase. Furthermore, the framework's adoption will be limited if top management is unwilling to use it and tends not to do so. Due to the lengthy acceptance and deployment process and the constrained timelines of construction projects, some sectors of the business might not embrace this framework. Additionally, the adoption and implementation of the framework are hampered by the absence of contracts and legislation that organise and manage ESI.

7 Conclusion and recommendations

It is the responsibility of the construction industry to deliver projects that are sustainable, suit the needs of the clients, and offer the best value for the money. The project life cycle's various phases all require the application of this idea. Post-construction is a crucial stage because it looks at building issues and design flaws. Many people considered maintenance to be an undesirable component of the building industry, despite the crucial role it plays in keeping or restoring the structure to a functional state. The operational budget for the facility includes a sizeable portion for building maintenance. Since many decisions made during this phase have an impact on the project's performance and maintenance, the design phase is an essential step in the construction process. However, the design process has not yet fully accounted for maintenance. Building maintenance, maintainability, the design process and ESI were all investigated during the course of this research using a literature review. Furthermore, three case studies were presented and analysed to investigate the role of ESI in improving building maintainability during the design process. Furthermore, the results of a survey questionnaire administered to a representative sample of Egyptian ADFs revealed that 'Difficulty of trusting external parties and sharing information with transparency' was ranked as the most difficult challenge of ESI in Egyptian ADFs, followed by 'Legal competitive advantage restrictions'. Moreover, 'Better estimation for operation and maintenance costs' was ranked the highest contributions of ESI towards enhancing building maintainability followed by 'Reduce the number of operation and maintenance problems or reworks'. Finally, respondents stated that 'Innovation, technical expertise, and competence' was ranked the highest supplier's selection criteria, while 'Paying consultation fees for offering advice and recommendations to the design team' was ranked the highest form of supplier's remuneration. Based on the findings of literature review, case studies and survey questionnaire, the research developed a framework to facilitate ESI in the design process as an approach for enhancing building maintainability. Accordingly, the research arrives at the following recommendations.

(1) Raising ADFs' awareness of the importance of incorporating suppliers into the design process as a means of improving building maintainability.
(2) Creating a business environment that promotes the integration and trust of external members by improving communication among project participants.
(3) Implementing laws, procedures and regulations to organise business relationships between suppliers and ADFs, as well as financial frameworks to define a sufficient and agreed-upon remuneration package for ESI in ADFs.
(4) Encouraging project participants to develop a shared project vision.
(5) Motivating ADFs to change their culture and adopt new approaches, such as ESI, to use their technical knowledge and expertise to improve the design process and building maintainability.
(6) Encouraging senior management involvement by providing successful examples of the benefits gained through ESI in the design process, particularly improving building maintainability.
(7) Providing the necessary training programmes, technologies, infrastructure and resources to enable supplier integration in the design process.

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