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An Strategy of Product and Process-Oriented Design of Industrialized Building System Qualities

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ABSTRACT: Industrialized Building has been introduced as a method with better productivity, quality, and safety, and it is defined as a construction system where components are manufactured at factories on or off-site, transported, and then assembled into with minimum work in the study of the use of building industrialization, the question of this study is to apply product-oriented and process-oriented in the quality of building industrialization and interaction and the overlap between the two areas in the category of industrialization. Explaining the characteristics of these two aspects leads to various structures that include the main objectives of this study. With the help of product-driven and process-driven approaches, it can be achieved with varying qualities of building industrialization. In this regard, several experts' views have been reviewed studied, and a five-step quality is extracted. Finally, employing interface tools to two product-driven and process-oriented approaches, a good choice concerning the five-step quality has been made for designers in building industrialization.

Keywords: *Building Industrialization, Product-Oriented, Process-Oriented, Design Qualities, Construction.*

INTRODUCTION

The extensive use of prefabricated components manufactured by industrial methods is crucial to reduce costs in the construction industry. The industrial production of buildings has various benefits, such as controlling the quality, reducing the construction time, decreasing construction waste, reducing environmental damages, and decreasing the need for the workforce at the construction site. The term "industrialized building system (IBS)" is used to describe the concepts of modulation, prefabrication, and assembly. In general, this term is defined as preparing equipment, facilities, and technology to increase output, reduce manual labor, and improve quality (Sebestyen, 2003, 120). Industrialization in architecture does not just include prefabrication and involves a wide range of architectural methods, from simple techniques to prefabrication and even traditional construction (Mirsaeedie, 2009). Besides, it is defined as a construction method produced, transported in a controlled environment, and added to the complex with minimal labor (CIDB, 2003). In an IBS process, all building components are mass-produced at the construction site or in a factory under meticulous control with minimum human activities (Trikha, 1999). IBS cannot limit its scope to the final product, which is a system. It primarily includes processes that lead to system production and application in construction. As a result, industrialization components make as a process, a product, a system, and technology. Most researchers have defined industrialization as a method, approach, and process. However, some experts have recognized industrialization as a product. This article intends to answer the questions of whether the qualitative components of IBS interact with each other have a process-oriented or product-oriented approach? Which one of the two components of process-oriented or product-oriented making the IBS quality is more effective?

MATERIALS AND METHODS

The attitude toward industrialization in modern times describes extensive assumptions of concepts, terms, and breadth of the field. In recent years, industrialization has been associated with the alternative focus on process and production process. Accordingly, the central question of the present study was: how

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product-oriented or process-oriented attitude is considered and interacted with each other in the design of industrial buildings in the contemporary era of industrialization? Therefore, the present study aimed to describe the product and process-orientated approaches to IBS and propose strategic rules to achieve various industrialization qualities. In order to achieve these goals, the quality indicators of IBS were categorized and defined. Two approaches led to determining the outputs obtained in the building's industrial design to achieve these qualities.

Moreover, the experts' views and opinions were classified based on two approaches in this field. The features of the term were also assessed, and the most frequent experts' opinions about the characteristics were selected as more comprehensive quality. Ultimately, the qualities were shown in a table using their interface tools, their product-oriented or process-oriented approach.

Industrialized Building System (IBS)

Nowadays, industrialization has a wide range of definitions. Therefore, it is necessary to determine precisely what industrialization is. In its latest report on industrialization, the Construction Industry Development Board (CIDB) defined industrialization as construction using mechanical power and tools, steering system and computer tools, continuous production, productivity improvement, product standardization, prefabrication, modulation, and mass production (CIDB, 2010). Table 1 presents some of the definitions of IBS from the perspective of experts.

IBS Features

In the construction view, industrialization is part of a broader modernization process by developing modern production methods, technology systems, and mechanized production operations that focus on mass and mainly factory production. A production that is organized in a focused way (Lessing, 2006). In other words, industrialized construction is a change of thinking and practice improving building production for creating a high-quality environment, optimization and standardization, organization, cost performance baseline, value, mechanization, and automation (Hashemian, 2005, 79). Today, there have been significant improvements in perspectives and theories related to building construction to become highly different from previous experts' opinions. Table 2 summarizes the differences from the perspective of Warszawski.

According to these definitions, industrialization does not necessarily limit its scope to the final product, which is a system. However, it mainly includes the processes that lead to the production of the system and its construction application. One of the changes in these theories is changing industrialized

Table 1: Literature of Industrialized Building System (IBS) according to experts

(Abd Rashid et al., 2019)	Either IBS is defined as a construction system that consists of a combination of components manufactured on-site or off-site, then positioned and assembled into structures. The benefits of IBS construction include labor cost reduction, support a desirable environment, maximize efficient use of resources, and waste minimization towards sustainable construction.
(Mohamed et al., 2018)	IBS is a construction method that refers to the components manufactured in a controlled environment (on or off-site), transported, positioned, and assembled into a structure with minimal additional site works.
(Rahim & Qureshi, 2018)	IBS can be described as a method to construct a building using prefabricated components manufactured systematically through machinery and mold in the factory. They are then transported and assembled on site.
(Berawi, 2017)	IBS is an integrated process involving all subsystems, components, manufacturing, and construction processes, requiring efficient management.
)Nawi et al., 2019)	It is a system or method in which parts are manufactured in factories or on-site and are installed in construction sites under the control, transportation, and installation with minimal use of workers.
(Fathi et al., 2012)	IBS is a construction method of building components either in a factory or at the site and then assembled on the construction site.
(Kamar et al., 2009)	IBS is the concept of industrialization as a prefabrication process in construction.
(Chung, 2006)	IBS is mass production of building components either in a factory (off-site) or at the construction site (on-site).
(Marsono et al., 2006)	IBS is a construction method using the best construction machinery, equipment, materials, and extensive planning.
(Lessing et al., 2005)	IBS refers to an integrated production and manufacturing process made by managing the organization and managing activities.
(Gibb, 1999,37)	It is a prefabrication process, organization, and completion of the final modules before installation into the location.
(Parid, 2003)	It refers to an industrial system of producing components or assembling a building, or both.
(Junid, 1986)	IBS is an integrated software and hardware system, and the building components are designed, built, transported, and assembled on-site.
(Vafamehr, 2013,17)	It is a set of technological factors, tools and machines and human skills, and technical knowledge

Table 2: Warszawski's views on conventional construction and industrialization of buildings. (Source: Warszawski,1999)

Industrialization	Conventional construction
Tasks are done in one permanent place.	Tasks are scattered among temporary locations
The low-moderate life cycle of a product	High product life cycle
The high number of iterations and standardization	Low standard; Given that each project has distinctive features
The low number of tasks for producing a specific product	A large number of required tasks and the high level of skills needed to complete a typical construction project
All tasks are performed in fixed workstations	Each task is performed by specific workers and in a large area of work, moving from one place to another
The workplace is carefully tuned to human needs	The workplace is relatively inhospitable to human needs
The workforce is relatively stable	Great labor force changes
Integration of decisions for design, production, and marketing	The division of labor is done between the employer and the designers.

building from product-oriented to process-oriented.

Process and Product in IBS

According to Ketels, a product is anything that can be offered to a market to satisfy a desire or need. Marketed products include physical goods, services, experiences, events, people, places, assets, organizations, information, and ideas (Porter, Ketels, 2003). Several prominent architects have been involved in product architecture in recent decades. Product architecture can be considered a method in which the functional elements of a product interact with its physical components and define how these components relate (Ulrich & Eppinger, 2008,124). According to Ulrich, product architecture has the following conditions:

- Arrangement of functional elements
- The link between functional elements and physical components
- Interaction and link between physical elements and components (Ulrich, 1995).

A focus on IBS as a product clearly shows the involvement of various factors in the quality of the formation of this architecture. These factors include modular architecture and integral architecture (Ulrich, 1995; Fine et al., 2005; Fixson, 2005; Ramachandran & Krishnan, 2008). A modular architecture includes a one-to-one mapping from functional elements in the function structure to the physical components of the product. Physical components will be easily placed next to each other and be replaced due to their standardization and quality, and coordination of dimensions. Significant advantages of modular architecture include:

- Product diversity (Sanchez, 1999; Ramdas, 2003; Jiao et al., 2007)
- Sharing components (Kim & Chhajed, 2000; Baldwin & Clark, 2000; Desai et al., 2001)
- Upgradability (Ramachandran & Krishnan, 2008, Krishnan & Ramachandran, 2011)

An integral architecture includes a complex mapping from functional elements to physical components or coupled interfaces between components. For an integral product, a change in some functional components and elements led to a transformation in other components to make the overall product work properly (Ulrich, 1995; Baldwin & Clark, 2000; Ulrich &Eppinger, 2008). In the last few years, IBS has been associated with the replacement of the production process and includes all activities required for a specific type of construction along with execution techniques and methods. Such a system includes various technical and managerial methods for producing and assembling elements for a specific purpose. It includes a set of related elements that operate to provide a specific construction function (Warszawski, 1999, 385). This technical advancement is often considered a process of industrialization of construction, including new materials, structures, computer services, and new knowledge, mechanization, prefabrication, and construction automation. Warszawski considers five factors for the success of industrialized construction:

- Centralization of Production,
- mass production,
- standardization,
- specialization,
- good organization,
- Integration (Sebestyen, 2003, 121).

From a constructive perspective, industrialization is recognized as a standardization process and a way to have higher efficiency, productivity, and quality (CIDB, 2010). There is consensus among designers in the industrialized construction field because moving towards the industrialized construction industry is a global initiative, not a local one. The process-oriented approach in industrialized construction is defined using the concept of mass production of industrial systems, produced in the factory or on-site in controlled environments, carried out in proper coordination with systematic planning and integration (Kamar et al., 2009).

Experts' Opinions about Product Orientation and Process Orientation in IBS

As a process-oriented structure, IBS faces a systematic system. Therefore, the process orientation and product orientation structure of IBS have been evaluated from the perspective of experts. Industrialized construction must be realized in an

organized process in different stages and components of the building, and a set of factors involved in construction is under a coordinated system and within the framework of its own rules and regulations governing the production process of the building (Vafamehr, 2013, 55). These experts have indicated six features for IBS, while other features may be detected in this regard. The six features include industrial production, transportation and assembly, on-site construction, mass production, planning-standardization, and process integration:

- Industrial production: is a process that increases system output and optimizes the operation of equipment, facilities, and technology by improving the quality, construction time, and use of labor. Therefore, we are talking about factories that produce all kinds of parts to be installed in construction. The main goal of this production method is to improve safety, quality, cost, and output levels (MAPSA, 2020).
- Transportation and assembly: are processes in which the prefabricated components of a building and its accessories are produced in a place other than the construction site. Besides, assembly in industrialization through mechanized processes decreases the amount of waste production and environmental impact.
- On-site construction: design, production, and on-site setting are closely linked and should be considered part of a convergent process and thus planned and coordinated.
- Mass production: is the manufacturing of large quantities of standardized products, often using assembly lines (Hashemian, 2005, 84). An automated mechanical process carries out this production of large quantities of a standardized product. The benefits expected from industrialization are often achieved in high-volume production (Vafamehr, 2013, 37). This process has had a positive impact on construction speed and quality essentially and has become one of the main principles in this regard.
- Planning and standardization: are components involved in IBS that require standardization for production to achieve modular coordination (Trikha, 1999). Modular coordination and standardization are the features required for the successful implementation of industrialized buildings. To meet the requirements of modular coordination, all components of IBS must be standardized. Therefore, the standardization program and its components in standardization are incredibly crucial, significantly to help the production process.
- Process integration: includes components and factors that affect industrialized construction are coordinated and complete each other so that the complete chain of the construction industry is formed by joining all the valuable links in it. There should be high coordination between various parties related to the designer, builder, owner, and contractor to achieve favorable results. This is achieved through an integrated system where all these parties are done under a single integration (Warszawski, 1999, 7). Given the necessity of improving productivity, sustainability, quality, and safety, it is imperative to use novel methods (e.g., automation and robotics) to eliminate this problem (CIDB, 2016).

The views of these experts based on product-oriented or process-oriented classification are given in Table 3. Their selection is made by covering the period and based on historical precedence.

Qualitative Characteristics of IBS

In the previous table, 19 experts defined IBS as a process-oriented method. On the other hand, only six experts recognized IBS as a product-oriented technique, which shows that industrialization is process-oriented even though process and product are inseparable. However, almost all experts emphasized factory production as an essential feature of IBS. Considering the mentioned conditions (i.e., factory production, transportation and assembly, on-site production, mass production, planning and standardization, and process integration), each feature can overlap or align with one or more features of IBS (figure 1&Table 4).

The quality components of IBS have been recognized as a potential category for the improvement of construction performance. Abdi et al. have summarized and presented examples of the qualitative components related to the industrialization features, shown in Table 5.

RESULTS AND DISCUSSION

According to Table 4, the five most critical qualitative components of IBS that had the highest frequency from the perspective of experts were access to high-quality level, high construction speed, cost savings, increased safety, and increased social benefits[1] These components are used to express how to use the core product or core process of the interface tool. This method is implemented using the features presented in Table 6. Therefore, these five components can be classified into two categories of product-oriented or process-oriented, which are presented in Table 6.

The process-orientation approach in IBS and its qualitative components have improved effectiveness and efficiency in the construction industry and have provided a suitable context for improving construction quality. The significant impacts of process orientation in IBS nudges a set of approaches and policies in the construction industry toward becoming more effective and efficient. Some of the approaches include:

The central part of the labor in the construction industry comprises ordinary laborers with limited education and skills. At the same time, IBS could be used to compensate for skill shortcomings in the construction industry. In other words, a trained and skillful labor force with special skills such as integration, factory production, and assembly will have higher importance and efficiency due to the various roles he can play. Hence, all the construction industry workers participate in IBS at various human capital empowerment processes.

Organized management at design and execution levels for

Table 3: Expert opinion based on product-oriented classification or process-oriented industrialization of the building

reference	Attributes						Classification	
	Process integration	Planning and standardization	Mass production	On-site construction	Transportation And assembly	Industrial production	Process-Oriented	Product-Oriented
Dietz et al., 1971	●				●	●	●	
Junid, 1986	●	●			●	●	●	
Sarja, 1998		●						●
Trikha, 1999		●	●			●	●	
Warszawsk, 1999	●							●
Badir et al., 2002		●				●	●	
Parid, 2003					●	●		●
Shaari &Ismail, 2003				●		●		●
MIGHT,2004		●	●		●	●	●	
Haron et al., 2005		●				●	●	
Lessing,2006	●	●				●	●	
Chung, 2006		●	●	●	●	●	●	
Hong, 2006		●			●	●	●	
Rahman &Omar, 2006		●			●	●		●
CIDB, 2007					●	●	●	
Hassim et al., 2009	●	●				●	●	
Kamar et al., 2012				●	●	●	●	
Fathi et al., 2012				●	●	●	●	
Jonsson& Rudberg, 2014		●			●	●		●
Musa et al., 2015	●				●	●	●	
Mahbub,2016					●	●	●	
Santoso et al., 2017		●			●	●	●	
Abd Rashid et al., 2019	●	●				●	●	
Thajudeen, 2020	●	●				●	●	

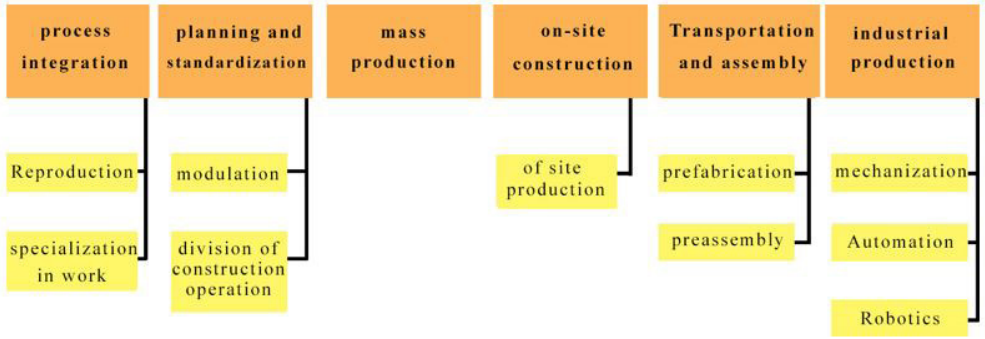

Fig.1: Features of IBS

Table 4: Literature of IBS components

No	Feature	Definition	Reference
1	Mechanization	Another feature industrial revolution that has entered the building field is the use of machinery instead of humans in the construction process. The efficiency of a human being is one percent, while the efficiency of a machine is at least 20 percent. Therefore, it is not economical to use a human workforce in constructions where machines can replace humans.	Vafamehr, 2013, 26
2	Automation	With automation, the equipment thoroughly performs the tasks performed by the workforce.	Richard, 2005
3	Robotics	With robotics, the same multi-axis equipment and flexibility processes can be done for different tasks.	Richard, 2005
4	Pre-assembly	Pre-assembly is a process in which prefabricated components of the equipment and its accessories are constructed off-site. Sometimes, in the construction process, they form part of a building unit through the "assembly" operation.	MAPSA, 2020
5	Off-site production	The "off-site production" term is used when both prefabrication and pre-assembly are integrated.	Jaillona et al., 2009
6	Modulation	Modulation is the standardization of building components and parts. In a way, productions are carried out in a logical and limited area instead of producing a part in very different dimensions and parts to achieve factory mass production. This is the only way we can mass-produce a product, which provides the conditions for reducing production costs.	MAPSA, 2020
7	Division of construction operations	Given the design and execution of the building as separate parts, it is necessary to separate construction operations such as parts manufacturing lines and the assembly of parts and perform them by production line and related experts.	Olia et al., 2010
8	Reproduction	Reproduction represents an innovative technology that can simplify the production of complex goods. The goal of reproduction is to shorten repetitive linear operations.	Richard, 2005
9	Specialization in work	Specialization in work means that the building is inspected and constructed in various parts and elements. Besides, the construction of each part requires the relevant expert and its unique product line. On the other hand, there are various industrialization methods, each requiring its specialized executive force. Notably, these methods are not as general and widespread as traditional techniques.	Olia et al., 2010
10	Prefabricated construction	Prefabrication is defined as the manufacturing process in which materials are generally linked together to form part of the final installation.	MAPSA, 2020

Table 5: Qualitative Components of Industrialization Features. (Source: Abedi et al., 2012)

Kamar et al., 2011	Achieve high quality	Increase safety	Increase construction efficiency			
Warszawsk, 1999	Reduce unskilled workers	Increasing social benefits	Increase flexibility in construction			
Hassim et al., 2009	Achieve high quality	Cost-saving	Increase safety	Increase construction efficiency		
Elias, 2000	Achieve high quality					
Din, 1984	Achieve high quality					
Nawi et al., 2007	Reduce unskilled workers	Increasing social benefits				
Alinaitwe et al., 2006	High build speed	Cost-saving	Reduce unskilled workers	Increasing social benefits	Increase safety	Operation and location optimization
Oliewy et al., 2009	Achieve high quality					
Peng, 1986	High build speed	Increase construction efficiency				
Masoud, 2007	Increase construction efficiency	Cost-saving	Reducing environmental hazards and construction waste			
CIDB, 2005a	Reducing environmental hazards and construction waste					
Shaari& Ismail, 2003	Reducing environmental hazards and construction waste	Achieve high quality	High build speed	Cost-saving		
Bing et al., 2002	Cost-saving					
CIDB, 2009	Increasing social benefits					
CIDB, 2005b	Increase safety					

manufacturers, executives, and consumers is considered the significant achievement of IBS process orientation. From the strategic point of view, organized management also aims to prevent the loss of resources and materials and high accuracy in work with a high level of technical competence, which will result in healthy competition between contractors and executives in the competitive industry of construction. Therefore, process orientation in IBS results in higher support and innovation.

Process orientation demands IBS to conduct accurate cost management and planning through all stages. Better cost data nudges executives toward systematic cost management and better estimation, resulting in a better estimation of the advantages and disadvantages of using IBS.

Historically, there has not been a favorable relationship between manufacturers, executives, and consumers in the construction industry. This lack of cooperation stems from weak connections, undesirable relationships, and lack of commitment in all parties. The existence of a supply chain improves these interactions in IBS process orientation. IBS supply change management consists of planning and managing all activities such as preparing, procuring logistics, and coordination between the contractors, suppliers, intermediaries, and sellers.

IBS process has a value chain in which each stage (chain link) adds value to its previous stage.

CONCLUSION

According to the results of the present study, IBS has excellent potential for increasing efficiency and productivity. While most

Table 6: Qualitative components and its tools of IBS

Qualitative components of IBS	Tools to achieve quality	Types of structures obtained in the industrial design of buildings	
		Process-oriented	Product-oriented
Access to a high-quality level	Factory production-planning and standardization- process integration	●	
High construction speed	Factory production- on-site construction- mass production	●	●
Cost savings	Transportation and assembly- on-site construction		●
Increased safety	Factory production- planning and standardization	●	
Increased social benefits	Mass production- process integration- factory production	●	●

experts have defined industrialization as process-oriented in the research literature, the scope of the industrialized building is limited to the final product, which is a system and includes processes that lead to the production of the system and its application construction. This is mainly because the process-orientated approach focuses on production, whereas product orientation focuses on the customer. According to Table 6, achieving high-quality construction and safety in industrialized construction has a process-oriented structure due to having macro and chain factors in planning. Due to a lack of structural and integration factors, cost savings have a product-oriented quality. High speed in construction and social benefits can also be included in product-oriented structures due to their result-oriented structure in addition to the process-oriented structure. As such, industrialized construction can be both process-oriented and product-oriented. In the meantime, there is no distinction or superiority between either of the above two axes for the industrialized building. The goal is to use these two axes in a way that they can work together and improve the industrialization process in general. Moreover, an instruction should be considered by designers to take a series of qualities in both product-oriented and process-oriented axes into account and improve several aspects of the best advantages of both systems in construction, including the level of productivity, quality, and safety, enabling construction industry's players to have a more efficient performance in the economics.

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ENDNOTES

[1]Social benefits include meeting the housing needs of applicants, which includes some qualitative, environmental, social, and cultural factors.

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