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Integrating the Principles of Lean Management into the Design Process of Green Tall Buildings

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***Abstract*- Tall buildings have become a sign of Economic and technological development in advanced countries, resolving different issues coming from the significant increase in the urban dwellers and land price. This type of buildings is characterized by its high levels of energy consumption and design complexity. The design process of tall buildings involves many professionals from several disciplines, requiring an efficient management to coordinate and interpret the interrelations between these various disciplines in the design stage taking into consideration the global awareness of energy consumption and the urgent need to reduce the quantity of energy used by this type of buildings. Lean process tools and methods have been adapted to the design management process in the AEC industry - known as Lean Design management (LDM) - to improve the context of design and overcome its deficiencies with minimum wastage with a greener comprehensive view of the whole project. Applying lean design management tools to the design process of tall buildings will help in overcoming the challenges coming from the complex design process of tall buildings. Thus, the objective of this paper is to set preliminary guidelines for the integration of the lean design management concept with the design process management of green tall buildings, through a literature review. More than 200 research paper -ranging from 2010 till present mostly indexed in Scopus database- including the aim of the study were selected for review. Research found a number of preliminary guidelines for optimizing the design process of green tall buildings through the adaptation of the lean design management concept. This research is meant to be the first phase of the study to assess the application of lean principles to the design process of tall buildings through practical analysis of case studies that will be carried out in further studies.**

***Keywords*: Green Tall Buildings, Lean Design Management (LDM), lean principles, design management.**

I. INTRODUCTION

Tall buildings are monumental structures that are typically constructed as symbols of power, wealth, and prestige. with the constant change of design trends, designing these buildings is a complex task in which all design constraints and potentials interact with one another [1]. Successful Tall building designs must use as little nonrenewable energy as possible, produce as little pollution as possible, and reduce their carbon footprint while maintaining the comfort, health, functional needs, and safety of those who reside in them.[2]. The design of green tall buildings should be accomplished by multidisciplinary teams with diverse qualifications and skills from various professions, taking into account both modern technologies and the richness of local heritage [3].

A systematic design management process is considered an urgent need at this level of project complexity, to ensure the effective collaboration of the various design disciplines to meet the expectations and requirements of customers while avoiding design errors and conflicts [4]. A review of the literature reveals that one of the primary causes of project failures could be inadequate design management conceptualizations [5].

Over the last two decades lean approach was introduced to optimize the process of design management by applying the lean principles to each step of the design management process producing the concept of lean design management [6]. Lean design management (LDM) has helped construction projects achieve remarkable results by increasing collaboration among project parties, adding customer value, lowering project costs, and solving design management problems. [7]

The study discusses the role of LDM approach in the enhancement of the design management of tall building complex design process, while setting some preliminary guidelines for this new paradigm.

A. Problem definition

The design process of green tall buildings, from conceptual design to final design documents, encounters various challenges, these challenges are dealt with by various interconnected methods through the conventional design process management, which can be insufficient and should be more developed to cope with the ongoing flow of management science development.

The problem of designing tall buildings came from the extreme complexity of their design process. the absence of a comprehensive and systematic method of defining multistakeholder and multidisciplinary goals, managing their evolution, generating and selecting among design options that respond to identified goals for a more successful design. Literature shows various examples of problems in tall buildings projects due to malfunctions in the design process management as per example a study of four LEED GOLD certified tall buildings, where dwellers experienced several issues that could have been solved with better design decisions to provide an efficient dwelling experience. [8]

The main issue with design management is that the process is complex and thus difficult to manage. Design management requires the input and collaboration of a large and diverse group of individuals and organisations, from identifying customer needs to visualising and developing construction solutions that meet those needs [9]. Traditional approaches to design management have limitations. New tools are required to reduce waste, increase value, and allow for continuous improvement. Lack of system compatibility can impede information transfer between stakeholders, resulting in rework and project overruns [10].

Egypt has entered the construction field of tall buildings and skyscrapers vigorously. According to "Egypt Vision 2030" and the urban development plan proposed, more than 50 tall buildings projects are set to be constructed in different new cities in Egypt. With this novel orientation, there is a pushing need to thoroughly understand the nature of tall buildings projects and to follow an efficient systematic design plan with minimum waste and maximum value.

B. Research objective

The objective of this study is to set preliminary design guidelines for the design management process of tall buildings through literature review and case studies and practical case will be carried out in further research. A design management process that is suitable with the complex nature of tall buildings design. Secondary objectives are as followed:

- Identifying the process of design of tall buildings.
- Identifying the traditional design management process that is carried out in tall buildings projects.
- Highlighting the lean principles which are suitable for application on the process of design management of tall buildings through the concept of LDM.

C. Methodology

To achieve the Aim of this study, analysis of literature review will be implemented. The analytical studies of more than 340 research works were selected for review but only 70% of them were selected after refining the data obtained to assure their relevance with the scope of the study and cover all the main keywords as shown in Figure 1 Using the literature findings.

A. The selected literature for the review is mostly papers that were published from 2002 to 2022 as presented in

Figure *2*. They are categorized into architectural studies and managerial studies according to the purpose of each study and the authors. The analytical studies of the selected researches were made to provide guidelines of design management process for tall buildings to facilitate the smoothness of the design process and to help achieve better designs with minimum waste.

A social network analysis (SNA) was performed on the selected literature to preview the weight, degree of centrality and the links between the various attributes of this study. The researchers studied the most dominant factors that appeared from the reading and scanning of the selected papers, these factors are categorized in two main groups architectural factors and managerial factors with a total of 12 factors mentioned and described in Table I. The factors mentioned below includes the main three keywords of the study; tall buildings, design management and LDM.

B. The analysis covered different relations between those factors including the presence percentage of each factor in the literature shown in

Figure *3*; the nodes present each factor with a size relative to the weight of its presence in the literature. The diagram demonstrates that the most dominant factor is "Tall buildings"; with a percentage of 49 of the whole literature, the second main keyword "Design management" exists in 25 percent of the literature selected, and the last main keyword; "lean design management" is present in 18 percent.

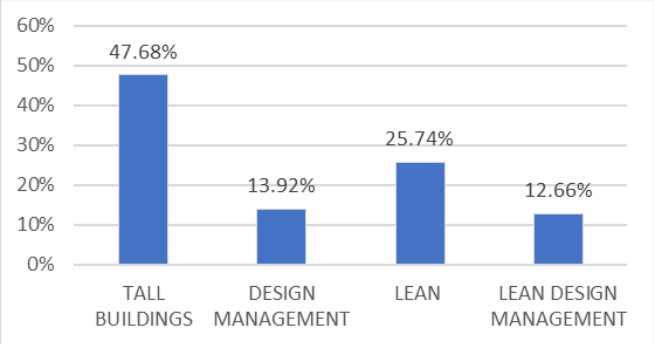

Figure 1. Percentage of readings for each keyword – Source: Authors

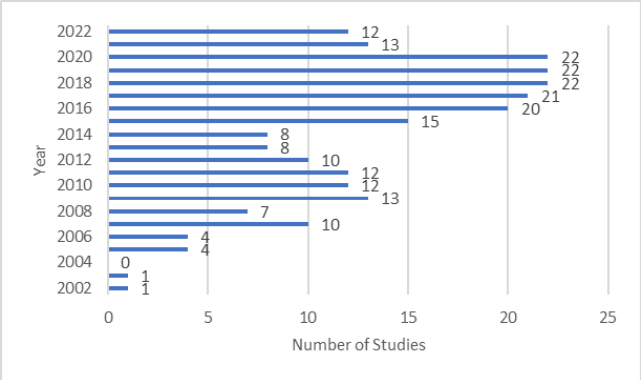

Figure 2. Literature by year – Source: authors

Table I. Factors Affecting the Literature Study - Source: Authors

Category	Factor	Description
Architectural	Tall Buildings	Tall buildings, high rise buildings, Skyscrapers towers
	Arch. Design Factors	Design factors; form, function, lighting, space program….
	Green	Green techniques; green roofs/walls, shading techniques, green materials…
	Sustainability	Sustainability aspects, indicators and measurement tools
	Structure	Building structure systems, techniques and different systems selection.
	Energy	Energy conservation and production in buildings
	Technology	Technology used in building construction and in design process with the focus on the usage of building information modeling (BIM)
Managerial	Management	The building different management systems throughout the building lifecycle
	Design management	The management of the design process stage
	Lean Management	Lean management principles and applications
	Lean Construction	The application of lean principles in the construction field
	Lean Design Management	The application of lean principles to the design management process

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Further analysis is performed to express the co-occurrence of these factors in the literature, presented in Figure 4; this SNA consists of nodes which present the 12 factors mentioned before and the size of these nodes are relative to the weighted degree centrality of each factor (i.e., the size of the node is directly proportional with the number of connections a node has and their strength) and edges which are the links between the nodes; the edges have different line weights that are dependant on the cooccurrence strength of the two linked nodes (i.e., the bolder the edge the stronger the link it represents is). The diagram shows the strongest links are that between the factors: tall buildings, architectural design factors, green, sustainability and technology, in other words these factors have a high degree of cooccurrence in literature.

Although it is noticeable that the links from lean management, lean design management and design management to tall buildings are extremely weak and tends to be not visible, which indicates the gap in literature in the area of knowledge linking these main keywords together. In Figure 5, a deeper SNA is established to focus on four main factors in the study (tall buildings, design management, lean management and LDM) and the links between these four factors and the rest factors with the negligence of the links between those remainder factors and each other. The focused study verifies the gap in literature between tall buildings and the factors (lean management, design management and LDM).

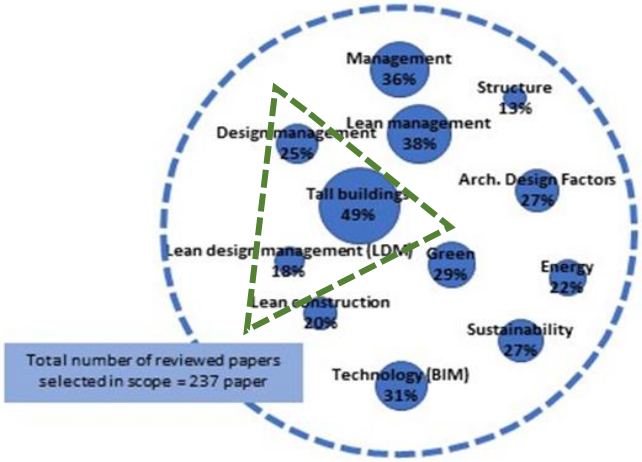

Figure 3. Scope of the study

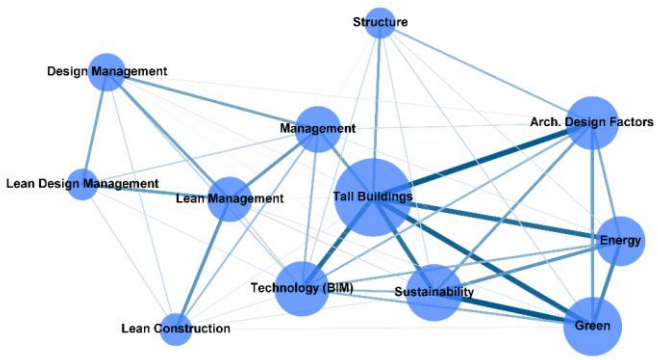

Figure 4. Social network analysis for the study factors of the literature - Source: authors

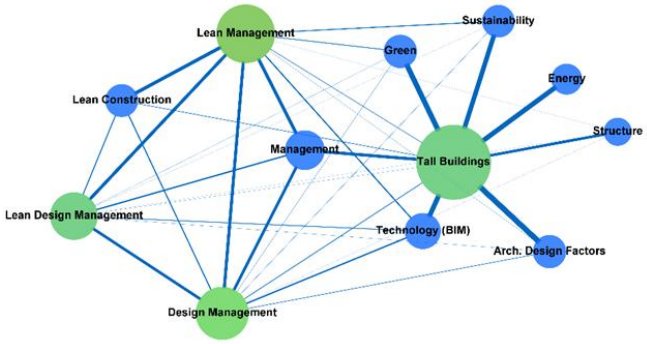

Figure 5. Focused SNA on the main attributes of the study – Source: authors

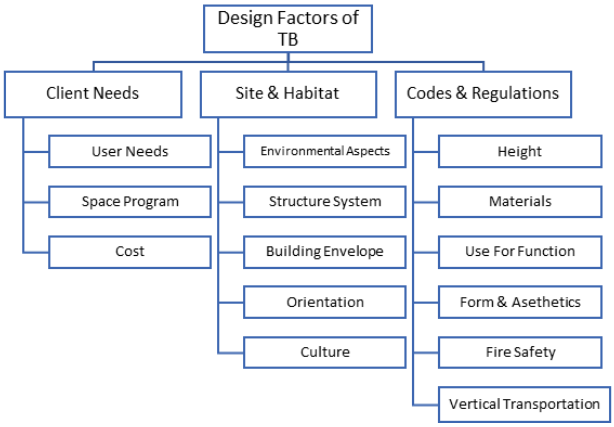

Figure 6. Design Factors of tall buildings - Source: authors after [11]

II. DESIGN PROCESS OF GREEN TALL BUILDINGS

The purpose of designing tall buildings is to achieve the best performance possible by carefully addressing the functional and anatomical variations of the building systems and subsystems, [11] in addition to the inter-system relationships and integration of these variations, including green features that are currently the new main focus of builders, designers, and users [12].

Tall buildings main design factors could be classified under three main factors; the client needs, site context and surrounding habitat, and local codes and regulations. Below these classifications come more detailed design factors which are essential for the design of tall buildings described in Figure 6 [11]. Because of these various design factors, the amount of information obtained to aid the design process is extremely complex, and it is shared by professionals from a variety of disciplines [13].

Tall buildings are a combination of architectural, structural, and environmental systems that require significant resources to build and operate. As a result, tall building design and construction is a highly collaborative effort which must be performed efficiently during the design stage to produce a high performance building [14]. Marketing, design, collaboration, discipline integration, project delivery, financial structure, recruiting, mentoring, metrics, Client focus, and generational transition planning are all part of the Integrated Design process. This Integrated design necessitates clarity of

purpose, concise and informed communications, the solicitation of input/approval, the provision of a challenge, and the embodiment of Leadership championship [15].

III. DESIGN MANAGEMENT

Design can be defined as a series of mutually reciprocal, interdependent iterations. Because of this, managing the design workflow is significantly hard [16]. the design stage has a significant impact on the final product of building projects from both views technically and financially. The customer's thoughts and needs are conceptualized into a physical model during this stage, outlining these demands and requirements into processes, drawings, and technical specifications [17]. The management of the design process is considered to be difficult because of the nature of design itself [18]. Design process management is essential to a successful project delivery since poor management and inefficient design process typically result in construction project delays and cost overruns [19].

The discipline of design management is mainly concerned with planning, coordinating, and managing the design process to achieve specified project goals and objectives. It involves managing people, their expertise and the flow of information to achieve project goals [20]. Design management's primary focus is on creating value for the client or customer, which entails the integration of specialized expertise and the timing of crucial decisions. This is accomplished by using an integrated team approach to the project's design, construction, implementation, and management [21], [6].

Design management necessitates considering the nature of the design work as well as the interaction of the design team, i.e., understanding how the design solution is created. As a result, it necessitates different methods and skills than managing economic constraints, taking into consideration that a building's sustainability is achieved largely during the design phase by collaboratively producing new innovative solutions [22]. Project management, concurrent engineering, process modelling, value management, new organizational forms, and IT support are just a few of the approaches that design management has tried to address different design issues. These approaches include many intriguing and apparently useful features, but they are fragmented and lack a strong conceptual base, which makes them a roadblock to advancement. [17]

The two main components of design management are the management of the process and the directing of the design as shown in Figure 7. The management makes an effort to maintain the process' adherence to schedule, cost, and quality standards. The team's knowledge and creativity are being maximized by the design leader. Strong collaborative environments are necessary due to the tremendous flow of information and the need of convenient judgments [18].

Since the design management process is concerned with the management of the design process, its flow and value generation, several studies proposed similar design work flow for construction projects with numerous correlations. The integration of studying of two different sources [23] and [24] for the current/conventional design process is presented in Figure 8, describing the conventional design process.

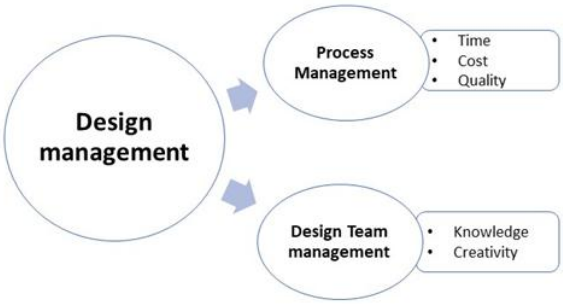

Figure 7. Design management main components

Figure 8. Description of conventional design process flow stages – Source: authors after [23], & [24]

It starts with the schematic design stage where the initiative design tasks occurs including meeting with the client and defining their requirements, space program establishment and the production of the initial models and design alternatives. Passing through the second stage defined as preliminary design stage, in this stage the initiative decisions for the structural system and the utility system are taken in addition to the production of the initial architectural working drawings and the study of the projects energy conservation systems. Thirdly and finally the stage of detailed design, in this part the final documentations of the project are produced, along with the analysis and construction of both the structural system and the equipment and utility system for the project, producing the integrating building final model and the building permit and handover to the client. The process may look smooth on the surface but it has lots of iterations and complications below the surface which often leads to design rework, time delays and can cause serious problems if these complications reached the construction phase without proper handling.

The current/conventional design management methodology is based on project management techniques developed in the 1950s and 1960s (the transformation view). This highly idealistic management approach has resulted in design production malfunctions. Reporting the following issues with traditional design: difficulty in designing for simplicity and product reliability, long development times, poor design for constructability, insufficient attention given to

clients (the specification of client needs and requirements is not recognized as adding value), poor links with suppliers (design subcontractors), and a lack of focus on continuous improvement. [23]

A. Design management of tall buildings

Tall buildings, despite technological advances that enable sophisticated and intelligent structures, necessitate careful and thoughtful integration due to their enormous scale and multidisciplinary features [25]. Sustainable tall buildings requires a higher level of integration than all types of buildings early in the design process due to the coordination of complex, interdependent systems[26]. The design management of tall buildings design process is a challenging process illustrated in Table II, showing the conventional design process of tall buildings, after the study of different strategies from the literature [24], [27], [28]

Table II. The design process of green tall buildings, stages, phases and tasks description - sources: authors after [24], [27], [28]

Design Stage	Phase	Description
Schematic Design	Site Appraisal	• Site analysis. • Determining open plazas zones, possible atriums and courts areas. • Defining orientation and best building position in the site.
	Conceptual Schematic Design	• Conceptual needs and space program • Form generation using 3d visualizing software and parametric design tools taking into consideration wind loads.
Preliminary Design	Preliminary Design	• Prototype structure System. • Generic floor plans • Mechanical system • Energy consumption simulation
	Preliminary Review	• Review energy consumption • Review Building envelope • Review building form, plans and structure system design
Detailed Design	Detailed Design / design Development	• Detailed structure system analysis and wind effect analysis • Detailed project drawings • Detailed energy consumption evaluation
	Review	• Review the refined data from the design development
	Construction Documentation	• Project reports • Final construction drawings • Final building model

IV. LEAN DESIGN MANAGEMENT (LDM)

Lean is a methodical technique to eliminating waste, continuously attempting to improve, and maintaining the production rate in accordance with client requirements [29]. Lean principles emphasize optimizing the whole rather than just individual components to create the desired value that the customer needs [30]. In an effort to enhance the effectiveness of construction management, lean principles were initially applied to the construction industry in the 1990s, showing great results in improving the product of the construction process [31]. The successful application of lean in construction, based on principles of lean, has opened the door to using lean design management (LDM) in the early stages to improve the overall system approach [32]. Lean construction and lean thinking application to design management have been investigated for several years, where the principles of lean offer a structured way to enhance the whole design system, that frequently entails a number of specialized businesses and individuals. LDM is a collection of lean techniques, tools, and social processes that can be used in the design process. LDM promotes customer value, information flow between enterprises, and project tasks while reducing waste [7].

The generation of value for customers and end users participating in the design process is also taken into account by the LDM method, along with the transformations of inputs into outputs and the flows of materials and information[33]. Literature showed that Utilizing the methodology of LDM improved the engineering process by lowering product mistakes, cycle times, and the proportion of non-value-adding tasks, resulting in a 31% increase in productivity [17].

The ability of the design team to transform complex, uncertain, and conflicting requirements into solutions that generate value for the client is critical to value generation in design production. Through a rigorous analysis of a systematized management of requirements and collaborative iterations for improvement, the quality of design can be improved by streamlining relevance, accuracy, levels of detail, timeliness, completeness, coherence, accessibility, compatibility, and validity of information. To that end, the following practical considerations for incorporating lean principles into architectural design and development processes are proposed [34]:

- Determine and exclude non-value adding activities in the design;
- Enhance output value by conducting a thorough evaluation of the client's needs and requirements.
- Reduce design process variability;
- Shorten design document approval cycles;
- Concentrate on the entire design process by incorporating stage gates into the design.
- Conduct a systematic performance evaluation by benchmarking against other similar projects
- Include continuous improvement goals in design processes.

Lean design supports diverse perspectives on how to model, examine, and comprehend the design process. In particular, it views the process as a collection of three unique models: conversion, flow, and value creation[17]. Lean design introduces several elements of the lean philosophy that are fundamental to the design phase, such as active and systematic client involvement during the early stages of a project, maximization of value generated, identification of the objectives and needs of all stakeholders, synchronization between the design of the process and that of the product, and deferring decision-making until the very last responsible moment to lessen the rework level [6].

A. Lean design building model

The perspectives of lean production are introduced to the previous proposed conventional design workflow process mentioned in the previous section. This application is performed after reviewing the lean design process model from

the literature [24]. The developed lean design model divides the design process into four stages (i.e., schematic design, preliminary design, basic design and detailed design) rather than the previously mentioned three stages (i.e., schematic design, preliminary design and detailed design). This new proposal is illustrated in Figure 6 with new improvements and additions. Firstly, the schematic design stage would contain the same initiative tasks as before. Then comes secondly, the preliminary design stage, this stage also remains the same as before. Thirdly, the newly added stage, the basic design stage is the stage where the analysis of the structure and the equipment and utility system took place and the production of the building's basic model as a prefinal look of how the project is supposed to be. Fourthly and for the last stage of detailed design, in this stage, the final output of design is produced including the structure system, utility system, integrated building design model, and the project construction documentation ready for the client handout.

An evaluation step is added to be performed after the completion of each stage to ensure design quality and reduce errors, adding more value to the client and eliminating process waste which are two of the main principles of lean. Moreover, the new lean design model promotes the involvement of all the project stakeholders from the beginning of the design process to increase the value and reduce the rework in the construction phase later which is caused by the neglection of the different stakeholders' opinions at the beginning of the design.

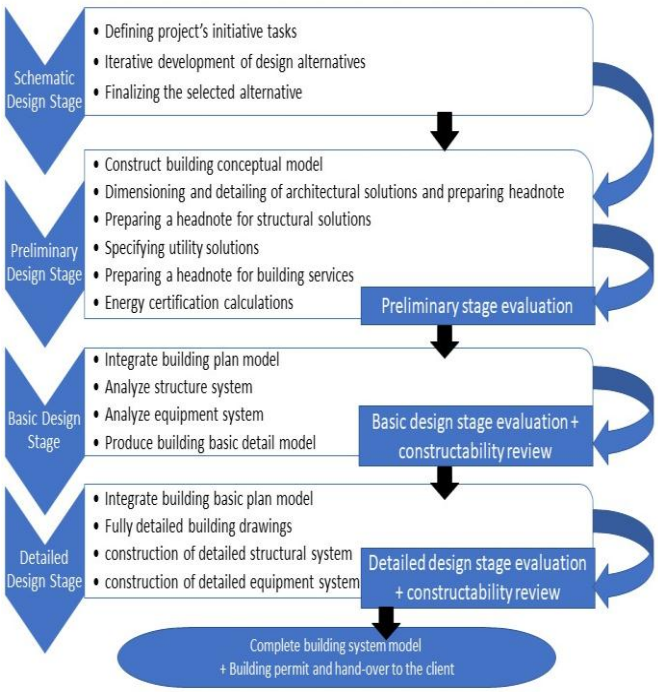

Figure 9. Lean Design building model - Source: authors after [23], & [24]

B. Integration of lean design model with tall building design process

In this section, the integration of the lean building design model proposed and developed in this study from the work of [23] and [24]. It is elaborated in Table III below, the basic design stage is added to the process, in addition to an evaluation step after each phase to evaluate the process work flow and develop new strategies if needed and also constructability check accompanies the evaluation step to ensure projects constructability from the early stages to avoid delayed changes and activities rework in the later construction phase.

Table III. The application of the lean building design model on the design process of green tall buildings after -source: authors after [24], [27], [28]

Design Stage	Phase	Description
Schematic Design	Site Appraisal	• Site analysis. • Determining open plazas zones, possible atriums and courts areas. • Defining orientation and best building position in the site.
	Conceptual Schematic Design	• Conceptual needs and space program • Form generation using 3d visualizing software and parametric design tools taking into consideration wind loads.
Preliminary Design	Preliminary Design	• Prototype structure System. • Generic floor plans • Mechanical and electrical systems conceptualization • Energy consumption simulation • Building model development
	Preliminary Review	• Review energy consumption • Review Building envelope • Review building form, plans and structure system design
	Stage Evaluation	
Basic Design	Basic design	• Analyze structure system and wind effect • Analyze mechanical and electrical systems • Integration of building model • Working drawing development
	Review	• Review the development process
	Stage Evaluation + Constructability check	
Detailed Design	Detailed Design / design Development	• Detailed structure system analysis • Detailed project drawings • Detailed energy consumption evaluation
	Review	• Review the refined product from the design development
	Construction Documentation	• Project reports • Final construction drawings • Final integrated building model
	Stage Evaluation + Constructability check	
Project handover		

V. CONCLUSION

The paper objective is to set preliminary design guidelines for the integration of LDM with the design process of tall building to help in enhancing the process flow, increase value and eliminate waste in the process through the literature review. Although lots of researches discussed the great influence LDM has on the design process in the construction field and on the design management process, there is little to no studies on the application of this theory to the design process of tall buildings, however a tall building was proven to be one of the most complex building types to design and construct successfully. The social network analysis performed

on the selected literature emphasized the gap in the literature, and proved the lack of studies concerned with the link between tall buildings design management and LDM in spite of the great potential this integration would present.

A. Preliminary Guidelines

According to the analysis of the previous studies, the integration of LDM on the design process of tall buildings. The findings of this paper could be mentioned as shown in Table IV.

Table IV. Guidelines for lean implementation to the tall buildings design process - source: authors

Lean principle	Implementation on tall building design process
Identify value	Client involvement in early design stages
	Contractor participation in early design stages to check the design constructability
Map the value stream	Remove non-adding value activities from the design process
Create flow	Shorten the approval cycles for the project documents
Establish pull	Putting off decision making to the last responsible moment to decrease work build up and activities redo
Seek perfection	Perform a systematic evaluation of the project by benchmarking with similar projects
	Promote continuous improvement of the project via adding improvement goals

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