Process Management of Spatial Structures to Address Positive Buildings with the Goals of Sustainable Development

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1 Introduction

By 2050, the EU aims to become a Union where buildings will no longer emit greenhouse gases. The traditional building design process is becoming ineffective in meeting new sustainability challenges, which calls for a fundamentally different and more advanced design process [1].

The building sector accounts for 30% of global final energy consumption [2] and nearly 50% of all resource extraction [3]. It also generates large amounts of construction and demolition waste (CDW), equivalent to nearly 40% of annual extracted construction materials [3, 4].

This target needs integrated design approach that the role of the iterative process is necessary [5]. A widely accepted concept in the design community is that high-performance projects require intense interdisciplinary collaboration to ensure that building systems are synergistic and "right sized" [6]. The need for high-performance buildings illustrates the fact that traditional design systems no longer answer current needs for decreased environmental impacts, as precise design decisions are not fully understood in the early stages of decision-making. The traditional building design is an evolutionary process where the detailed design decisions are not fully known at early stages [7].

Spatial structures by using new technologies and lightening and by applying scientific and applied concepts in design and execution, as well as observing seismic safety requirements that lead to the durability and stability of the structure, play

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an important role in reducing environmental pollution, especially performs in massive projects.

The aim of this research is to define parameters evaluating the contribution and limitation of strategies by defining a managerial view of the spatial structure process to optimize energy consumption, pointing out the climatic design as a solution to improve the efficiency as structures with the potential for positive buildings. This requires a complete understanding of all the processes of spatial structures from initial studies to the operational period.

From the perspective of the author in this article, the proposed solution to this challenge is the existence of a comprehensive and energetic system in which all stages of the building construction life cycle are considered. In this system, the commitment to the protection and care of the environment is increased and an optimal balance is established between costs, environmental, social, and human benefits. The goals of the proper building design are to avoid wasting energy, water, and raw materials, prevent environmental degradation, reduce climate heat, reduce carbon emissions, and ultimately create a safe, livable, comfortable, and resilient environment.

Regarding the integrated design process (IDP), all of them as an innovative and collaborative design approach for green building (GB) delivery have gained recognition in practice over the past decade.

Michael et al., in their paper "Delivering Green Building: Process Improvements for Sustainable Construction," define an emerging research and education program at Penn State called the Lean and Green Initiative. Focused on understanding all aspects of the delivery of high-performance projects, this program is underpinned by established process-based theories and structured around a systematic methodology designed to minimize waste, maximize value, and reduce cost. Current research and educational activities are described in the paper including nine primary research thrusts and their respective goals [6].

"Assessing environmental performance in early building design stage: An integrated parametric design and machine learning method" is research that has been done by Kailun Feng and his coworkers in 2019. They developed a method to quantify and map uncertainty in the early design stage. They showed that designers can evaluate and compare the performance of early design scenarios. This was an innovative way to connect parametric design and machine learning algorithms [7].

Lapinskiene and Motuziene in research as "Integrated building design technology based on quality function deployment and axiomatic design methods" presented the newly developed technology of the design concept of the building, which integrates design methods, digital design and simulation tools and the principles of IBD that are well known in common engineering. The validation of the proposed technology has shown that the technology requires fewer design iterations, and the main requirement is fulfilled to a greater extent (by way of lowering energy consumption) [8].

Spatial structure has different types of connections with various methods that allow designers to create different forms in terms of form and shape. This capability encourages the designer to use these structures in different applications on the big project. On the other hand, a key tenet of lean construction is the expanded use of prefabrication due to the production advantages of prefabrication environments [9]. These structures with the prefabricated potential have a great capability to design as a lean construction. The location and function of a building, flexibility, orientation, shape, structure, type of heating and cooling system, ventilation, and the materials used are different factors affecting the amount of energy consumption for construction, operation, maintenance, and transportation, so with considering these items during the different sector of designing and construction ultimately can lead to the sustainable architecture [2].

As the Architecture, Engineering, and Construction (AEC) industry develops the strategies and technologies for different projects, an increased emphasis must be placed on the processes and competencies required to deliver high-performance buildings, and it is necessary for spatial structures too, as structures with most pottentional to high-performance buildings.

Due to the complexity of the process of spatial structures, despite the different capabilities of these structures, there are many reasons for wasting energy in these structures from starting the process of designing to operation and maintaining. Furthermore, given the importance of considering environmental issues in construction projects, this should be a concern for engineers working in the field of spatial structures. Unfortunately, the issue of energy efficiency in spatial structures, as well as the various capabilities of climate design, has received less attention in the process of these structures, and no effective research has been done in this field. This is a significant challenge in the field of environmental protection. To achieve the sustainable goals without the existence of an integrated process that makes an effective connection between all sections of design and construction buildings cannot be operative.

Due to design Spatial structures with a positive paradigm and sustainability goals, the existence of an integrated design system that shows the process of these structures from the beginning of the initial studies to the period of operation can be effective because the existence of integrated design technique on the designing process of spatial structures can eliminate the drawbacks of traditional building design, and to ensure a sustainable and customer-oriented design solution, the existence of an integrated diagram can decrease primary energy demand with less design iterations to match the initial project requirements. The structured diagram of the technology facilitated the communication between project groups.

Minimizing or maximizing a function means that this function is a measure of the design process, which improves efficiency in preventing energy and material wastage. Figure 1 shows the optimization charter.

Optimization can be defined in different areas—optimization in energy consumption, structural optimization, economic optimization, use of manpower, etc. In this article, since one of the basically goals of sustainability is optimization, and sustainability is the first step to access the high-performance building, the beginning of the design process has been based on the issue of optimization and the main diagram has been started from the optimization chart.

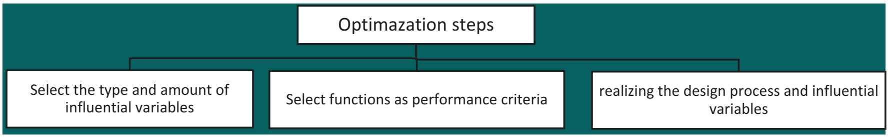

Fig. 1 The optimization charters

2 Methodology

In this article, the authors have tried to identify gaps and shortcomings in the field of sustainable architecture in spatial structures by studying and reviewing research in the field of positive buildings and integrated management system, and by introducing various factors affecting the sustainability aspects of these structures. It is presented a process diagram for spatial structures and its relationship with the discussion of optimizing an integrated management system for the process of these structures. The existence of an extensive and effective system in which all stages of the building construction life cycle are considered. In this system, the commitment to environmental protection and care is increased and an optimal balance is established between costs, environmental, social, and human benefits. The goals pursued in the proper design of the building are avoiding the loss of energy resources, water, and raw materials, preventing environmental degradation, and ultimately minimizing building pollution during operation (positive building approach). The process of spatial structures consists of four stages [10]: (1) design of spatial structures process, (2) construction of spatial structures process, (3) carrying spatial structures process, and (4) assembling and installation of spatial structures process.

2.1 Design of Spatial Structure

Design of spatial structure sequential process includes the selection, and the other part includes calculations and numerical studies. Considering that to approach the optimal design, it is necessary to consider all the relevant options, and taking into consideration the variety of researchable choices while constructing a spatial structure. Despite having sophisticated computers, determining the best alternative for a spatial arrangement is typically not straightforward.

To integrate the design process: the process of designing spatial structures includes the following: (a) to design the form, (b) to design the construction method, (c) to design the texture and installation, (d) to design how to transport and transfer to the place, and (e) to design the maintenance method.

(a) *To design the form as a multi-step process:* Architecture and structure are two processes that must be done in parallel; Fig. 2 shows the multi-step process of form designing.

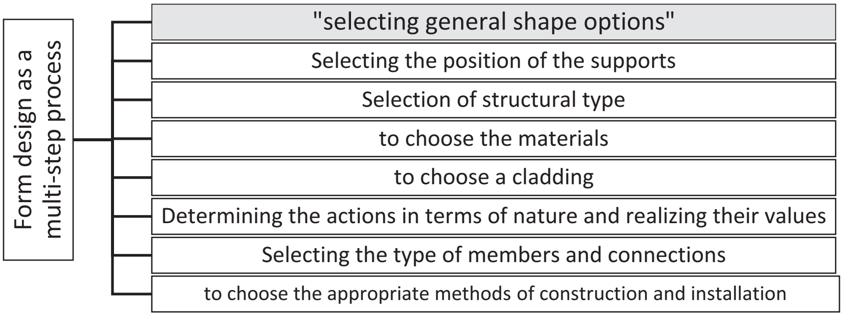

Fig. 2 Form design process

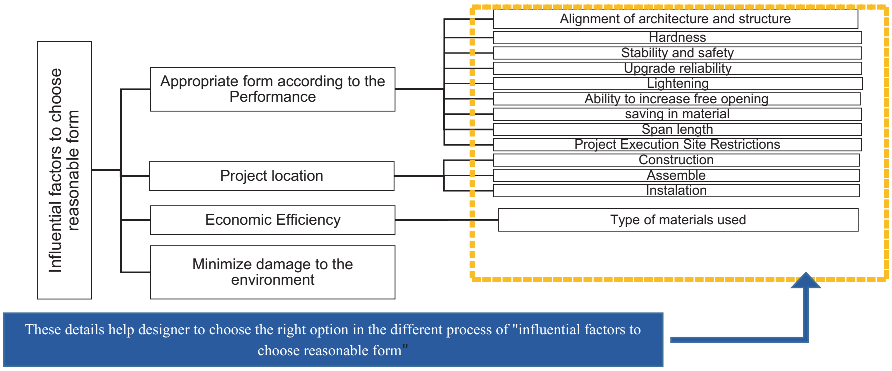

Fig. 3 Influential factors to choose an appropriate form

Selecting general shape options: proper form, project location, economic savings, and minimal environmental damage will all affect the choice of options. Each of them is affected by the items shown in Fig. 3.

The report containing the studies of this stage should show the logic and the way of choosing the studied options and the criteria and the way of choosing the superior option by presenting convincing arguments. If the competent authority confirms the quality, quantity, and accuracy of the studies, from now on, the detailed design steps of the superior option will be followed.

(b) *To design the construction method:* The design of the construction method depends on the type of form and structure that is considered in the form selection stage. Construction engineers will suggest the best of the various manufacturing processes for the next design to the construction design team. The selection of the construction process and the design of the construction method are two different separate, but parallel processes. Therefore, it is necessary to emphasize that the structure design process is not only a process that cannot be separated from the practical measures of construction, assembling, and installation of the structure but also determines the step-by-step activities and methods of construction [10].

(c) *To design the texture and installation*: After selecting the type of texture and installation method, the design engineers draw the texture and installation method according to the proposed option and provide it to the construction engineers.

(d) *To design how to transport and transfer to the place:* Depending on what method is chosen for transporting the structure, the creativity and experience of design engineers in designing the transport method is very important. The weight of the built modules and the size of the parts will be depending on different texture and installation methods, and choosing the best and the most economical method in designing the method of transporting the structure will have a great impact on reducing costs and construction speed.

(e) *To design the maintenance method:* If at the beginning and at the time of designing the structure the maintenance methods of the building are considered and designed, this will reduce maintenance costs and reduce renovation during operation, as well as the life of the structure.

2.2 Construction of Spatial Structures

The manufacturing process includes the manufacture and preparation of components and connections, followed by their storage, transportation, and connection to each other based on detailed drawings of construction, assembling, and installation.

The construction process from component part to whole is shown in Fig. 4.

2.3 Assembling and Installation Process

Any special or supplementary requirements related to texture and installation for a particular structure must be clearly specified in the specifications of all projects. In the design process from the component to the whole stage of assembling and installation of a spatial structure, according to the specific limitations of each project, two methods are effective: (a) assembling method and installation in place and (b)

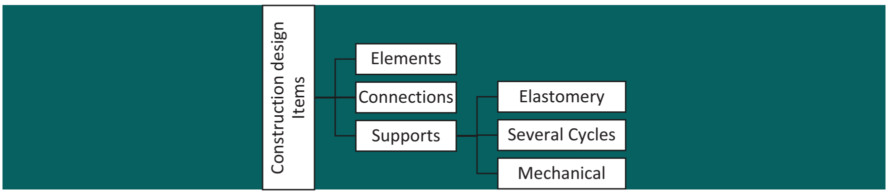

Fig. 4 Construction design items

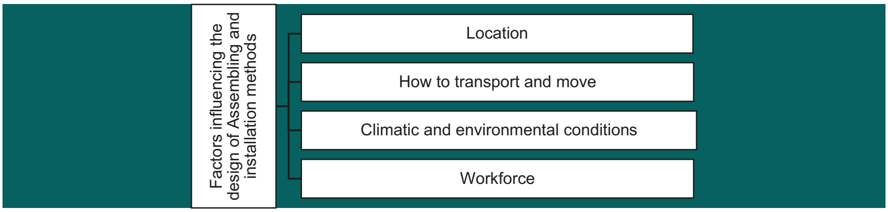

Fig. 5 Factors influencing the design of assembling and installation methods

weaving method and installation on the ground. Normally, due to environmental conditions such as wind and especially temperature and careful selection of the position of the structure in the final adjustment stage, the faults are decreased as much as possible. Figure 5 shows factors influencing the design of assembling and installation methods.

2.4 Maintaining and Repairing Operation Period

Building operation and use is one of the most critical aspects of high-performance buildings, but operation and maintenance (O & M) information is often not communicated effectively to the design and construction team. Operating expenses represent over 95 percent of building life cycle costs, yet operations and maintenance personnel are usually the last to be consulted during programming and design. In order to manage the integrated design of spatial structures, the Design-Build-Operate-Maintain (DBOM) making a contract between the operations and maintenance staff and the owner would have an improvement impact on high-performance results [11].

3 Results and Discussion

According to the investigation done, an integrated management diagram to optimize energy consumption and to address positive buildings is presented. This diagram is designed around a systematic axis, and it manages the optimal time, cost, and energy while considering the sustainability to develop a decision model and to strategically adopt spatial structure as prefabricated and engineered systems in the design and construction planning of green facilities. The diagram is divided into four stages:

Step 1—Metric determination for positive design
Step 2—Integrate axiomatic design and detailing
Step 3—Integrate design knowledge and environmental impact to develop the concept considering climatic potential
Step 4—Result verification by using software tools

Step 1: Metric determination for positive design

The first step provides the correlation between the basic requirements (customer needs) and the technical requirements. The requirements of the employer are examined at the same time as the technical requirements provided by the design and construction team. Then the performance requirements including optimization and initial data to improve the positive performance of buildings are at the highest level of this process. The output of this step will be to identify the basic needs, which includes design requirements and limitations and functional and unfunctional potentials of the design (Fig. 6).

Step 2: Integrate axiomatic design and environmental impact

According to the functional needs, the design parameters are considered by IBD team; at this stage, the process of designing spatial structures is begun, and the parameters show how and with what tools the functional needs of each part can be met. The goal is to meet all the functional requirements to meet the basic need. According to the most important functional needs, the graph grows the parameters are developed. The result of this step will be the primitive concept of building, which details are related to the type of structure, type of assembling, type of carrying, and initial form with climatic characteristics (Fig. 7) (Table 1).

Step 3: Integrate design knowledge and environmental impact to regenerative design

Addressing the regenerative design principles framework, especially at this stage, is necessary, to reduce energy consumption and decrease environmental impact. After categorizing the targeted parameters by the IBD team, this information will be presented to the design team. All three categories of the design process, Architecture, Structure, and Mechanical, must be done in parallel.

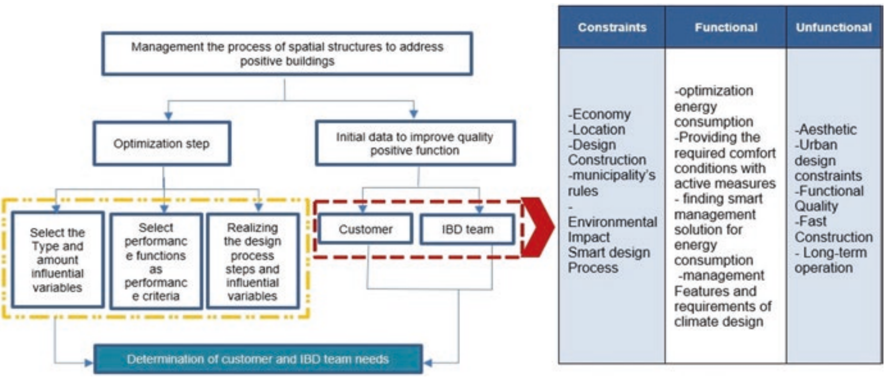

Fig. 6 Determination metrics

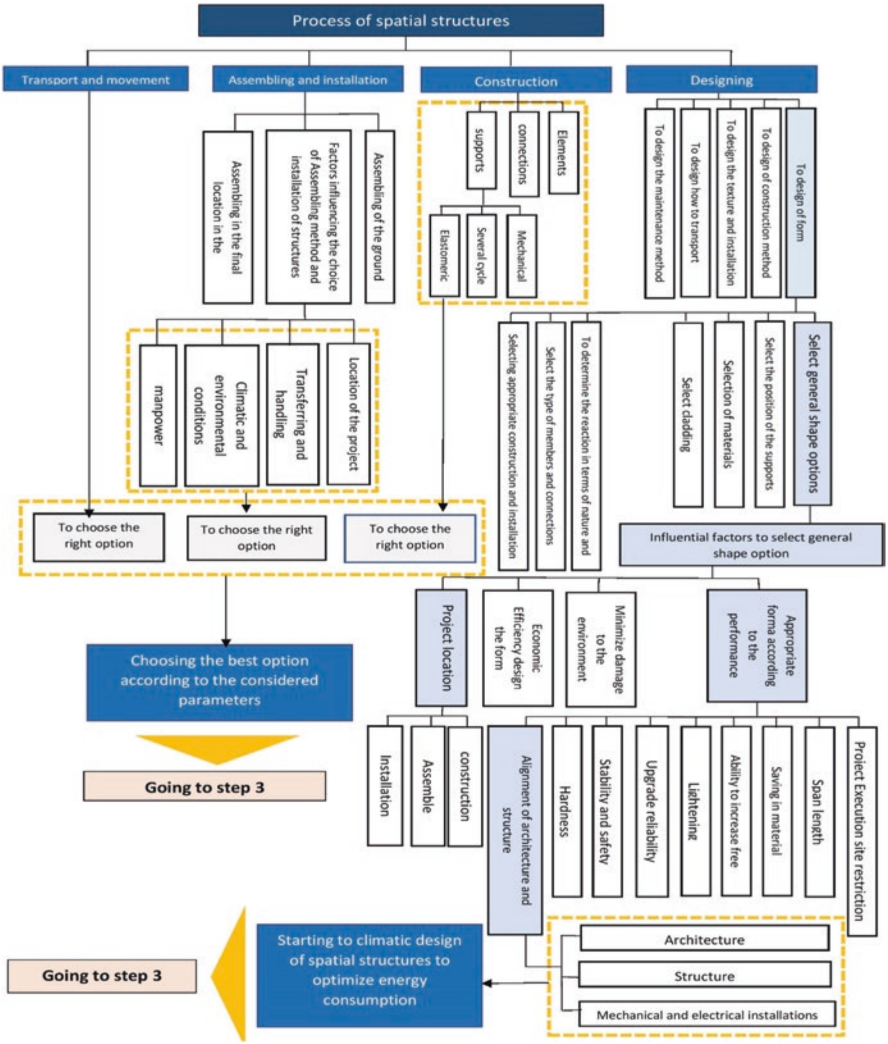

Fig. 7 Step 2 (integrate design and detailing)

In fact, this process is reciprocal, and after each step, the results of the three design groups are reviewed and, if necessary, changes are applied according to the goals (Fig. 8).

Step 4: Verification of result

To validate the result at this stage, the designer team must check all consequences of the impact on the environment and energy consumption again.

Table 1 Requirements and parameters

Functional requirements	Optimization energy consumption	Providing the required comfort conditions with active measures	Finding smart management solution for energy consumption	Management features and requirements of climate design
Parameters	Realizing the design steps and influential variables in different spatial structures process	Alignment architecture and structure Appropriate form according to the performance	Mechanical and electrical system New energy resources	Appropriate materials, alignment architecture and structure, hardness, stability and safety, upgrade reliability, lightening, ability to increase free opening, saving in material, span length

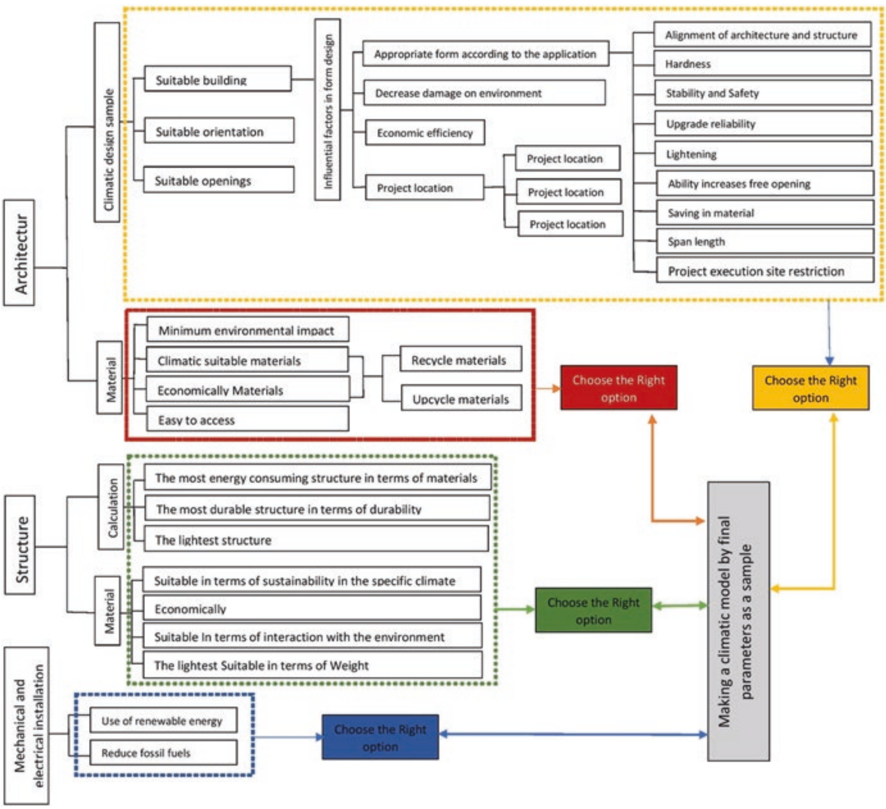

Fig. 8 Step 3 (integrate design knowledge and environmental impact)

4 Conclusion

Since achieving a basic model of positive buildings required enough knowledge about all stages and effective parameters in different processes of spatial structures, in addition, the existence of a management potential is necessary to direct all parts at the same time in order to eliminate mistakes and not wasting time. This process management of spatial structures is the necessary way to address positive buildings. The knowledge of management can lead all stages of a design to the goals of sustainability, by reducing the environmental impact in different views and aspects. This article presented all details, important parameters in different processes, processes that must be done simultaneously, and interdependent processes, along with a sample of tables including basic needs and effective parameters to meet those needs.

Due to the various factors involved in the structural design part, and the multiplicity of influential parameters, here authors have considered materials as one of the most important common parts between structure and architecture, but to achieve more realistic results, it is important to consider the connections, the type of spatial structure, the substructures for claddings on the amount of energy consumption and environmental impact.

Since the purpose of this paper, in an overview, is to create an integration process and show how the different parts of a spatial structure's process are performed in parallel, no further details are provided here, but it can be an issue for the future research to fill the existing knowledge gap about these structures.

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