Analyzing the Collaborative Design in Architecture Through the Lens of Computer Systems and Prefabrication Vision

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***Abstract*—The aim of the paper is to analyze the study hypothesis according to which, the mission of an information systems designer is to develop advanced technical solutions, capable of satisfying complex business requirements. The subject of the analysis is the prefabricated architecture process and the way in which it can implement a sector of construction systems, positioned as an industrial niche with added value, oriented towards the market and it could improve the productivity of the construction sector in the inclusive sense of sustainability. The methods of study are critical and phenomenological analysis. The interaction between the two concepts: IT systems and prefabrication, is highlighted by the case study on "Modern Constructions Methods" (MMC). The expected results of the research constitute a possible framework for approaching sustainable architecture.**

Keywords—context awareness, pattern analysis, business data processing, data collection, data analysis.

I. Introduction

By introducing ecological thinking into the human socio-economical order, the contemporary ecosystem could be defined through the interconnectivity between the different forms of capital (human, social, financial, productive or natural). In this sense, a business ecosystems can be described [2] as a networks of different entities/independent firms, which use common standards and collectively offer goods and services to its customers in accordance to the principles of sustainable development.

Through a phenomenological approach, the work aims to identify the manner in which, in a digital era, the architecture redefines the way of designing and building, trying to establish collaborative relationships between different industrial sectors. Therefore, the general objective of the phenomenological research is to describe how architecture has analyzed the experience of different industries, trying to see the buildings as a product and to promote the off-site solution as a performing response to the currently problems. The specific objectives of the research derive from this, having as a central point the way in which the collaborative platforms developed in the field of other industries will encourage innovation in the construction field.

The context awareness could be the starting point for a pattern analysis of the architectural product as a results of a business ecosystem interactions (figure 1). In such an ecosystem, the main players (producers, suppliers, consumers, competitors and government agencies) facilitate an economic community by using the resources of the habitat (raw materials and technologies), operating with typologies of capital that consider the economic sectors: primary – extraction of raw material; secondary – raw material processing; tertiary – provision of services and products and quaternal – training of human capital: education. Similar to a biological ecosystem, the participants and processes in this business environment continuously evolve to increase and maintain efficiency, giving to the system a dynamic character that reacts to forces such as innovations, technological advances and competitiveness.

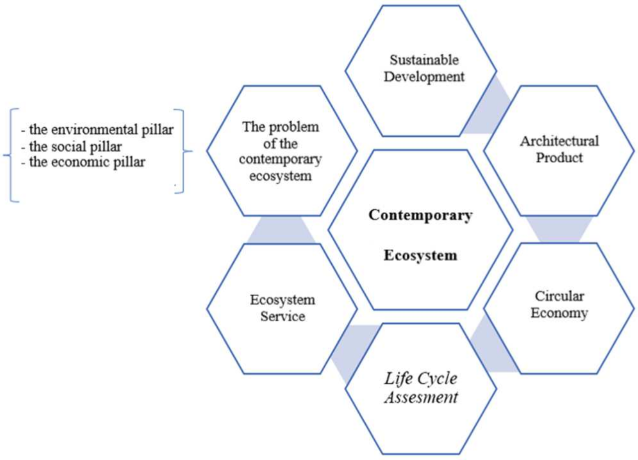

Fig. 1. Context awareness of an architectural product

The industrial ecosystem, as a part of the business ecosystem, took over the essence of the ecosystem concept, namely, the idea of functioning on the basis of a continuous flow of substance and energy (figure 2).

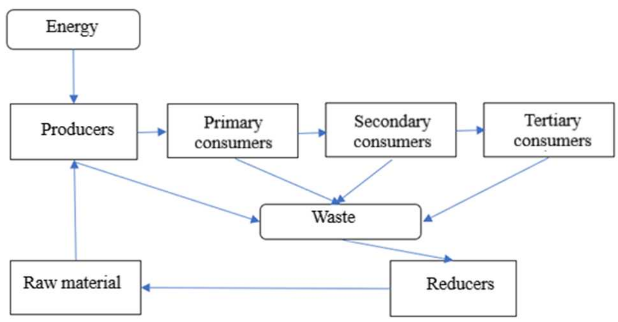

Fig. 2. Pattern analysis of a continous flow of substances and energy

Through a critical analysis of the industrial ecosystem, the literature underlined that, compared to the natural ecosystem, the industrial ecosystem was characterized by the intensification of the degree of use of the energy flow, which led to the idea of a global imbalance, manifested by the reduction of resources and the accumulation of waste. Another negative aspect of industrial ecosystems is that the

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information flow is directed by people's immediate interests/ needs, which involve matter and energy in linear processes and lead the system towards a state of increasing instability. To reduce these weaknesses, the literature [3] illustrated the idea of an Eco Industrial Park. This concept, emerged in 1960s as a set of collaborative strategies. These strategies have been applied by different industries in order to make the consumptions of row material more efficient and to recycle and reuse the waste. Over the time, this idea has evolved to be found today in the definition of the Eco Industrial Park (EIP) as a business organization grouped around material needs and results [3].

In the same time, the digital ecosystem, as a part of the business ecosystem, is increasingly being analyzed and implemented by organizations which are looking for higher flexibility, adaptability and scalability. Defining itself through highly variable software ecosystems, based on cloud technology, this modern business model, compared to traditional business models, has the opportunity to create passive added value. At the highest level, the architecture of such an ecosystem is a conceptual model that describes the structure of the technological system (describe the purpose, role, the elements and how they interact), as well as design principles and techniques (modularity, interface design and openness). This hypothesis could be developed and adopted in the area of prefabricated architecture in the context of nowadays digital transformations.

A brief of literature review, [15]-[18], illustrated that the area of architectural design and constructions could become a space of creativity and technology through a mixture of collaborative platforms, blockchain, robotics, AI, VR, BIM and sustainable technologies. The central key of this future evolution is data. Therefore, the next sections of the paper, will be analyzed the way of how to collect and use data in the process of architectural thinking. The architectural design will be analyzed through the lens of the collaborative process concept, highlighting the need to approach it as a decision-making and problem-solving process. As an expression of the technologies of implementation, the third section will be intended for the prefabrication process viewed through the lens of the use of collaborative platforms.

II. Architectural Design Process in a Culture of Collaboration

A. *Conceptual model*

Architectural design (figure 3) is a problem solving process with the final goal to reach a synthesis through analytical approaches, by trying to discover appropriate combinations of input data that describe the physical environment (location, topography, model, climate, etc.), the cultural environment (historical, social, economic, political, aesthetic components, etc.) and technological environment (science, technology, etc.) to create a functional and sustainable environment [4].

From this perspective, the architect's mission is to use available resources to create a built environment which meets the best needs of clients. Equally, the architect is in the position of decision-maker regarding the future of that environment. In the decision making process, he operates with concepts as: 'function', 'technology', 'environment', 'economy', etc.. The thinking methods used in architectural design could be rational (deductive or inductive) or heuristic thinking. By using rational thinking the final solution is obtained by using experience from the past improved with the results of an analytical thinking of the errors. The heuristic thinking involve to use a holistic method of thinking in which the synthesis, filtration, addition, reduction or expansion, produce plenty of options to solve problems.

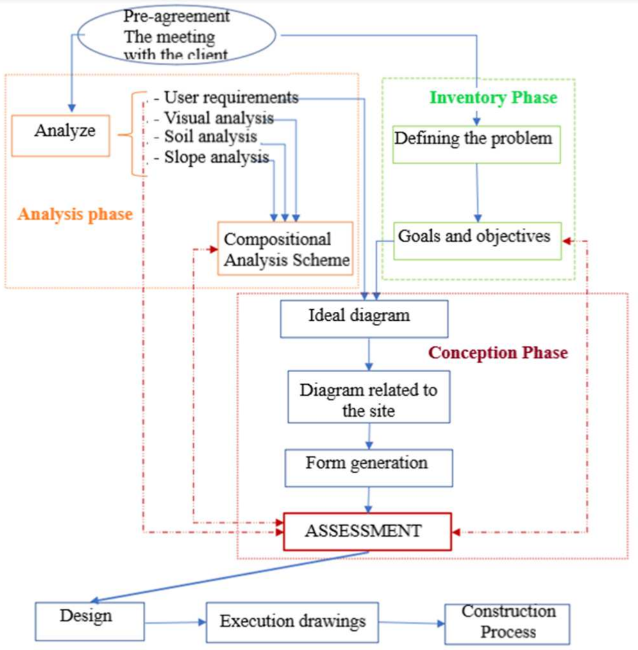

Fig. 3. Architectural design as a problem solving concept

The evaluation of the architectural design is carried out by evaluating the input data necessary to operate with these concepts both from the user and the designer. The process of defining the specific elements of the total performance in construction involves, in the first phase, a complete understanding of the concepts implied in, and then the optimization of the requirements and the levels of performance allowed for the final product.

B. *Case study: Analysis of the architectural product performance through the lens of computer systems*

The case study aims to exemplify the way to analyze the performance of the architectural product. A primary stage of the analysis of the performance concept of the architectural product consist in the identification and analysis of user requirements with the highlighting of the type of major function. In the next stage the requirements are subjected to a quantification process in order to reach specific performances criteria.

Table 1 proposes an analysis matrix of the criteria for assessing the performance of the architecture design process, based on which the quality of the product could be established. The legislative framework establishes minimum conditions for each essential requirement, necessary to satisfy the minimum quality applicable in constructions, useful for the designing process. The process of evaluating the Total Performance in the design phase is a complex process, easy to achieve with the numerical instruments of calculation [5].

The use of BIM (Building Information Modeling) and BPM (Building Performance Modeling) in a sustainable design, requires a certain training in the field of numerical programming, but also costs related to the acquisition of computer equipment and user licenses.

TABLE I. ANALYSIS MATRIX

Objective	*Scope*	*Score*
Functionality	Suitable for functional conditions	0-10
	Suitable for aesthetic conditions	0-10
	Suitable for communication conditions	0-10
	Suited to user requirements	0-10
	Suitable for health conditions	0-10
Achievability	Suited to user requirements	0-10
	Suitable for health conditions	0-10
Economicality	Flexibility	0-10
	Suitable for economical conditions	0-10
Sustainability	Adequate in terms of energy efficiency and resources use	0-10
	Appropiate from the point of view of waste management	0-10
	Appropiate from a pollution management point of view	0-10

The application of BMP in architectural design has shown a great potential in providing coherence in the collaborative process, defining an explicit configuration for the exchange of digitized information. In the same time, it is necessary to accelerate the development and standardization of BIM sub-models to provide a wider coverage of user requirements and information flows throughout the project life cycle. Although it also presents a series of disadvantages, BIM has the potential to become the leading technology of the construction industry, offering advantages in every stage of the project.

III. PREFABRICATION IN A CULTURE OF COLLABORATION

As a subject of architectural analysis, prefabrication peaks in a modernist context. Over the time, circumstances have changed, production methods have evolved simultaneously with the research and analysis methods. Despite the inevitable changes and fragmentations of the modernist narrative, there has always been a certain notion of prefabrication, often marked by misconceptions or equivocal connotations. Under the sign of change, materials and methods of construction lost their specificity, fundamental for a certain area, and new material appeared, more or less local, new technologies and new methods of production.

These transformed the ancestral mode of architectural intervention, archetypal based on a patient dialogue with the immediate environment and made the sphere of the natural and the vernacular, characterized by an evolutionary organic consistency, to be progressively abandoned and to move towards a construction of an abstract, taxonomic and typifying, characterized by a numerical consistency, in which, the scale of production became a major statement, indicating increasingly global processes. Prefabrication brings to the fore the notion of an architectural product which take the characteristics of a commodity or consumable. This aspect brings into discussion the mannerism of a globalized world, expressed in debates as local versus global, art versus reproducibility, control versus otherness, etc.. These could be reflected in natural, anthropological, semiotic or typological dimensions of the architectural product.

A. *Vision of prefabrication*

The vision of prefabrication involves a consultative and collaborative process that aims to implement a sector of the construction system, positioned as an industrial niche with high aided value, oriented towards the market and the improvement of the productivity of the construction sector in the sense of sustainability seen through the economic component (increasing profitability to allow lower investments), the environmental component (reducing the carbon footprint, minimize residues and waste) and the social components (improving people's health and safety, ensuring quality of living, adapted to population dynamics). To achieve this vision it is necessary to develop a strategy and an action plan for the implementation of the defined sector and an approach based on partnerships between companies, research organizations, governments, etc., which will allow those interested to respond adequately and quickly to the ever increasing global demand, while offering products in accord with the needs identified on the market. Among the priorities considered could be listed: innovation, market analysis, realization of reflection projects, creating digital BIM models (3D architectural plans), etc.

B. *Study: Prefabrication between mass customization and mass production*

In most general sense, prefabrication could be defined as the manufacturing process of the construction elements before their assembly at the work site. The various uses of the term contain information about the technical evolution in a given context and can have various characteristics. Nowadays, housing production varies from a singular, hyper-customized house for a distinct user, to mass-produced housing models and repetitive construction models. At the beginning of century, the industrialized economy was based on mass production, mass distribution, mass marketing and mass communication. The field of constructions, also, was folded on the mass industrial production of construction components. The elements produced in series were specialized and classified according to different criteria: doors, windows, beams, pillars, bricks, pipes, etc.. The intermediate products were made in a limited range of sizes, being cataloged and stored for use, concluding their road during assembly on site or off site. Therefore, in the mass production stage, the elements produced as a versatile materials will be customizing in the next stage, that of making the architectural product. Strictly customized for the architectural product, this mass production means homogenous, rigid, fixed, authoritative, hierarchical, predetermined processes, techniques and projects.

As a reply to these shortcomings, mass customization requires flexibility and quick response. Customized for architecture, the process of mass customization means heterogeneous, flexible, adaptable, collaborative, non-hierarchical, parametrization based processes, techniques and projects, etc.. Architecture based on the new paradigm of mass customization is significantly different from conventional building design. Completely new tools are used, developed to create the diversity and complexity of the structural and visual varieties of the custom architectural product. All of these are based on simple rules applied in treating behavior patterns to produce relationships between all building components. The driven force for organizing the behavior of geometry control points comes from the interaction on internal and external forces with the three dimensional model.

From a business perspective, there is a significant difference between mass production and mass customization. Mass customization promises the best of both approaches: uniquely designed products that better suit the user's needs in terms of efficiency and production costs. In addition, construction based on mass customization often adopts practices such as prefabrication, thereby reducing waste and water and energy consumption [8].

Also from a conceptual point of view, mass customization is different from mass production. While mass production involves changing, assembling or modifying the components of the product or service in accordance with the needs of clients, customization refers to the intense communication and interaction between the two parties: customer and supplier.

Mass customization engages customers to become co-creators [9] and participate in the design of the desired product or service, the components of the process being: product design, supply chain design and production system design. Customization supposes the existence of a basic product that can be customized during the manufacturing stage. Pure customization means that the product is customized from scratch. However, there must be a standard initial configuration, which makes this strategy correspond to prototyping rather than customization.

Recent research on mass customization in the field of housing construction also addresses the needs of space, including the type of space, the relationship between spaces and their customization to requirements of the end user. This perspective has a great potential to avoid unnecessary demolitions and renovations and even allow families to stay in the same house longer, favoring lower income families [11].

A brief review of literature [6], [7], [8] enunciates three typologies of product customization: modular, adjacent and dimensional customization. Modular customization is based on the use of modules as basic elements, which can be assembled in different combinations. Adjacent customization refers to using adjustments as a reversible way to customize the architectural product. These adjustments can be made indefinitely. Separate adjustments provide configurations with limited selections that can be set at the production, vendor, or customer level.

Dimensional customization involves irrevocably cutting the elements to the desired size to fit into the considerate subassembly. Dimensional customizing can be unlimited or have a limited set of options. The dimensionally customized elements can be made automatically using numerically controlled equipment, ordered through a system of commands generated by a package of parametrization software programs. Therefore, the mass customization of housing can be considered a model of systemic approach to design that changes the role of architectural design from the production of discrete buildings to articulated systems that address not only aesthetic and technical issues, but also environmental, social and economic, thus bringing into discussion the dialogue between local and global factors in the design of the built environment.

In order to be effectively applied in architecture, mass customization must be understood in an holistic approach that includes not only design, production and construction, but also communication, economics and risk management.

C. Study: Prefabrication and Modern Construction Methods

Modern construction methods (MMC) have been defined in UK as a common term used for off-site or on-site construction methods. Off-site MMC define those methods in which prefabricated elements or part of structures are built in the factory, then transported and assembled on site (figure 4). On site MMC are defined as those methods in which the elements and parts of structures are made directly on the construction site.

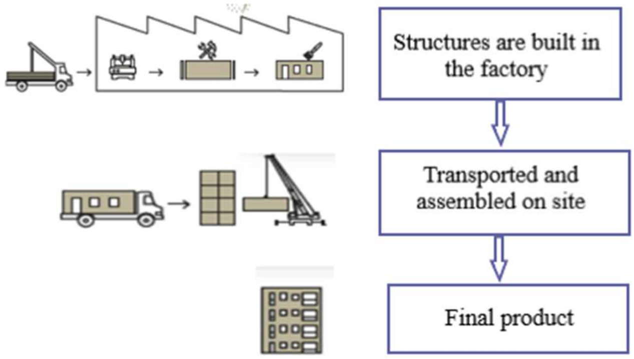

Fig. 4. Offsite MMC flow diagram

MMC methods could be classified into five categories: volumetric, panelized, hybrid, off-site manufacturing (OSM) and non-OSM subassemblies and components. Volumetric constructions involves the production of three dimensional units (figure 5) under controlled conditions in the factory before to be transported to the site. Panelized constructions produce the panel units in the factory and assemble them on site to produce a three dimensional structure. The hybrid category, also called semi-volumetric combines both volumetric and panelized approaches. Typically, volumetric units are used for areas with varied and repeatable functions, such as kitchens and bathrooms, with the rest of home or buildings being constructed using panels.

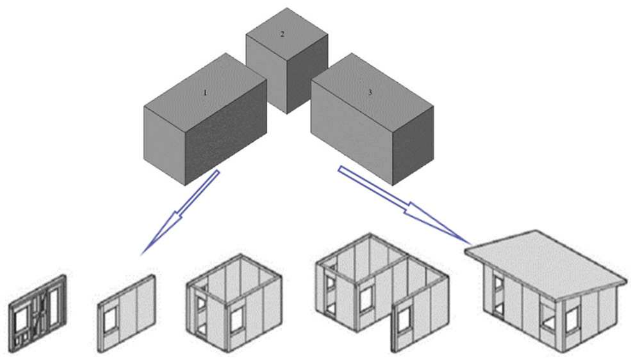

Fig. 5. Operating methodology with prefabricated elements

OSM subassemblies and components constitute a category intended to respond to approaches that cannot be classified as systemic OSM, but which use several subassemblies or innovative components built in factory, in a traditional/specific manner. The non-OSM category includes schemes that use housing construction techniques and structural systems that are not part of the OSM category. The most widespread examples of MMC are: precast panel system, 3D volumetric modules, flat slab construction, precast concrete foundation, Twin Wall technology, precast cladding panels, Mivan technology, etc..

Digital manufacturing technology has changed the way in which the products are thinking, produced or designed. Many products in the past were standardized, but now, with digital manufacturing equipment and software, a product can be customized and manufactured easily. There are multiples digital fabrication technologies. For example, the stages of digital manufacturing of prefabricated wooden elements (figure 6) are: 3D designing of the building and of prefabricated elements (1), conversion of drawings into machine language (CNC) (2), control of the production process (3) and diagnosis of possibles errors (4).

Fig. 6. Digital fabrications stages

The contemporary blur between the areas of design and digital manufacturing, were the design process merges with manufacturing, is given by the fact that data is transferred directly from a 3D modeling application to a CNC machine. "Fille to factory" methodologies are a relatively new phenomenon, mostly unique, in the field of architecture and industrial design. They can be used at different stages of the design process:

- As a way of volumetric investigation, through successive iterations, in which, models and 3D digital modeling are used simultaneously.
- As simulations that run concurrently (structural, volumetric, functional and aesthetic).
- As reverse engineering processes based o models that are translated into digital representations.
- As manufacturing strategies, were the design process is perfectly combined with the manufacturing of designed object through digital manufacturing

It is important to mention that the generation of 3D virtual objects for constructions requires a way of working that involves the development of library objects from 3D CAD primitives, based on the use of architectural rules to build parametric representations of architectural operating elements. Through the user's application of some algorithms and computer rules, elements (walls, windows, pillars, facades, etc.), spaces, buildings, chosen from a grammar and a vocabulary of shapes, are generated. The design approach is based on the concept of shape grammar. New trends of the digital era give new potential to 3D geometry models.

For example, BIM is representative to incorporate in recent years the 7D dimension, by including the management of using operational performance data [13].

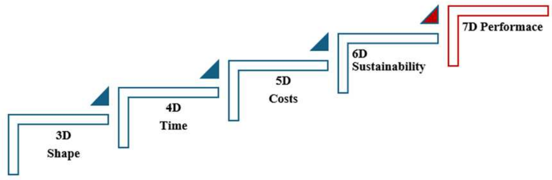

Fig. 7. BIM potentials dimmensions

IV. Conclusions

It is a certainty that architecture has a vital role in meeting contemporary sustainability objectives. In accordance with the digital transformations at the level of society, the digital transformation of the business ecosystem specific to architecture is required. The use and improvement of collaborative platforms based on cloud solutions with real time collaboration functions can be stated as the applicable future premise. This will enable and encourage the innovation and diversity in design and construction practices.

In order to analyze the success of architectural design in the sense of the principles of sustainable development through the use of construction technologies specific to the digital era, three axis of study can be identified: the construction materials axis, the construction systems axis and the implementation methods axis.

The holistic approach, specifically to the analysis of ecosystems, proposes various typologies of prefabrication.

Digital manufacturing technology has changed the way of produced, built or even design an architectural product.

Studies on prefabrication processes complete the image of the architectural project and optimize future solutions.

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