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MODULAR BUILDINGS AND THE ARCHITECTURAL EXPERIENCE OF THE END-USER – A SCIENTIFIC REVIEW

Nikola JELENIĆ
Buda Tomovica F7, 81000 Podgorica, Montenegro
e-mail: nikolajelenic@gmail.com

Simon PETROVČIČ
University of Ljubljana, Faculty of Architecture, Zoisova 12, 1000 Ljubljana, Slovenia
e-mail: simon.petrovcic@fa.uni-lj.si

ABSTRACT

This paper aims to reveal recent trends in the development of modular buildings, using the knowledge of experience in architecture. The first part of the paper provides an overview regarding recent scientific developments in modular design and construction, accompanied by a historical overview that outlines the specific features of modular construction. The second part outlines the issue of architectural experience through the perception of architecture and the enactive approach. The intersection of neuroscience and architecture is outlined as one of the emerging fields in this subject matter. Example case studies of modular design are presented, and a basic assessment of potentials for their architectural experience is given.

Keywords: modular building, modular approach, architectural experience, enactive approach, perception, end-user experience

EDIFICI MODULARI E L'ESPERIENZA ARCHITETTONICA DELL'UTENTE FINALE – UNA REVISIONE SCIENTIFICA

SINTESI

Lo scopo di questo articolo scientifico è quello di rivelare le recenti tendenze nello sviluppo di edifici modulari utilizzando la conoscenza dell'esperienza in architettura. La prima parte del documento fornisce una panoramica sui recenti sviluppi scientifici nella progettazione e costruzione modulare, accompagnata da una panoramica storica che delinea le caratteristiche specifiche della costruzione modulare. La seconda parte del documento delinea la questione dell'esperienza architettonica attraverso la percezione dell'architettura. L'intersezione tra neuroscienza e architettura è delineata come uno dei campi emergenti in questo argomento. Vengono presentati casi di studio di esempio di progettazione modulare e viene fornita una valutazione di base dei potenziali per la loro esperienza architettonica.

Parole chiave: costruzione modulare, approccio modulare, esperienza architettonica, percezione, esperienza dell'utente finale

INTRODUC TION

In recent decades modular construction has become a global trend (Li et al., 2014; Boafo et al., 2016). With an ever-increasing number of building projects worldwide, modular construction directly influences architecture and challenges architects to explore this revived phenomenon of design and construction through contemporary analysis.

This paper aims to reveal recent trends in the development of modular buildings using the knowledge of experience in architecture. In order to achieve this goal, it is necessary to explore two independent focal points: the modular building on the one hand and the architectural experience on the other. When these focal points are established and well-structured, they can be united in an independent field where it is possible to recognise the potential for the further development of a modular building to create higher architectural values. This setting can be used for further scientific research and development.

What makes modular building specific? Simplicity. Modular buildings are constructed from dimensionally standardised and repetitive elements that are generally fabricated off-site. They represent the final result of modular design and modular construction. Modular construction, as a principle, responds with simplicity to the different demands of users, individual or collective, market or artistic, research or conventional. As such, it is a field of interest for architects, engineers, designers, industrialists, economists and sociologists.

Since mostly modular elements and units are assembled at the construction site, the logic of its architectural design and production differs from conventional buildings. At its core, modular construction is an automated industrial and technological process that aims to raise productivity, reduce costs while also increasing safety and efficiency in the construction sector. As an architectural concept, it represents a simple method in terms of performance, but the process of designing and producing a modular building is complex. Along with the development of modular construction as a way of creating buildings, after a certain period of architectural production, architects realise that the dominance of the visual aspect, the established norms regarding functional, technical and formal characteristics, make the end-user a passive actor in architecture. This changes the discourse of the role of the user in the design of architecture from a passive to an active actor, creating an architectural experience. In accordance with this change of discourse, the question arises of how modular construction can embrace such a change and what the architectural experience in a modular building is/will be.

Therefore, this paper also investigates the process of designing modular buildings to find links/possibilities between architectural experience in such buildings. The implementation of new insights in the field of neuroarchitecture can bring new methods in the process of design and construction of modular buildings, by which the end-user would have the final benefit in the spatial experience.

In the first part of the paper, an overview of the anatomy of modular design and construction is given, based on a review of recent scientific literature, followed by a historical overview that outlines the specific features of modular construction, which makes it uniquely different from conventional construction methods. The first part concludes with some contemporary definitions that are specific to the modular approach in architecture.

In the second part, the paper outlines the issue of architectural experience through the perception of architecture and the enactive approach. The intersection of neuroscience and architecture is also presented as one of the emerging fields in this subject matter. Some recent examples of modular design are presented as case studies, and a basic assessment of potentials for their architectural experience is given.

The paper concludes with a discussion regarding modular buildings and architectural experience and establishing a proper relationship between users/human beings and space. Based on this discussion, some potential directions for future research are given.

MODULAR DESIGN AND CONSTRUCTION

Anatomy of modular design and construction

Digitalisation and advancements in new materials and construction technology play an important role in the generation of modular buildings. In order to better understand this notion, it is necessary to thoroughly analyse the process of modular design and construction, which differs significantly from conventional or traditional construction methods. This forms the basis for establishing the thesis that a modular building has a specific way of its materialisation in a 'product' of the modular approach, as well as because of its features, application, and achievements in the field of architecture.

Modular design in architecture aims to develop prefabricated construction products or entire buildings made of physically detachable units for rapid product development, ease of assembly, services, reuse, recycling and other product life cycle objectives. Almost all contemporary design

Table 1: State-of-the-art research topics in modular design and construction.

Research topic	Subtopic / Category	References
Industry prospect	Realising lean construction through off-site manufacturing	Bertelsen, 2004; Höök & Stehn, 2008; Marhani *et al.*, 2013
Development and application	Opportunities and constraints of off-site construction	Goodier & Gibb, 2007; Schoenborn, 2016; Velamati, 2012
Performance evaluation	Surveying the perspective of housebuilders on off-site construction trends	Pan *et al.*, 2007; Li *et al.*, 2014
Environment for technology application	Policymaking	Park *et al.*, 2011; Hwang *et al.*, 2018
Design, production transport and assembly	Design solutions	Delfani *et al.*, 2016; Gonzalo *et al.*, 2019
	Software implementation potential	Cerovšek *et al.*, 2010; Abanda *et al.*, 2017; Berčič *et al.*, 2018; Niu *et al.*, 2019; An *et al.*, 2020
	Future perspectives	Blismas, 2007; Nadim and Goulding, 2010; Hong *et al.*, 2018; Verovšek *et al.*, 2018

and construction forms integrate prefabrication to some degree – from a single prefabricated window system to an intricate prefabricated building module (Boafo et al., 2016).

Modular systems include components and modules (units) that are based on a modular design. They are prefabricated in an off-site manufacturing plant and are produced under controlled conditions using the same materials and designed to the same codes and standards as conventionally built facilities (MBI, 2020).

Modular construction refers to creating modular buildings for which modular systems or individual elements are transported from their production facilities and assembled on-site to form an entire building. Modular buildings reflect identical design intent and specifications as site-built buildings. They represent various typologies of the building stock, meaning residential buildings, hotels, schools, hospitals, offices, student residences, and other types of buildings where repetitive units are preferred (Ferdous et al., 2019; Fathieh & Mercan, 2016; Fifield et al., 2018).

Even though the design and construction of modular buildings or their components are widely present, there is generally no uniform definition of modular design or modularity in scientific literature, although various sources share a common principle. That principle is based on a '*simple design approach that considers a system as a whole and separates it into smaller parts which can be either independent or interconnected according to usage. In terms of the scale of design, individual units may consist of simple geometrical shapes like a square, a rectangle, a triangle, a circle and etc.*' (Kubat & Kürkcüoglu, 2016). Moreover, several technical terms (e.g., prefabrication, pre-assembly, off-site fabrication, modularisation) are used to describe a modular process in which structural components are either manufactured at the plant and assembled at the construction site made on site (in-situ).

Innovation in most sectors is predominantly diffused through three central themes of People, Process, and Technology (Davenport, 1993); this is also true for the case of modular design and construction. This complex subject is covered by a wide range of research topics and subtopics. In their review paper, Li et al. (2014) identified five research topics, covering the state-of-the-art research of management in prefabricated construction. In Table 1, the research topics by Li et al. (2014) are presented and expanded into subtopics based on the categorisation of Boafo et al. (2016), who categorised the recent research focus in modular prefabricated architecture in seven categories. Some recent relevant scientific references regarding each specified category are also given. It is interesting to note that none of these research topics focus on the end-user and his spatial or architectural experience.

Furthermore, in 2013 The International Council for Research and Innovation in Building and Construction (CIB) issued an overview of the off-site manufacturing market and discussed the key requirements for successful adoption and uptake (Goulding & Arif, 2013). It presents findings from a three-year study, leading to the development of a Prioritised Off-site Production and Manufacturing Research Roadmap, which is briefly summarised in Figure 1.

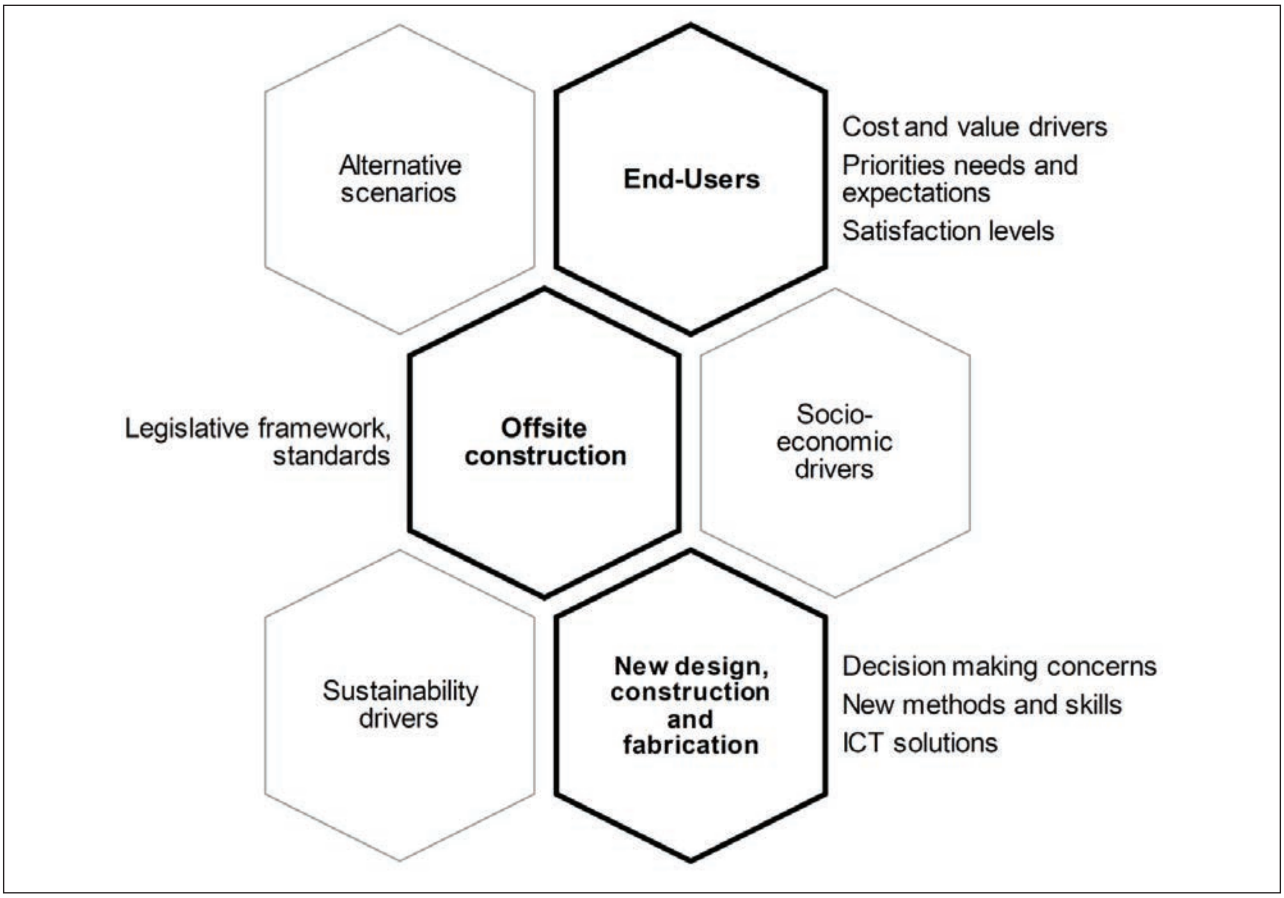

Figure 1: Future research agenda based on Goulding & Arif (2013).

The authors indicate that there is a reluctance by end-user groups to promote and advance more efficient processes in the off-site construction industry. Therefore, a lack in the assessment of the end-user experience and satisfaction levels may be discussed.

Historic overview

Modular construction focuses on a variety of building elements across different historical periods and geographical regions. It can focus on technology, procedures, theories and processes of constructing, the contexts, the structures, and conditions of production associated with a building, all of which have been identified as being of central importance (Meyer & Hassler, 2009).

Historically speaking, modular construction first began to appear in the 17^{th} century, specifically in 1624, when houses were prepared in England and sent to the fishing village of Cape Ann, in what is now a city in Massachusetts, USA (Smith, 2009; Boafo et al., 2016; O'Neill & Organ, 2016). Although some researchers, such as Agkathidis (2009), identify its origins much earlier when Mesopotamian, Egyptian and Greek houses and temples were constructed by handmade mass-manufactured units, comprising of 'quasi identical' mud-bricks and stone building blocks.

Smith (2009) describes how prefabricated dwellings were made and delivered to Australia later in the late 1700s and early 1800s. They were timber framework structures, with either timber panel infill or lighter timber infill system or canvas with weatherboarding. Various types of buildings were constructed in this manner.

During the Industrial Revolution, improvements in transportation brought forth the movement of standardised and prefabricated materials. The effect of the Industrial Revolution on construction was significant, and this is also evident in the growth of prefabrication (O'Neill & Organ, 2016). With the introduction of industrialisation, the brick had been the material to be first standardised. The innovation associated with Industrial Revolution possessed an effect that is significant for housing construction. Staib et al. (2013) discuss that the origin of modular housing production dates to the first half of the 19th century. In 1820, the first prefabricated housing was delivered to Southern

Figure 2: Modular construction of the residential neighbourhood Fužine from the 1980s in Slovenia, consisting of prefabricated sections of the façade, prefabricated wall panels and interior partitions (Photo: Simon Petrovčič, 2020).

Africa. These were basic cottage houses that were assembled on-site and did not include as many modular features as modern fabricated housing (Smith, 2009).

One of the most extensive examples of prefabrication is Britain's Great Exhibition of 1851, featuring a building called the Crystal Palace. Designed by Sir Joseph Paxton in less than two weeks, the building used light and cheap materials: iron, wood, and glass. The construction period lasted only a few months and consisted of assembling the prefabricated components. The palace was taken apart, piece by piece, and moved to another location after the exhibition (Slivnik, 2004).

At the beginning of the 20th century, technology played a decisive role in innovation in architecture. After World War One, traditional building materials were in short supply. O'Neill & Organ (2016) report that in the 1920s, manufacturing capacity, specifically pre-casting technology, was widely used to provide housing. In that period, prefabricated systems comprised two categories: the first utilised steel, timber, and large component pre-cast concrete; the second comprised small scale on-site pre-cast and in-situ concrete systems.

In the Weimar Republic, affordable housing was scarce. The government involved the public sector in overcoming this shortage. The general notion was to provide affordable housing under the premise of 'light, air and sun' for a large share of the population. The construction of the Dessau-Törten Housing Estate was thus commissioned by the city of Dessau in the framework of the *Reichsheimstättengesetz* (Homestead Act). The estate was conceived by the Bauhaus as a solution for cost-effective mass housing (Bauhaus Dessau Foundation, 2020).

Diverse housing typologies were included in the estate; as a part of a trial, the German Reich society for economic efficiency in building and housing wished to study the rational manufacture of residential housing as well as the suitability of new building materials and industrial products. Therefore, following the industrial principles, the building site was organised like an industrial production line. Several houses were built simultaneously during one construction phase by specialised labour brigades. Building components, such as the pre-cast concrete joists (so-called 'Rapidbalken'), were made on-site and transported with a small wagon and by crane (Bauhaus Dessau Foundation, 2020).

After the Second World War, numerous technological innovations were evolving in prefabricated housing. Technological innovations are described by Smith (2009) as a reflection of socio-cultural innovation. Prefabricated housing after Second World War was influenced by multiple factors. For instance, in the mid-1950s, mobile homes, built as a module on a chassis in a factory, accounted for 25% of all single-family houses in the United States (Boafo et al., 2016). Moreover, several prefabricated building systems, such as prefabricated beams, slabs, facade units, and vertical structural components, were extensively developed in Eastern and Western Europe to satisfy the massive demand for housing reconstruction after the war (Li et al., 2014).

In the 1950s and 1960s, a shift towards industrialised buildings within the construction industry was observed (O'Neill & Organ, 2016). The philosophies of the Bauhaus movement brought forth modernisation and non-traditional methods that contributed to a 'factory manufacturing methodology', particularly in social housing (Hayes, 1999).

Table 2: Technical terms describing the modular approach based on CII classification.

Term	Definition
Prefabrication	A manufacturing process, generally taking place at a specialised facility, in which various materials are joined to form a component part of a final installation. Prefabricated components often involve the work of a single craft.
Preassembly	A process by which various materials, prefabricated components, and/or equipment are joined together at a remote location for subsequent installation as a sub-unit; generally focused on a system.
Off-site fabrication	The practice of pre-assembly or fabrication of components both off-site and on-site at a location other than the final installation location.
Module	A major section of a plant resulting from a series of remote assembly operations and may include portions of many systems, usually the largest transportable unit or component of a facility.

Table 3: Terms describing the degrees of off-site construction.

Term	Definition
Component manufacture and sub-assembly	The traditional approach in construction. Raw materials and components are used to build on-site.
Non-volumetric pre-assembly	In this concept, 'two-dimensional' elements are prefabricated off-site and assembled on-site.
Volumetric pre-assembly	Volumes of specific parts in the building are produced off-site and assembled on-site within an independent structural frame.
Modular building	In this concept, much of the production is carried out off-site, with modules fabricated to a high level of completion. The only work performed on-site is the assembly of the modules and finishing operations.

Throughout the 1970s, volumetric construction was used, employing prefabricated construction in the form of frames (timber or steel) or concrete 'boxes', while several volumetric construction systems were used into the late 1970s and early 1980s (Figure 2), and in the mid-1980s many countries began to introduce prefabrication along with standard modular designs in public housing projects (O'Neill & Organ, 2016).

In general, post-Second World War prefabricated housing, which deviates from the traditional norms in terms of appearance and construction methods, faced resistance and suspicion from the public relating to innovations in the construction industry (O'Neill & Organ, 2016). From the 1990s until today, this began to dwindle since the negative attitudes were based broadly on the quality of the building materials and the poor workmanship of this form of construction.

Furthermore, until the 1990s, numerical modelling and simulations were restricted to those who could afford them. Nowadays, small manufacturers and fabricators use Building Information Modelling (BIM) tools, Computer Numeric Control (CNC), and 2-D laser cutting devices (Boafo et al., 2016), which allows for a much higher degree of production quality. It also greatly reduces the times and costs of fabrication and erection.

In general, modular construction allowed mass production of modular buildings after the process of its design and fabrication was standardised. The main principle is based on the reproduction of homogeneous, identical modules produced by existing technology. However, the wide deployment of prefabricated buildings is nowadays limited mainly due to restrictions of production approaches: the high cost of ad-hoc fully customised prefabricated buildings, and the lack of customer appreciation of low-cost, mass-produced prefabricated buildings (Marchesi & Ferrarato, 2015).

The modular approach

The modular approach is a complex system consisting of design, development, production and construction phases. This process can be further divided into smaller groups such as pre-design, design, development, detailing, ordering, fabrication,

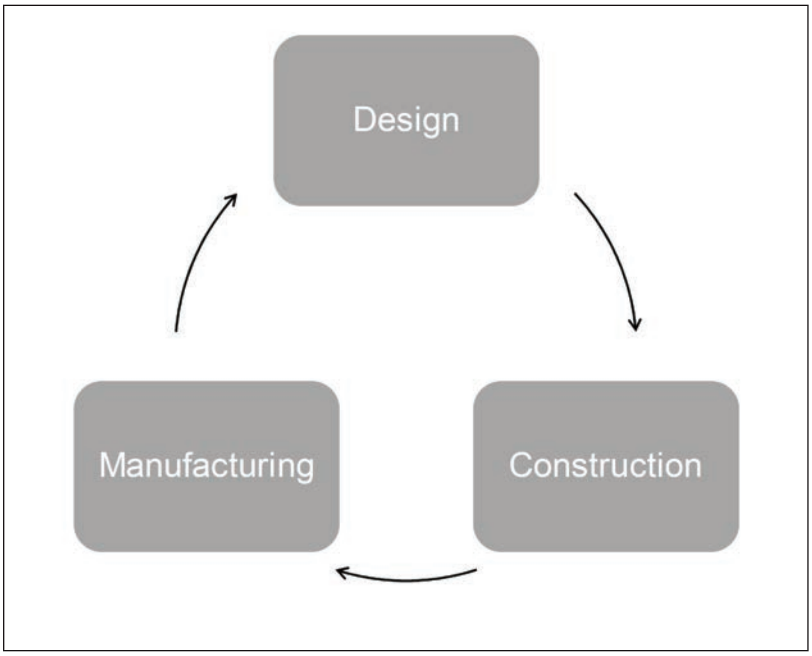

Figure 3: Core Interrelated Areas as proposed by Goulding & Arif (2013).

delivery, and assembly (AIA, 2018). In the authors' view, these areas should be explored further to clearly define the parameters and factors that influence modular building creation.

Several technical terms (i.e., prefabrication, pre-assembly, off-site construction, modularisation) describe the modular approach. In his PhD thesis, Bekdik (2017) uses terms from the classification of the Construction Industry Institute (CII, 2002) that are presented in Table 1, while an additional classification that identifies four degrees of off-site construction is also suggested (Table 2).

In an article published by the American Institute of Architects and National Institute of Building Science (AIA, 2018), the abovementioned classification is not considered. This article instead describes structural elements of modular buildings prefabricated off-site as non-volumetric components or volumetric units. The non-volumetric modular construction is defined as the off-site prefabrication of building elements that are then connected once on-site. These include structural elements, such as frames, beams and columns; sections of building façade and cladding; wall panels and interior partitions; floor cassettes and planks; roof trusses. As an example of volumetric units, the authors specify multiunit residential buildings, such as apartment buildings, hotels, and dormitories.

The core themes that are considered pivotal for developing the modular approach are three dominant paradigms that drive modular design and construction, along with their intertwined relationships (Figure 3).

ARCHITECTURAL EXPERIENCE

Perception of architecture and enactive approach

Architectural experience is a complex, delicate, and subtle issue with no clear scientific background; in many cases, it is a philosophical issue. The level of understanding of architecture primarily starts from visual perception. This requires the engagement of the sense of sight as the sole preceptor in the interactions between the observer and the environment. Since the human experience can be diverse, this also indicates that the human perception of architecture should be richer. As time passes in our experience of the environment, we create patterns and habits that fill our attention. We have also learned to choose only those aspects that we can understand or have previously experienced. The following question comes to mind. What would be our architectural experience if we were aware of all the human abilities that create it? In order to answer this question, it is necessary to explain what architectural or perceptual experience is and what influences the cognitive experience between human beings and the environment.

Since the phenomenon of architectural experience has no precise or scientific definition, there is a need to use knowledge from other disciplines to establish this corpus. Architecture is made up of many elements that can stand in different relationships and still belong to it. These are the thoughts, emotions, intentions, needs, imagination, decisions, and actions that form the stages in the formation of architecture. Moreover, a human being interacts with his whole being and senses with architecture, creating certain moods, states, feelings, and physical and mental adjustments that then lead to the architectural experience.

In the context of analysing modular buildings, this principle would be based on modern theory, education, and practice through which the visual aesthetic value of the created spaces, its materiality, were perceived. The principle would also extend to its historical development, functional, technical, and formal characteristics. In conjunction with the aforementioned notions, this means that this type of analysis treats architecture as a physical object and space based on geometric and compositional qualities without essence.

In the chapter The poetic and phenomenological approach of his Architecture as Experience, Juhani Pallasmaa (2018, 10) writes:

> *On the other hand, the phenomenon of architecture has also been approached through subjective and personal encounters in a poetic, aphoristic and essayistic manner, as in the writings of many of the leading architects from Frank Lloyd Wright to Alvar Aalto, and Louis Kahn to Steven Holl and Peter Zumthor. In these writings, architecture is approached in a poetic, philosophical and metaphorical manner, without any qualifications as scientific research. These writings usually arise from personal experiences, observations and beliefs* […] *The experiential and existential core of architecture has to be encountered, lived and felt rather than understood and analysed intellectually. There are surely numerous aspects in construction, in its performance, structural essence as well as formal and dimensional properties that can be studied "scientifically", but the experiential and mental meaning of the entity can only be existentially encountered and experienced.*

This attitude does not encourage the establishment of an architectural experience. One reason is the complexity of the experience issue accompanied by the architect's lack of interest in approaching the problem in a scientific way. The problem can be recognised in the dual nature of architecture: artistic and scientific. There are reasons why certain phenomena have not been interpreted in a scientific way when they can be evoked or manifested in an artistic way. One reason for this attitude among architects about this theme can be explained by their dominant field of interest in expression through form and formal structures. In the same article, Juhani Pallasmaa (2018, 15) argues that a new approach in the architectural experience shifts 'research from form and formal structures to emotive and dynamic experiences and mental processes. It is evident that when the focus shifts from the physical reality and form to the mental reality and emotion, also the methodology of the study is bound to change'.

To achieve the goal of optimal architectural experience in modular building, it is necessary to establish a proper relationship between users/human beings and space. In this case, a methodology based on the physical features of the form and space, its materiality, functional and technical characteristics will be replaced by an approach in which the human being is an architectural subject that experiences architecture. People gain experience with the environment through the body; therefore, many architects assert that the body measures architectural quality.

The user/human-space relationship is a two-way one. As architecture is the embodiment of human activity, architectural spaces affect human well-being in all aspects. As a result of certain views in architecture in which the human being has been reduced to a position of a disembodied architectural observer, due to the pronounced dominance of visual aspect and intellectualisation in design, researchers have begun to change that discourse and place a human being in a user-centred design. Some researchers in that context use an enactive approach (Di Paolo, 2017), which emphasises the nature of perceptual experience. The perceptual experience is a manifestation of people's engagement with the architectural environment through relational embedding between the user and artificial space (Jelić et al., 2016; Jäger, 2017; Afshary et al., 2018; Gračanin et al., 2018). As the authors argue in their work 'The Enactive Approach to Architectural Experience: A Neurophysiological Perspective on Embodiment, Motivation, and Affordance' (Jelić et al., 2016): '*the way in which we perceive, experience, and engage with architecture depends on the particular kind of body we have and the possibilities for body-environment interactions that are inscribed in terms of the motor or skilful knowledge as potential for action*' (p. 3). For phenomenologists such as Merleau-Ponti (1964, 3), '*the body is our general medium for the existence of the world*' through which we experience the environment. Therefore, for the followers of enactivism, it is necessary to consider the nature of perception and the related phenomenological conception of the living body.

Neuroscience in architecture and other insights

An emerging field called the 'neuroscience of architecture' promises an empirical platform from which to study experiential dimensions of architecture that have been largely overlooked in modern building science. In this field, the intersection of neuroscience and architecture is studied (Sternberg & Wilson, 2006; Eberhard, 2009; Coburn & Chatterjee, 2017). Another active new field is called 'neuroarchitecture', which uses neuroscientific tools to understand architectural design and its impact on human perception and subjective experience better (Ruiz Arellano, 2015; Karakas & Yildiz, 2020; Chiamulera et al., 2017). The form or shape of the built environment is fundamental to architectural design, but not many studies have shown the impact of different forms on the inhabitants' emotions.

In the past, architectural studies were based on philosophical constructs or analysis of behavioural patterns to relate human responses to the design under investigation. While such approaches provide descriptive evidence, they cannot specify the reasons for different behaviours in built environments. Recently, progress in neuroscientific methods has made it possible to investigate how different architectural styles can influence human perception and affective states. Neuroarchitecture studies the effects of the built environment on its inhabitants by using neuroscientific tools (Banaei et al., 2017). Neuroarchitecture studies have been attempting to close the gap between architecture and psychology by describing some of the underlying mechanisms that explain how differences in architectural features cause behavioural outcomes (Vartanian et al., 2013).

EXAMPLE CASE STUDIES

Modular building, as a principle of design and construction in recent years, provides architectural answers to diverse requirements from industrial, social, design, and professional fields. In architecture, it is proving to be an adaptable, changeable, transformable, and economically observable method that finds its realisation in reconstructions, upgrades, extensions, independent realisations or in combination with other models of construction as a technical, engineering, market or experimental response to different demands. Furthermore, merely as a principle, it is applicable to different typologies of architectural objects and, as a realised object, represents architectural structures with specific features.

Currently, this industry has focused on specific market segments and on low-to mid-rise buildings and is not readily able to produce a wide range of project types and sizes (AIA, 2018). Even though some buildings have been successfully designed and constructed as modular buildings (e.g., Conservatory in Montreuil, France, by Claude Le Goas and Robert Bezou, Kisho Kurokawa's Nakagin Capsule Tower in Tokyo, Habitat 67, by Moshe Safdie), some architects claim that this principle limits their design or restricts their control (AIA, 2018). That is why architecture lacks successful buildings accomplished through this method.

Figure 4: House NA in Japan by Sou Fujimoto (Liotta, 2017).

The first presented example is called The House NA, designed by Sou Fujimoto. It is an 84 m^2 modular home designed for a young couple and stands out because of its transparency. Associated with the concept of living on branches of a tree, the interior is made up of 21 platforms located at different heights: this satisfies the desire of customers to live as nomads within their own home, as they can move from platform to platform. Described as 'a unit of separation and coherence', the house is both a single room and a collection of open rooms where separation is not given by the walls but rather by the distance between the spaces (Liotta, 2017).

An increasingly popular modular element in contemporary modular design is the use of the shipping container (Vijayalaxmi, 2010; Taylor, 2016; Sun et al., 2017; Elrayies, 2017). Shipping container architecture presents a milestone since it eliminates the need for conventional construction methods, which are a major source of CO2 emissions.

The Cancer Centre Amsterdam is part of the Antony van Leeuwenhoek Hospital in the Netherlands and is one such example. The existing centre needed to be rebuilt and enlarged on its existing site. The extension is conceived as a series of containers on a small site. A temporary institute was to be erected during the construction activities. This structure was installed in a few weeks and can be removed and shipped to a new location in a similar amount of time (MVRDV, 2005).

Another similar example is a coffeehouse in Taiwan designed by Kengo Kuma. The structure consists of 29 used shipping containers stacked together to create a two-storey geometric space (Figure 6). The stacking of the shipping containers creates a tall space that provides natural sunlight through the various skylights found throughout the structure (Starbucks Corporation, 2018).

Another interesting example of modular design is the project by Bjarke Ingels Group (BIG), which recently designed a 66-unit affordable housing development in Copenhagen made from stacked prefabricated modules (Bellini and Arcieri, 2020). The modular prefabricated building incorporates the use of simple wood and concrete building materials both inside and out, which lowered the construction costs. The Dortheavej Residence, located in the neighbourhood of Dortheavej in north-western Copenhagen, was commissioned by Danish non-profit affordable housing association Lejerbo as part of the 'Homes for All' mission.

In November 2019, the French architect Sophie Delhay and her office received the *Ekuerre d´Argent*, the most important architectural award in France, in the category of residential buildings for Grand Dijon Habitat (Figure 8), which was produced as a modular building (Hespel, 2020).

Figure 5: Cancer Centre Amsterdam (MVRDV, 2005).

Figure 6: Container coffeehouse in Taiwan by Kengo Kuma (Starbucks Corporation, 2018).

Figure 7: The Dortheavej Residence in Copenhagen by Bjarke Ingels Group (ArchDaily, 2020).

Figure 8: Grand Dijon Habitat, Sophie Delhay architecte (Photos: Betrand Verney, 2019).

It is important to point out that this example does not represent modular design as defined in Section 2 of this paper. The presented building is not a prefabricated volumetric building but was rather generated in-situ. The presented example reflects a different type of modularity, which is modularity in the architectural sense. The building consists of one typical unit, i.e., a 3.60×3.60 metres square shape module, which can be considered a modular building from an architectural (design) point of view.

The implementation of architectural experience requires set boundaries for the modular approach. In the scope of this study, a preliminary assessment of the presented case studies in terms of potentials for the end-user architectural experience is given. The following principles of neuroscience and architecture, which are likely to enhance the creativity, cognition, and comfort of those occupying or working in such spaces, are adopted (Sternberg & Wilson, 2006):

- **Space versus place:** a sense of place within an environment is defined by its topology, indicating how locations are connected through exploration or movement and not simply by the configuration of the space itself (the topography of the environment). This emphasises the benefit of architectural design, which is reflected in the functionality of a space (topological characteristics), such as movement and usage patterns, and aesthetic elements (topographic characteristics), such as physical layout and form. The internal representation of a place is strongly influenced by how an individual moves within it, with different places connected based upon the ability to move between them.
- **Orientation and place:** a sense of place is usually enforced by visual landmarks, which contribute to determining the location and orientation of individuals within an environment. They provide a global reference frame to track the direction a user is facing within an environment.
- **Memorable places:** A strong sense of place can be strengthened by providing prominent local cues in the form of local decorations (e.g., pictures, objects, distinct colours, textures, etc.) that may establish uniquely memorable routes. Therefore, by planning the routes that will take the users moving within an environment, architects can incorporate design elements that allow these paths to be more readily navigated and remembered.
- **Physical environment and the stress response:** In some cases, the features of the physical environment can trigger a physiological stress response. Examples of such triggers in the physical space include crowding, sudden loud noise, bright lights, multiple choices, lack of landmarks, and new environments.

For each of these principles, the examined case studies are assessed based on their potential for the end-user architectural experience. A mark of '3' indicates a strong potential for a selected principle, while a mark of '1' indicates that this potential is weak. A mark of '2' indicates an intermediate potential for architectural experience. The given assessment values are presented in Figure 9. It can be seen from the table that memorable places have the largest potential for all of the examined cases, while the House NA exhibits the highest potential for architectural experience. Due to its unique and innovative design, a user may experience all four potentials to a great extent. In the other four examined case study examples, the user may experience two principles based on the conducted evaluation. It should be emphasised that this simple evaluation presented herein only identifies the individual potential, but it is up to the user to experience it or not. Moreover, the assessment values were given based on the authors' interpretation of the publicly available data of the selected case study examples.

DISCUSSION

Recent advances in structural engineering and in the development of new building materials led to the construction of taller and safer buildings than ever before. In Western architectural practice, this trend also triggered a philosophical shift towards the concept of buildings as machines (Coburn et al., 2017). As a result of this philosophical shift, the minimalist, reductive form that resulted from this philosophy came to embody a new aesthetic ideal in which architectural beauty is reflected mainly as a by-product of design based on functionalism (Rattenbury & Hardingham, 2007).

This notion also brought forth many changes in the pivotal themes of the modular approach: design, manufacturing, and construction. A study on a housing settlement in Istanbul conducted by Altaş & Özsoy (1998) has shown that a complex relationship exists between the perceived space and real dwelling size in terms of space organisation and that the proper organisation of rooms can encourage flexible use or adaptation in a dwelling. Therefore, to achieve the goal of optimising architectural

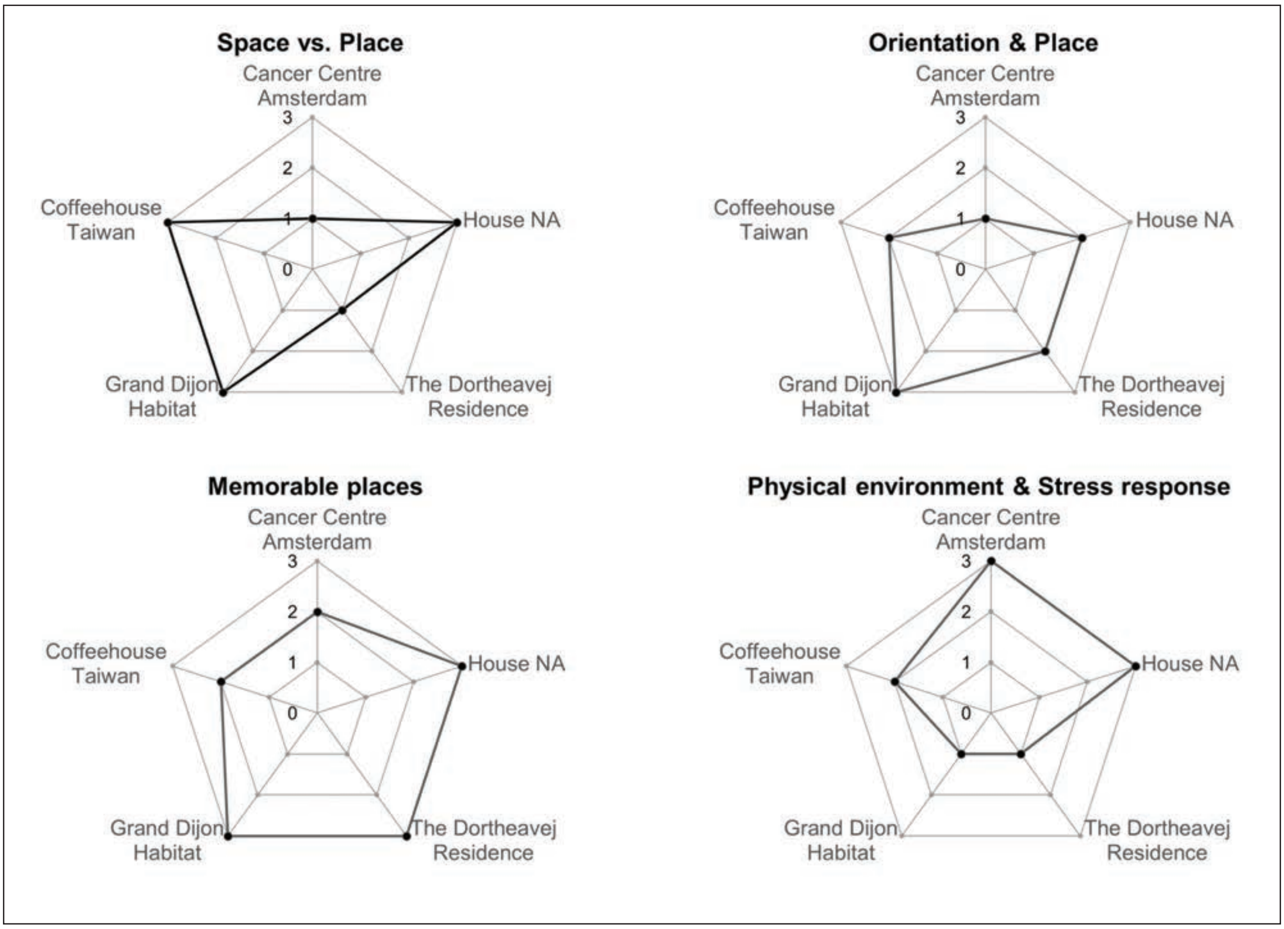

Figure 9: Architectural experience potentials for the examined case study examples.

experience in a modular building, it is necessary to establish a proper relationship between the users/human beings and space. In this case, a methodology based on the physical features of the form and space, its materiality, functional, and technical characteristics would be enriched by an approach in which the human being is an architectural subject that perceives architectural experience. People gain experience with the environment through their bodies and senses, and new insights in the fields of neuroscience and cognition can be used in achieving this goal.

Therefore, based on these concepts, some potential questions and directions for future research can be outlined:

- What would be the effects of the widespread use of modular architecture, and how would this affect the architectural experience of end-users?
- What influence will the advancements in the field of neuroarchitecture have on spatial qualities?
- What are the potentials of neuroarchitecture as a tool for achieving a more profound architectural experience?

In order to find answers to these questions, it is first necessary to implement the acquired knowledge in the field of neuroarchitecture and to define and structure it more closely. Based on the conducted review, it can be concluded that, as a scientific field, it is still in its early stages. There are generally no existing scientific indicators for determining architectural values that can define feelings, mood, ambience, atmosphere, and similar. An enactive approach is used to establish a scientific system to structure architectural experience. It assumes that human beings use their bodies to acquire and establish experiences with the environment. This approach stems from an altered discourse on the role of the human being in architecture. The enactive approach brings the concept of the active role of humans in the environment in gaining an architectural experience via their bodies. This means that in the focus of their design architects should establish a system of values relating to the human/user-space relationship (i.e., as a user-oriented design). Doing so would further enhance the modular approach to achieve the architectural value of the modular building and contribute to the enrichment of certain stages in the creation of modular buildings, such as pre-design, design, and development.

CONCLUSION

This article aimed to identify trends in the development of modular buildings using the knowledge of experience in architecture. The paper strives in identifying a link between how modular buildings are designed and constructed and how this process ultimately affects the end-user and his experience of space.

From the reviewed literature on modular design and construction, it has been found out that even though modular construction as a principle responds with simplicity to the different demands of users, the consideration of the end-user experience is not taken into account. In contrast, recent advances in the fields of the neuroscience of architecture and neuroarchitecture have shown a trend towards a better understanding of the impact of architectural design on human perception and subjective experience.

Based on this review from both perspectives and the notions given in the discussion, it can be concluded that a modular building that results from the process of modular design and construction is not a mere technological process devoid of interest in the human being and his experience of space. As much interest is given to the process of efficiency, productivity, cost reduction, safety and sustainability, the question remains regarding what aspects of architectural experience are crucial to obtain a richer architectural experience in modular buildings.

MODULARNA GRADNJA IN ARHITEKTURNA IZKUŠNJA KONČNEGA UPORABNIKA – ZNANSTVENI PREGLED

Nikola JELENIĆ
Buda Tomovica F7, 81000 Podgorica, Črna gora
e-mail: nikolajelenic@gmail.com

Simon PETROVČIČ
Univerza v Ljubljani, Fakulteta za arhitekturo, Zoisova 12, 1000 Ljubljana, Slovenija
e-mail: simon.petrovcic@fa.uni-lj.si

POVZETEK

Modularna gradnja je globalni trend, ki spreminja gradbeno industrijo po vsem svetu. Čeprav metoda konceptualizacije in materializacije modularne stavbe sama po sebi ni inovacija, se ta metoda nenehno izboljšuje s sinergijo z drugimi disciplinami. Namen tega članka je razkriti nedavne trende v razvoju modularnih stavb z znanjem izkušenj v arhitekturi. Prvi del članka vsebuje pregled nedavnega znanstvenega razvoja modularne zasnove in gradnje, skupaj z zgodovinskim pregledom, ki opisuje posebne značilnosti modularne gradnje. Drugi del članka se dotika vprašanja arhitekturnih izkušenj, povezanih z dojemanjem arhitekture s strani končnega uporabnika. Presečišče nevroznanosti in arhitekturne teorije je izpostavljeno kot eno od nastajajočih perspektivnih področij v okviru obravnavane problematike. Predstavljene so študije primerov izvedenih projektov modularne gradnje in podana je osnovna ocena potencialov za arhitekturne izkušnje končnih uporabnikov. V prispevku je ugotovljeno, da čeprav se modularna gradnja kot načelo preprosto odziva na različne zahteve uporabnikov, upoštevanje izkušnje končnega uporabnika na splošno ni upoštevano in da modularna stavba, ki izhaja iz procesa modularne zasnove in gradnje, ni zgolj tehnološki proces, temveč zaključena celota, ki vključuje tudi uporabnika in njegovo doživljanje in dojemanje arhitekture. Poleg tega lahko nove ugotovitve na področju nevroarhiteture privedejo do novih metod v procesu načrtovanja in gradnje modularnih stavb, z večjim poudarkom na končnem uporabniku.

Ključne besede: modularna gradnja, modularni pristop, arhitekturna izkušnja, uprizarjanje arhitekture, doživljanje arhitekture, izkušnja končnega uporabnika

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