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Research paper

MODULAR SOLUTIONS FOR RESIDENTIAL BUILDINGS - KEY TO AFFORDABILITY AND SUSTAINABILITY

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Abstract

The global housing crisis, exacerbated by rising construction costs, land shortages, labour limitations and even climate change, has underscored the need to experiment with designs to deliver quality accommodation. Prefab construction technologies present a promising solution, targeting these problems by reducing construction time, material waste, and overall expenditures. This paper aims to explore the potential of modular housing as a key strategy for improving affordability and enhancing the comfort of the inhabitants of residential developments, with a focus on using different types of solutions.

The paper analyses the application of the three main types of modules, previously defined by the author - construction, spatial-functional, and planning module through several examples. Their flexibility, adaptability and contribution to the construction process is studied. Their advantages and limitations are evaluated. The study employs a qualitative methodology, including a review and comparison of case studies, to define several key findings highlighting that modular construction significantly reduces construction timelines and labour costs, with each type of module offering distinct advantages for different housing needs. However, challenges remain in terms of size of single units, customization, integration and blending with the existing built environment, as well as the amount of initial investment.

The significance of this study lies in its ability to demonstrate how pre-fabrication for housing can serve as a cost-effective and sustainable solution to the growing demand for accommodation, especially affordable one. By highlighting the practical applications and limitations of different module types, the study provides valuable insights into how modularity can be applied to maximize their effectiveness in addressing the contemporary residential crisis – both in terms of affordability and lack of housing due to different factors.

Key words: *pre-fabrication, modular constructions, residential solutions, housing crisis, affordability, experiments*

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1. INTRODUCTION

In the context of over-urbanisation and rapid urban population growth (with 54% of the world's population now residing in cities, which is expected to rise to 68% by 2050), the shortage of housing in large megacities is a serious problem, highlighting the contemporary housing crisis. In contrast to the 19th and 20th centuries, when the primary causes of urban migration were attributed to changes in people's livelihoods and warfare leading to significant destruction of housing stock, contemporary urban migration is predominantly driven by economic factors – search for better services, working conditions and payment. Locally in Bulgaria, this has resulted in abandonment of small towns and suburban parts, and higher attraction of individuals to urban centres and bigger cities, leading to lack of enough residential units in particular areas and huge number of empty apartments in others. In this scenario, a viable solution would be to construct housing from prefabricated elements, as the rationales for this pragmatic approach are rooted in the primary benefits associated with this construction method, namely:

- faster execution speed leading to reduced construction timeline.
- consideration of the construction method as an economical one, mostly due to the elimination of certain processes, which are unavoidable in the conventional construction process, as well as the possible typification of most of the elements.
- high degree of precision during constructing.
- the possibility of reduction in the maintenance and operating costs of buildings throughout their life cycle.

In contemporary practice, the use of different materials and lightweight constructions has created opportunities for more flexible planning solutions and interesting volumetric developments. The avoidance of wet processes and the reduction of construction waste, the unification of elements leading to more cost-effective solutions, are just some of the reasons why it has and should continue to stimulate the interest of researchers, planners and investors. The utilisation of "*eco-friendly materials ... advanced technologies for the design, construction and 'smart' management*" [1] of housing constitutes an integral part of contemporary practice in prefabricated housing.

The prevailing sentiment amongst our society, locally, is one with an initial hint of negativity towards prefabricated construction, largely attributable to historical memories and associations, compounded by the characteristics of national psychology. Despite certain traditions and past experiences, its utilisation is intentionally avoided, and contemporary solutions are regarded more as an exotic practice than as a widespread implementation.

The fundamental distinction is that until the 1990s, prefabricated construction, in its mass manifestation, was utilised in the construction of apartment housing on a substantial scale in the residential neighbourhoods built from the 1960s to the late 1980s. So currently it is facing certain controversial opinions, without considering its indisputable advantages. The prevailing economic conditions in the country, coupled with the relatively modest cost of man-labour, render monolithic construction financially viable under certain circumstances, thereby ensuring its preference and wider application. Prefabricated structures, predominantly composed of wood, find application in the construction of single-family dwellings, while prefab reinforced concrete and steel elements are primarily utilised in the erection of warehouse, industrial and hall buildings. However, this phenomenon is mostly local, and, in the interests of the wider community, it is considered better that it should be a transient one.

This paper explores the potential of modular systems as a strategic response to two of the most pressing issues in the housing sector: affordability and sustainability. Drawing from recent advancements in design and prefabrication technologies, the study highlights how modular construction methods can meet diverse residential needs while minimizing environmental impact. The contemporary potential of prefabrication does not constrain the functional or spatial configuration of an architectural entity. Instead, it facilitates the customisation of dwellings to align with the particular requirements of the occupants, while maintaining cost-effectiveness at a specific stage in their life cycle [2].

Previous studies have demonstrated the efficiency and ecological benefits of prefabricated structures; however, this research expands the discourse by further analysing the three distinct types of modules, as previously defined by the author [3]:

- modular solutions, based on a specific structural dimensions and proportions (structural/ construction module).
- modular solutions which combine both the space, the function and the structure in a single shape (space-functional module).
- planning module – not necessarily related to the shape or the structure.
- hybrid module – some or all the above combined in different ways.

These types, except for the simply planning module, will be studied through three selected case studies - The Urban Village Project by Space 10 & EFFEKT Architects for IKEA, The Puzzles of Complexity Project by Architectural Mythologems and the GOMOS system, developed by Summary in Portugal. The paper examines the practical applications of these modular types, evaluating their advantages and limitations in conceptual and real-world contexts. By identifying patterns in how, when, and why specific modular systems are applied, the study contributes to a deeper understanding of the role modularity can play in shaping the future of sustainable and accessible housing. The findings aim to inform architects, planners, and developers seeking effective solutions to contemporary residential challenges and eventually to support re-establishing and reviving the construction method in Bulgaria to a certain extend.

2. METHODOLOGY AND RESEARCH OBJECTIVES

The aim of this study is to explore the potential of modular construction as a viable solution to two major challenges in contemporary residential architecture: affordability and sustainability. The research seeks to identify how modular approaches can optimize building processes, reduce costs, and minimize environmental impact while maintaining flexibility and quality in residential design.

To achieve this, the study adopts a comparative case study methodology, analysing three residential projects, both conceptual and real, based on modular planning:

- Urban Village Project by Space10 & EFFEKT Architects.
- Puzzles of Complexity by Architectural Mythologems.
- GOMOS plug-in system developed by Summary in Portugal.

Each case could be listed under some of the defined by the author types of modular solutions. The research evaluates how these modules are applied, their integration into the design and construction process, and the resulting advantages and limitations in each context.

Data is gathered from architectural documentation and online published information about the projects. The analysis focuses on qualitative aspects such as environmental performance, adaptability and flexibility answering to user needs, architectural image and defining and creation of shared common spaces. Comparative conclusions are drawn to outline patterns of use and highlight best practices in modular residential developments.

3. ANALYSIS AND DISCUSSION

This section presents briefly the background, and the essence of the three modular housing case studies and finishes with their comparative evaluation, based on the above-stated four key criteria.

3.1. Space10 & EFFEKT Architects – The Urban Village Project - modular concept for IKEA

The Urban Village Project is a conceptual development born by the collaboration between Space 10 and Effekt Architects under the management of IKEA. It is "*a vision for creating shared living communities for people of all ages, backgrounds and living situations …. "* which *"objective is to enable a better everyday life through the multiple benefits of living in a tight-knit community, with shared facilities and services like day-care, urban farming, communal dining, fitness and shared transportation*" [4]. In accordance with the concept behind IKEA packaging it is supposed that the buildings materials are "*prefabricated, mass-produced and flat-packed*" [4] thus making the solution quite affordable. Both the construction and closing material is wood which gives high sustainability to the solution, reduces exploitation costs within its lifecycle and forms better living environment for the inhabitants.

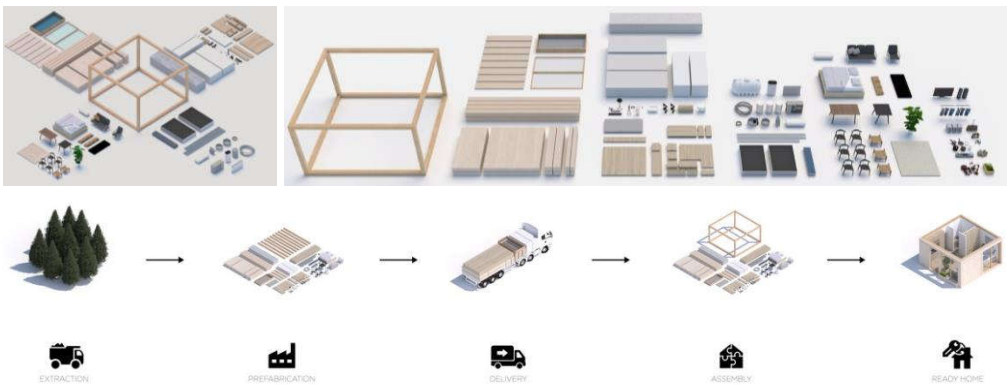

Figure 1. The Urban Village Project – elements of a single modular residential unit and creation of the unit – transition from the woods to the city; source [5, 6]

The development of the project is "*based on a standardized modular building system*" [4], which is a grid of squares with sizes 6 meters x 6 meters within which is proposed a possible separation of the single residential units with different sizes, starting from 36 sq. m., thus making them suitable for diverse in size and needs households (fig. 2). All of this provides great extent of flexibility of the project and could be considered a key benefit. In terms of usage of the defined types of modules it could be deliberated that the project is interpreting the structural type of module, tending to transform it into a hybrid type. This is created through the combination between a planning and construction type of module since it is developing

itself within a structural grid, which defines the shape, the sizes as well as the proportions of the units and the common spaces.

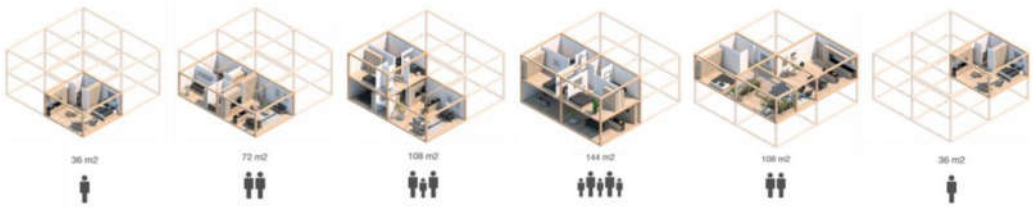

Figure 2. Different options for housing units – high-level flexibility depending on the size of the household and their personal needs, source [5]

Being on the boundary of creating shared and co-living spaces the project could find its multiple places within the city fabric both as a standalone construction and as a densification instrument in already built environment (fig. 3), thus serving as a possible restriction for the observed in the recent years, rapid urban sprawl. The architectural form is simple, minimalistic and compact, as it gives the possibility of creation transitional in-between spaces within the grid, in order to create a sustainable and quality living environment [7].

Figure 3. Possibilities to integrate the modules of the Urban Village Project within the urban fabric, source [5]

3.2. Architectural Mythologems – Puzzles of Complexity - modular housing in China – research and concept project

The Puzzles of Complexity project is a highly conceptual design proposed by the architects from Architectural Mythologems. The project's urban layout is inspired by a chessboard pattern, symbolizing binary principles foundational to computing [8].

Figure 4. Puzzles of Complexity – chess influence and appearance of the compact architectural form, source [8]

Similarly to the Urban Village Project it has grid-like arrangement and facilitates a visually articulate community structure, where the repetition of simple units ends in a dynamic urban

complex with a mixture of private, public and semi-public spaces. The design philosophy underscores the idea that complexity can emerge from the strategic assembly of simple elements. While the individual modules maintain a minimalist appearance, their collective arrangement results in a visually complicated architectural image (fig. 4).

This project's grid has sizes of 3 meters x 3 meters and is defining modular units with numerous possibilities for combinations. The solution could be listed, similarly to the Urban Village Project, as a hybrid type of module – a combination between structural and planning modules, since the residences occur within the framework of the structural lattice, which serves as the foundation on which residents are able to customize and expand their living spaces over time, according to their evolving needs, thus giving this project also a great extent of flexibility (fig. 5). This approach not only promotes affordability by enabling incremental construction but also supports sustainability through efficient use of materials and space. The minimalist aesthetic allows for scalability and adaptability. The smaller sizes of the grid give greater possibility for creating human scale and successful zoning [9] of the public and semi-public spaces incorporated within the project.

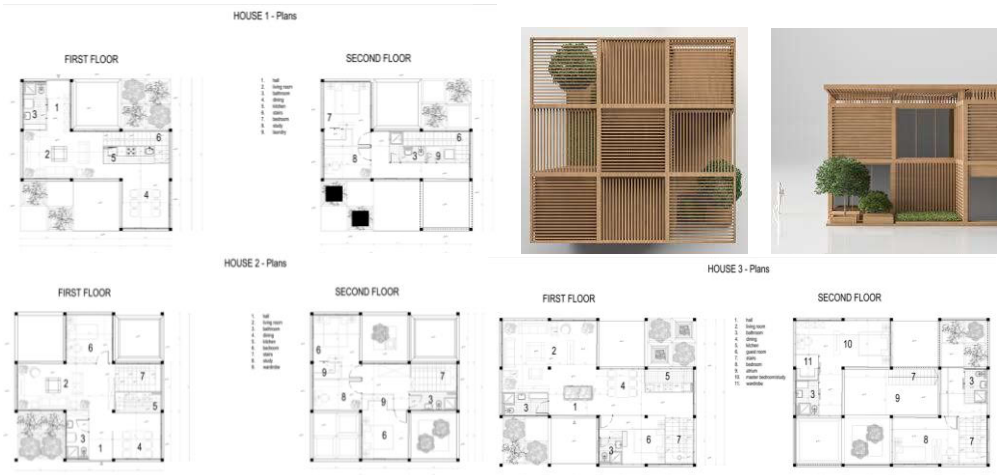

Figure 5. Puzzles of Complexity – floor plans and appearance of the tree types of residences, source [8]

3.3. Summary, Portugal - GOMOS modular system

The GOMOS System, developed by the Portuguese architecture studio Summary, led by architect Samuel Gonçalves, is a modular construction approach inspired by the assembly of concrete sewer pipe. This system reimagines such structures for residential use, maintaining their rapid assembly and structural stability. In its essence it is a concrete shell prefabricated to live-in and ready to be installed on-site.

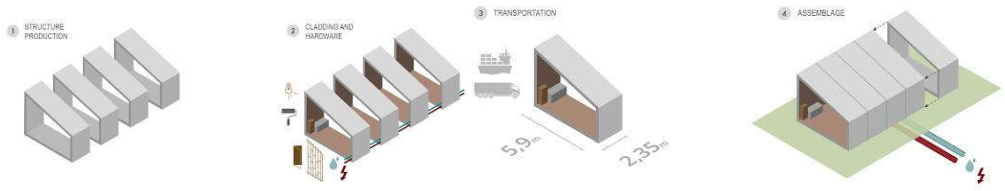

Figure 6. GOMOS modular system – shape and size of the prefabricated elements, source [10]

Elements could be defined as a space-functional module, according to the author's classification due to the fact that they are arriving on-site completed with their interior and exterior finishes, insulation, window frames, plumbing, electrical installations and fixed furniture – all incorporated within their specific shape (fig. 6). The system's design allows for adaptability to various programs beyond housing. Modules can be added post-construction to accommodate expansion, and the system can adapt to different land conditions, residents' requirements and needs.

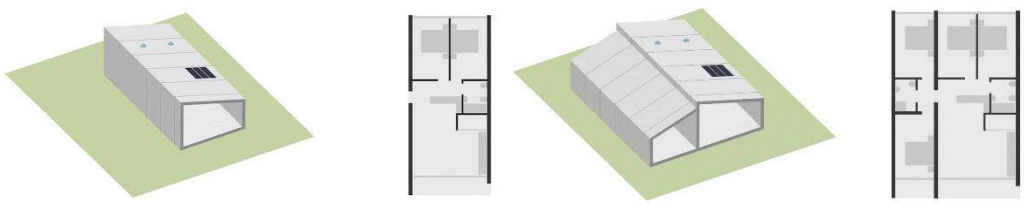

Figure 7. Possible solutions for the shape and the floor plan, using the GOMOS system elements - flexibility of the solution, source [10]

The construction process is divided into four phases – production of the structure, installation of finishes and facilities, transportation, and assembly. This streamlined approach allows for on-site assembly to be completed in just a few days. Module dimensions are optimized to comply with transportation regulations, facilitating easy delivery to construction sites (fig. 8). Design choices, including natural ventilation corridors and effective insulation, contribute to low energy consumption in GOMOS buildings. Factory production under controlled conditions ensures consistent quality and reduces the likelihood of construction issues commonly found in traditional building methods, although in some realizations using the system internal signs of leakages could be seen. This is showing some week points in the process of insulating the joints between different elements, especially in projects where the concrete structure is left visible, such as Vale de Cambra housing in Portugal, constructed in 2019 (fig. 8).

Figure 8. Phases of construction process – fig. 8 – left; internal problems with the connections between elements – fig. 8 - right, source [11]

The system is flexible enough and is tested in designing and creating different types of buildings without limiting its usage to residential constructions (fig, 9). It represents a significant advancement in modular construction, offering a solution that is both efficient and adaptable. Its emphasis on prefabrication, rapid assembly, and flexibility makes it a

compelling option for addressing contemporary housing challenges, particularly in contexts where affordability and sustainability are dominant.

Figure 9. The GOMOS system elements are used for constructing variety of buildings, including single family housing, apartment buildings, student dormitories, kinder garden as well as public buildings, source [11]

In the following table the three above-discussed projects are evaluated in accordance with the initially set criteria - environmental performance, adaptability and flexibility answering to user needs, architectural image, defining and creation of shared common spaces and usage of the different types of modules, defined by the author.

Table 1. Qualitative comparison and evaluation between The Urban Village project, Puzzle of Complexity and projects, adopting the GOMOS modular system

CRITERIA / PROJECT	Urban Village Project	Puzzle of Complexity Project	projects, adopting the GOMOS System
Environmental Performance	**HIGH** -based on circular design principles -usage of natural materials -reusability of materials – design for deconstruction -reduced footprint via shared resources.	**MODERATE** -modular structure -potential for reuse, -no clear information about the used materials.	**HIGH** -usage of prefabricated concrete modules -reducing site waste and construction time -good thermal mass for energy efficiency.
Adaptability & Flexibility to User Needs	**VERY HIGH** -possible reconfiguration, extension, and spatial personalization.	**MODERATE** -adaptable layouts -higher class living – closer to single family housing in a complex.	**LOW–MODERATE** -highly standardized units with minimal options for post-construction adaptation.
Architectural Image	-distinct and contemporary -strong design identity based on usage of the wood and the modularity within urban context -highly conceptual.	-blends modular logic with vernacular motifs or typologies -more anonymous in appearance but contextually responsive.	-minimalist and industrial -visually uniform -architectural identity comes from repetition and the usage of simple forms.

Common / Shared Spaces	**HIGH** -shared amenities are within the core of the concept (laundry, gardens, workspaces) -promoting community and reducing loneliness -shared/ open-air spaces could be integrated anywhere in the structure – ground floor and above.	**MODERATE** -shared corridors or courtyards where appropriate -not a primary focus but considered within the plans -shared spaces could be only on the ground floor.	**LIMITED** -projects are focused on self-contained living units -shared/ open-air spaces depend on external planning and layouts of regulated plots as well as the one of the particular building
Type of modules used, as defined by the author	**hybrid type of module** – mixture between structural and planning type of module	**hybrid type of module** – mixture between structural and planning type of module	**space-functional type of module**

Each project offers distinct advantages and challenges. The buildings which are using the GOMOS modular system excel in environmental performance due to the efficient, prefab process and simplicity, but are less responsive to user diversity and community integration. The Urban Village Project presents an ambitious model for future urban living, with high adaptability and sustainability, though it remains largely conceptual. It sets a visionary example for modular urban communities. The Puzzle of Complexity Project offers a tested, pragmatic balance between standardization and contextual responsiveness - incorporating some flexibility and shared use while being grounded in local needs and urban practicality, making it particularly relevant for rapidly urbanizing regions. All the studied examples present specific spatial structure which is generally defined by other authors as "*modular structure obtained through the combination of a sequence of typical... modular elements*" [12], which is a fundamental asset to the possibility for creation human scale and the proper organization of the shared spaces.

4. CONCLUSION

This study highlights the growing relevance of modular construction as a key strategy for addressing the dual challenges of affordability and sustainability in residential housing. The analysis of the three international case studies – each applying the types of modules, defined by the author, demonstrates that modular approaches can effectively reduce costs, shorten construction timeframes, and minimize environmental impact, while maintaining flexibility and architectural quality.

The comparative evaluation reveals that modular systems are most successful when tailored to local conditions, supported by clear planning strategies, and integrated early in the design process. The Urban Village Project by Space10 & EFFEKT Architects shows the value of systematized, replicable design; the Puzzles of Complexity Project illustrates rapid urban-scale implementation; and the projects built with the GOMOS system emphasizes

material and energy efficiency through prefabrication. All key features well-known in our local practices but seemingly forgotten long ago and being avoided in design and construction process at any cost. Although the fact that we have long-lasting traditions and know-how in prefabrication processes local architects and mostly contractors are evading the integration of prefabricated elements within the construction process of residential buildings, no matter that materials, such as wood and concrete, are locally produced and could be easily implemented, thus significantly reducing construction time and material transportation costs.

Despite the benefits, limitations such as design constraints, restriction in sizes due to transportation challenges, and regulatory hurdles persist. Future research should address the long-term performance of modular housing, user adaptability over time, and the integration of circular economy principles. In addition, broader quantitative studies on lifecycle cost analysis in modular systems would deepen the understanding of their environmental and economic impact.

Ultimately, this study affirms that modular housing is not a universal solution but a powerful tool – one that, when applied strategically, can contribute meaningfully to more equitable and sustainable living environment.

REFERENCES

[1] Deianova, Elitsa: **The role of underroof intermediate space in small houses for achieving sustainable habitation.** *International Conference 80 Years UACEG*, Sofia, 387-400, 2023.

[2] Nanova Milena: **Mass housing in the digital era.** *X Int. Sci. Conf. ArCivE 2023, May 29, 2021, Varna, VFU "Chernorizets Hrabar"*, Varna, 296-306, Vol. 3 -2021.

[3] Christova Constantina: **Contemporary prefab structures – application in the residential buildings construction process.** *XI Int. Sci. Conf. ArCivE 2023, June 03, 2023, Varna, VFU "Chernorizets Hrabar"*, Varna, 67-77, Vol. 4 -2023.

[4] https://urbannext.net/the-urban-village-project/ *(10.04.2025.)*

[5] https://space10.com/projects/urban-village *(10.04.2025.)*

[6] https://www.archdaily.com/918417/ikea-explores-future-urban-living-for-the-many *(10.04.2025.)*

[7] Deianova, Elitsa: **Classification of in-between spaces.** *Annual of the UACEG Sofia*, Vol. 57 No. 1, 181-197, 2024

[8] https://thearchitecturalmythologems.com/portfolio/puzzles-of-complexity-china/ *(14.04.2025.)*

[9] Ivanov, Valeri, Georgieva, Snezhina: **Open air public spaces within the urban environment.** *Jubilee Journal of the Urban Planning Department at UACEG Sofia,* 32-40, 2024

[10] https://blog.prefabium.com/2020/05/gomos-system-modular-prefab-reinforced.html *(20.04.2025.)*

[11] https://summary.pt/en/updates/gomos-system/ *(30.04.2025.)*

[12] Georgieva, Snezhina: **Spatial structure of contemporary student dorms**. *XI Int. Sci. Conf. ArCivE 2023, June 03, 2023, Varna, VFU "Chernorizets Hrabar"*, Varna, 131-140, Vol. 4 -2023