# DESIGN OF A RE-MODULAR HEXAGONAL CONSTRUCTION UNIT

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**Abstract**
Modular construction is an innovative approach that is gaining popularity in response to the increasing demand for sustainable building solutions. This article introduces a modular hexagonal construction developed at the Faculty of Civil Engineering in Košice. The contribution presents the genesis of its development, based on the analysis of modular construction and the synthesis of knowledge required for the design and development of a specific modular structure concept. The article highlights the potential for various solutions depending on the purpose of the modular construction. In this context, it contributes to the advancement of sustainable architecture in the pursuit of achieving environmentally friendly building solutions.

**Keywords**
Modular construction, re-modular unit, sustainability

# 1 INTRODUCTION

Nowadays, sustainability and environmental friendliness play an increasingly important role. Construction is thus becoming a sector that must adopt new innovative approaches to ensure long-term sustainability. With increasing environmental challenges and concerns about resource conservation, it is essential to change the approach to construction throughout its lifecycle, which includes changing the approach to design, to the construction process, to the sustainable management and maintenance of the building, to its disposal. It is in this context that modular systems become an appropriate model for achieving a more sustainable construction industry.

Modular construction is a process where by a structure is built off-site under controlled conditions, using the same materials, and designing to the same codes and standards as conventionally built structures, but in at least half the time. Thai et al. [1], in the context of modularity in construction, talk about a disruptive technology that offers faster construction, safer production, better quality control and lower environmental impact compared to traditional on-site construction. According to Musa et al. [2], the main benefits that modularity in construction is expected to bring with it are:

- Speed of installation on site.
- Quality improvement of the production process.
- Processing accuracy.
- Re-use after dismantling.

The principle of modularity is now widespread in the creation of modular buildings by joining off-site manufactured cells. One example is 'The Stack' [5], a residential building project created by joining 56 prefabricated cube-shaped modules made off-site. Another example is Vermeer's project [6], which used the modularity principle to create an intelligent housing core that can be used in townhouses, flats, conversion projects or small houses. The core consists of a kitchen, bathroom, toilet, and storage room. Both projects utilise modularity for the rapid construction of the units, but once construction is complete, the modules become part of a static unit with no possibility of future mobility. The idea of mobility-based module design was already addressed in 1991 by Frey et al. [7], who designed a prototype modular unit measuring 2,4 m with a length of 3 to 12 m for the construction of portable military temporary shelters. As far as today's construction industry is concerned, the idea of similar mobility has great potential.

To respond to the growing demand for sustainable construction, a re-modular unit was designed at the TUKE Institute of Civil Engineering according to the concept of modular construction. The article describes the unit's design, the structural solution and visualisations of its different uses, addressing the mobile remodelling project's objectives. The importance of modularity lies in its ability to create multi-use building solutions that can be adapted to different needs and environments. Currently, there are several studies on modular structures for temporary needs. For instance, the 'Click House' module has been designed for temporary emergency housing, comprising two units each measuring 3120 × 3120 mm with a height of 3120 mm, intended for a family of 4 or 5 members [9]. An interesting idea of using the modularity principle is the design of floating modular hexagonal houses that respond to rising water levels [10]. The aim of this proposal is to create a modular unit that is not only suitable for living purposes but can also be adapted for other uses, such as resting,working, etc. [10].

# 2 METHODOLOGY OF THE RE-MODULAR UNIT DESIGN

The project is based on the ambition to create a building unit that is flexible, multifunctional and simultaneously adaptable to different purposes and requirements, with the potential for rapid interior and exterior application. A separate sub-chapter is dedicated to the idea of designing the unit, which also presents possible design solutions for the wall, ceiling, and foundation panels, selected according to the anticipated needs of the unit.

The design concept of the unit‘s form aimed to achieve the most efficient planimetric form, enabling the combination of individual modules into larger multi-module unitsmaximizing the use of the created area. The planimetric design of this unit is based on the interconnection of basic geometric shapes – squares and circles – which led to the creation of hexagonal base (Fig. 1). This composition of shapes allows for an efficient use of available space, which also influences the final effects through its different groupings. The creation of a hexagonal-shaped unit provides a practical and easily compatible base.

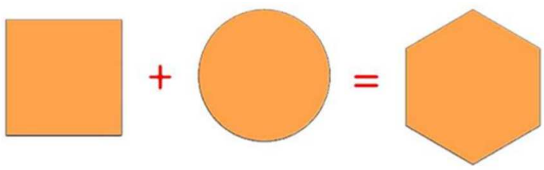

Fig. 1 Design of the shape of the re-modular unit (source: Authors).

The design of the hexagonal shape reflects not only a good basis from a spatial point of view, but also from a social point of view based on chemical mechanisms. The hexagonal plan chosen for the unit is a shape that can evoke feelings of contentment, harmony, rest, energy, stability, etc. when grouped in different modular formations, which increases its emotional resonance (Fig. 2). Design, therefore, serves not only as a technical solution but also as a tool for evoking specific feelings and moods in users. Numerous studies have been devoted to this type of coupling, defining this relationship as molecular architecture [11], [12], [16].

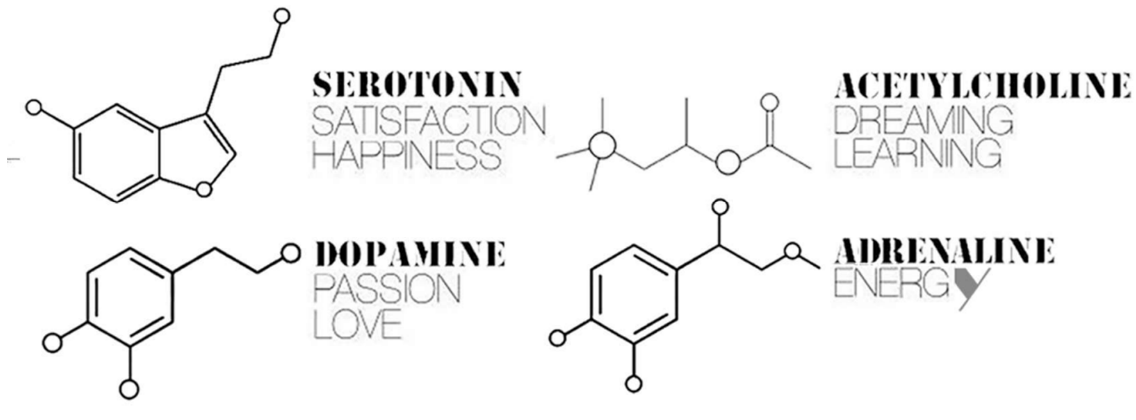


Fig. 2 Design mechanism of the reconfigurable chemical unit (source: Authors).

## The purpose of the use of the re-modular unit

The proposed re-modular unit can be expanded or reduced by connecting individual modules according to current requirements. This concept enables the creation of different module configurations to achieve optimal solutions. An example of a specific use of the re-modular unit is the creation of a relaxing refreshment area. This relaxation zone can be used both indoors and outdoors and can beimplemented in different sizes.

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Fig. 3 The design of a chill zone from one to three modules (source: Authors).

Another application is the creation of a bus stop (Fig. 4) with the potential to connect to the digital environment using so-called SMART elements. This includes incorporating mini-computer systems and digital monitors to present information regarding the movement of public transport vehicles and their access to the respective stop [3], as well as implementing remote monitoring to optimise energy consumption by estimating stop occupancy [4].

Fig. 4 A SMART bus stop proposal (source: Authors).

Using full-wall panels, a social or hygienic background can be created. The design of sanitary facilities is also a subject of typological solutions (Fig. 5). The concept of using remodelled units for enclosed facilities involves the use of ceiling panels to accommodate wiring requirements such as ventilation, aeration, lighting, alongside the use of full-wall panels. Examples of such use may include a bathroom with a shower or two separate toilets with washbasins.

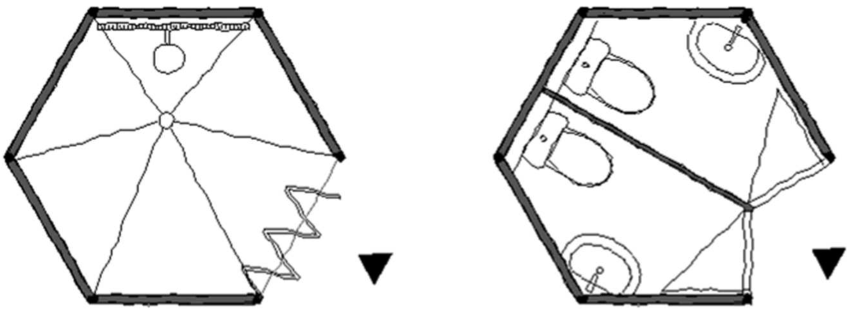

Fig.5 A possible typological solution for the sanitary installations of the modular unit.

## Structural-material solution of the unit

In terms of structural and material solutions modular systems offer a wide range of options. Therefore, when designing a re-modular structure, it was necessary to consider the most effective panel design and material options from the outset, as highlighted in the analysis by Lacey et al. [8]. This analysis reviews of possible design solutions for volumetric modular systems, the ways in which multiple modules can be joined together, types of joints within a single module, material design options and transport and handling options for the modules [8].

A prerequisite and limitation for the size of the hexagonal unit was the maintenance of mobility in its volumetric state, or transportation the unit by truck. The plan dimension of the proposed unit is a hexagon with a side length of 1250 mm and a diameter of 2500 mm. The proposed height of the unit is between 2640 mm and 3000 mm, depending on the purpose of the unit. Structurally, the modelled hexagonal unit consists of a complex system of several components, including a frame designed with a fastening system to allow for the integration and modification of different wall panels, along with a set of panels with different material solutions (Fig.6).

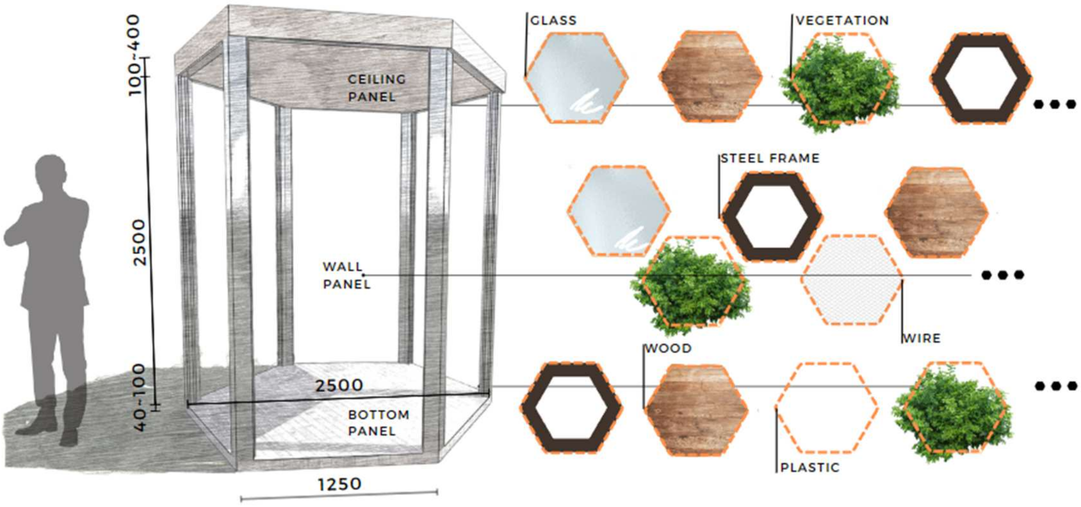


Fig. 6 Construction-material solution of the re-modular unit (source: Authors).

The design of the remodelled hexagonal unit includes wall panels with defined dimensions of 1075 × 2500 mm. An important aspect of the design is the adaptability of the wall panels to the specific requirements of the unit. In terms of materials, wall panels can be divided into solid panels (e.g., plastic/wood-based panels), transparent wall panels (e.g., glass, gabion mesh, etc.) or vegetated wall panels (green wall, green façade).

**The bottom panel** is designed with a frame structure rigidly connected to the hexagonal panel. In cases of exterior application, the bottom frame can also function without a floor panel.

The design of the **ceiling panel** offers flexibility and variability with respect to specific requirements and applications. The thickness of the ceiling panel is designed within a range of 100 to 400 mm, with the specific value depending on the features and functions the ceiling panel is intended to support. For ceiling panels with greater thickness, active use is considered, such as a green roof. This approach allows vegetation to be integrated on the roof, thus improving insulation, environmental sustainability, and visual comfort. The ceiling panel can also serve as a platform for other technological solutions (e.g., air conditioning, cabling or artificial lighting). Due to its greater thickness, technological elements can be integrated into the panel without compromising its footprint.

# 3 RESULTS

For a sustainable application, it is essential to focus also on other design options. Further research and development should include the resolution of technical issues such as structural reinforcement, increased insulation and installation efficiency that could affect the durability and efficiency of these units. In addition to technical aspects, it is important to consider aesthetics and user comfort. The proposed unit should contribute positively to the environment‘s aesthetics and enhance user comfort.

By combining different types of panels and adjusting the number of modules, the hexagonal remodelling unit offers the possibility of being specifically adapted to different environments, functions, and requirements, thus ensuring exceptional variability and versatility in the proposed modular construction solution.

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# 4 DISCUSSION

Modular solutions, like the design of this re-modular unit, have the potential to significantly contribute to sustainability in the construction industry. In-depth design considerations for the re-modular unit should also focus on its entire life cycle, including possibilities for recycling and adaptation to different environmental solutions, such as the use of photovoltaic panels. Sustainability is a topic addressed in several publications [13], [14], [15], which consider the module disposal to maintain sustainability principles, which should also be considered in the design of a hexagonal re-modular structure.

The creation of a re-modular unit project is an option for the application of sustainable construction principles due to its adaptability to different needs and challenges. The modular building unit is a concept that demonstrates its ability to provide multi-purpose solutions, such as a refreshment area, bus stop or social facilities.

# 4 CONCLUSIONS

The article presents the design of a hexagonal remodelled unit with lateral dimensions. The article focuses on developing the unit's shape design, which is based on an effective combination of two basic geometric shapes: the cube and the circle.

The paper discusses design solutions for the types of foundation panels used in the proposed unit, namely the ceiling, bottom, and wall panels. The design of the ceiling and bottom panels covers material and structural designs for the hexagonal-shaped panels. The wall panel, with defined dimensions of 1075 × 2500 mm, is presented in the paper from the perspective of material and design, divided into 4 basic groups of possible solutions: solid panel, transparent panel, vegetated panel, and other types of panels.

The main idea behind the re-modular design is the possibility of combining individual modules into larger units, offering versatility for different purposes. The paper presents several possible applications of the unit, namely the design of a chill zone, a bus stop, a promotional banner, and the creation of a social area. The proposal also shows the possibilities of creating a unit ranging from one to three modules, using the example of a chill zone design.

Further research steps could involve creating an initial 1:1 scale prototype re-modelling unitto establish a more precise methodology for the unit production. A prerequisite for near-term research is to solve structural design optimization, construction materials, or even incorporate other concepts (such as smart or renewable elements) for sustainable unit use.

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