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STUDY ON DESIGNING A MODULAR HOUSE

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Abstract: *The paper presents a study on creating a modular construction based on a simple shaped module. The solution resulted following a large research on existing designs, the idea of modular house having not a long history, but a rich one. The existing solutions helped in formulating a list of requirements which included most of their advantages. The basic module is a square shaped panel that can be easily personalized according to necessities: wall with door or/and windows, ceiling, floor. The study includes solutions regarding electric wiring and plumbing design for bathrooms or kitchens. The design included solutions for creating different configurations and volumes for the final building involving the designing of connecting modules.*

Key words: *modular house, design, virtual modelling.*

1. Introduction

Modular constructions provide numerous advantages, this being the reason why this solution is widely used in modern design. A modular construction is simple, because the variety of components is smaller. It also permits designing different constructive structures, depending on the customer requirements, starting from the same basic components, the modules. In the case of a building, usually the module is a volume that can be extended according to the space functionality and needs. A modular building, unlike a structure *built on-site*, like a usual brick house, is *assembled on-site*. This solution comes with advantages, both for the customer and contractor, not mentioning the environmental aspects.

The main objective of this paper is to present an original solution for modular building used for home as the main purpose. The design should be simple to produce and permitting the on-site assembling. One important objective of the project is to design a versatile module solution which should permit obtaining buildings with different dimensions/volume.

2. Modular Buildings

A modular building is a type of building that results by assembling smaller elements, called modules, often detachable and reusable, that are connected one to another in such a way to obtain a fully functional structure with many pre-established purposes. It often

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consists in a frame or support structure to which other constituting elements are attached, either permanently or temporarily. It will not be confused with prefabricated constructions, in which fully designated spaces are fabricated in a factory, already assembled before shipping, and then sold as finite, fully functional, living or working spaces. Their functionality could be either as temporary structures (hospitals, military camps, schools, event buildings, disaster relief housings) or permanent structures such as offices or fully functional homes.

The constituting elements of the modular building are the modules. The solution optimisation involves minimising the number of different modules. A smaller number of modules reduce the design effort, and the production costs. This also facilitates the assembling/disassembling operations, the modules transportation and their replacement in case of damages.

The modules should be designed and fabricated with the intent of having a unitary design and respecting a functional language; they are envisioned not only as a unit/module, but as an ensemble, a complete functional building. If the units wouldn't be thought beforehand to be the constituting elements of a whole then the design of modular elements for building purposes would be pointless. [1]

2.1. Exploring existing modular buildings

The history of modular buildings is not very long, but quite rich in solutions, proving the designer's creativity, determined by the local materials as resources and the possibilities offered by technology, as in time evolution.

Maybe the most well-known module in our days is the standardised metallic shipping container. It represents a very good solution as an individual construction, or by juxtaposing several units (Figure 1). Being built with normalised dimensions, they can be easily transported or assembled. With little effort they can accommodate homes, hotels, hospitals, schools etc.

Fig. 1. *Building made of containers (left)[2] and Brunel's modular hospital (right)[3]*

Modular and prefabricated constructions were intensively used during the wars. Prefabricated constructions were very useful in the battle field because they could be built fast and easy, and they were not very expensive. The modular infirmaries and mess halls represented a good solution for the troops fighting far from their countries, like in the

Crimean War (1853-1856), where prefab hospitals were firstly used. The Renkioi hospital (Figure 1) designed by the well-known British architect Isambard Brunel and opened in 1856, is considered one of the first modular prefabricated construction. The modular hospitals could be extended in order to accommodate from 500 to more than 1500 patients. They were designed to house every needed comfort possible while also remaining a very cheap and easily transportable solution. [3]

Most of the times, modular buildings have been the solution to economical scarcity, given the fact that the materials and techniques involved in fabricating the construction elements were (and still are) many times cheaper than acquiring materials for the on-site constructions. The cost is not reflected only in the manufacturing stage, but rather on the maintenance of the structure and the option one has when making use of it or when it gets out-of-use. Requiring less and recyclable materials and simple technologies, the environmental impact of these buildings will be smaller than in the case of traditional ones. Modern times came with another requirement regarding houses: people move from one place to another and the possibility to move out "with the house", instead of "from the house", might be an extra bonus because modular houses can easily be disassembled and reassembled, not requiring much of foundation.

3. Developing the New Concept

Exploring the existing solutions lead to identifying their advantages and disadvantages. This helped our project in formulating some of the requirements for the new solution.

A fundamental requirement is that the new design should be simple. This means creating a basic module, simple in shape, which can be easily assembled to obtain a complex, functional structure. The solution should be versatile, permitting assemblies with different volumes according to the needs. Also, the versatility should be useful when designing spaces with different functionality, like a bathroom or a kitchen. A working space differs from a medical facility or a home. This extra versatility can be fulfilled by creating the basic module not as a box, but as the side of a cubic box. This was the fundamental idea on which our design started from. This solution was inspired by the Japanese rectangular module, called "tatami" used in their traditional buildings [6].

Besides simplicity, other qualities are necessary for the design solution. Modular constructions should respond to the "green building" requirements that involve reducing the environmental impact both when building and using it, but also as waste, when the modules are out-of-use. Also, the materials and technologies used to build the modules should ensure the necessary insulation level for reducing the building energy inputs [7].

The basic module is represented by a square panel that measures 2800 x 2800mm in exterior and 2400 x 2400 in interior; its width is 200mm. Between the interior and the exterior panels are the four contact plates weld together forming the frame, which is reclined at 45^0. The square panel can be personalized according to the necessities with minimum of design and construction effort: module with window(s), module with door, modules for ceiling and floor and module connector. These modules can be assembled according to the building intention, more precisely, according to the space purpose: bathroom, living room, bedroom, etc. (Figure 3) [8].

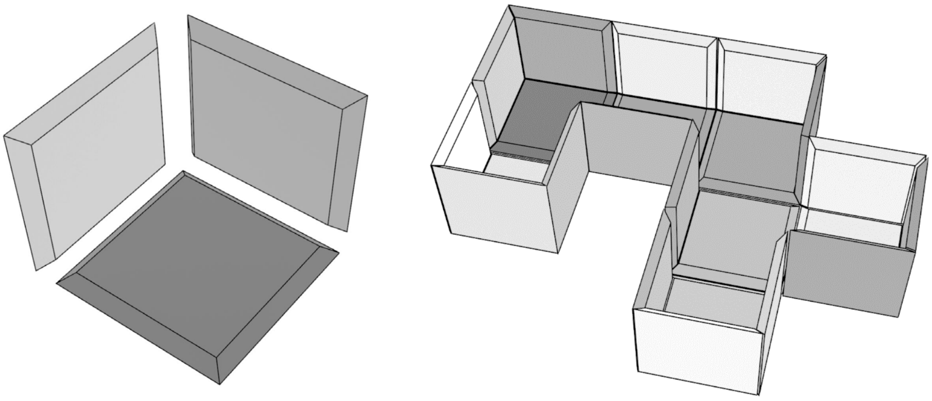


Fig. 3. *The modular panels assembling (left) and modular "cubes" juxtaposed (right)*

Assembling the functional units/modules should result into a complex construction like the one presented in Figure 3 (right). The versatility of design allows the house surface variations by juxtaposition of several square modules obtaining the desired area and configuration. Then the walls and the roof modules can be assembled. The roof weight is supported by the internal walls (also modules) or by columns. A column is obtained by putting together four side connectors, part of the frame connector (Figure 7).

For connecting the modules, an original system is used, which design is not part of this paper, being described in detail in [9]. Most of the existing solutions for fixing the modules are universal ones, like bolts and nuts; the research on locking systems did not reveal dedicated solutions.

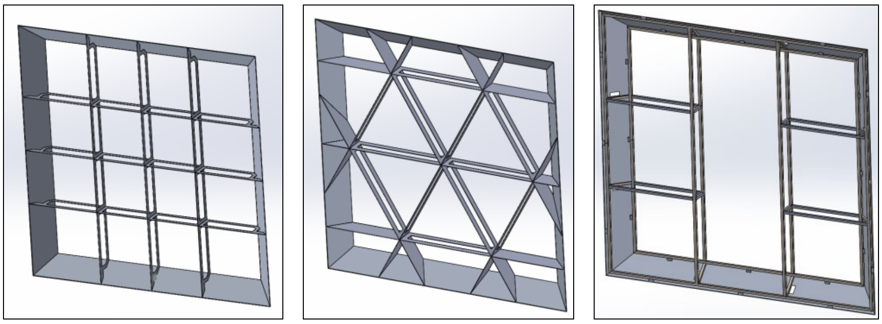
4. Construction Design

Following the conceptual solution, the components design belonging to the modular house assembly will be performed following the concepts, sketches, technical requirements, needs and specifications determined for this particular conceptual solution. The component design phase started with the determination of the main elements to be designed as a preliminary project part.

In order of complexity, the components that will be designed in a first phase will be: plain vertical wall module, floor module, roof module, door insertion module, window insertion module, inter-connection modules (connectors for adjacent modules) and other structural elements.

The vertical walls modules are the main, least complex elements in the modular house assembly. They serve aesthetic and functional/structural purpose as they enclose the living spaces created inside the modular building structure and also ensuring the stability of the structure itself. Their inner structure design will be presented as follows.

The first option (Figure 4.a) have a simple square grid internal frame, made of the same material as the external contact plates and same thickness. They are designed as a frame to be weld directly onto the contact plates. The second option (Figure 4.b) is a type of triangular honeycomb structure. The idea behind it is exploiting the triangular shape properties as a structural element to overtake loads and redirect them along the frame; it should be weld onto the metal plate structure. The last design (Figure 4.c) takes a different approach since it employs the use of a separate steel frame made of 25 x 25 x 2 mm steel profile beams cut and weld together in such a way to function as a structural support frame and also give anchor point for internal and external elements. This kind of structure is assembled non-destructively onto the contact plates, with bolt and nut fixtures [8].



a. b. c.

Fig. 4. *Different configurations for the internal frame*

After a careful analysis and forecast on future design iterations, the last variant structure was chosen, for the following reasons. The technology and skills needed for the assembly such a structure are less compared to the technical restrictions that may appear for the other internal frame solutions, especially a triangular honeycomb one that may create several alignment and assembly issues. Then, less material is required, as it involves easy to purchase, standardized steel profiles which can be easily cut and weld together. It also permits placing the openings for window(s) and/or door.

The design of the floor and roof modules follows the same principles as the design of the vertical wall module. The intention behind the unitary design principles is to conceive a continuous, easy traceable and to manufacture solution that would be common for all the modules of the assembly. This facilitates the design process of new modules and additional components needed, reducing the errors and using standard procedures, as well as reducing the manufacturing cost and tooling required. Some simulations and calculus were performed regarding the loads during use determined, for example by furniture and people for the floor and snow for the roof.

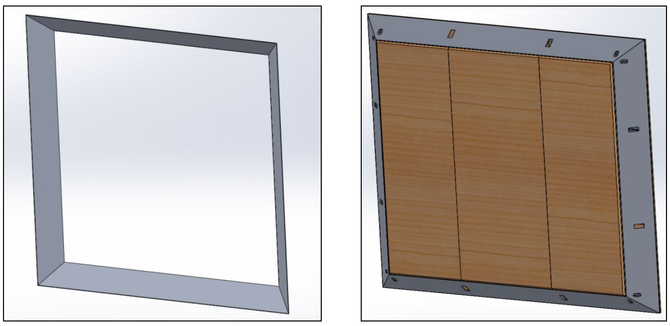
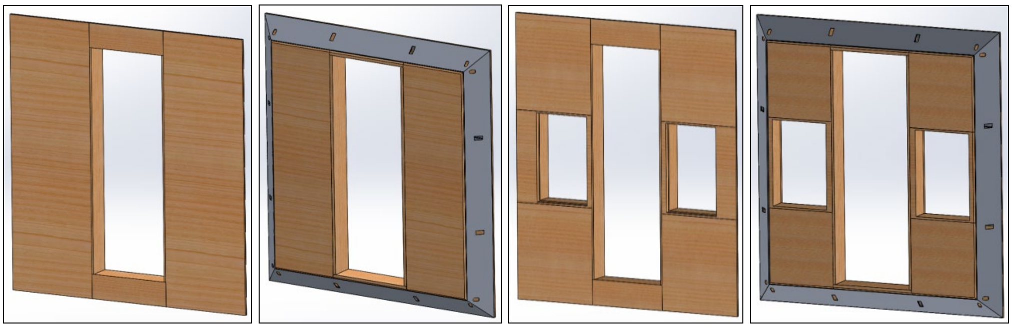


Fig. 5. *Module frame (left) and internal wall cover (right)*

In Figure 5 is presented the module frame without the grid, on which is assembled, on both sides, to the interior, and to the exterior, a cover wooden wall. In the space resulted between the cover walls is the chosen internal frame (Figure 4), but also the electrical grid and the plumbing, according to the needs.

The door module has a central vertical opening into which a door can be installed (Figure 6.a). The window module has a central opening and two side openings, into which windows can be installed on preference. The geometrical solutions adopted ensure the correct working of the modules, and their interlocking. In Figure 6.b can be seen the door module assembly with cover panels. The door slot is left free and can be used to fit a large number of doors, depending on preference and design choices. Figure 6.c and 6.d show the window module assembly with cover panels applied. The middle slot has the same dimensions as the door slot presented in Figure 6.a, the dimensions of the side window slots being 620 x 850 mm.



b. b. c. d.

Fig. 6. *Door module with frame (a,b) and window module with frame (c,d)*

It is notable that the door module can be used as a window module, thanks to the symmetric construction, which permits the module rotation and allows the user to choose the form and position of each element. This facility is permitted by the interlocking system which provides the modules assembling identical on each side of the panel. For connecting the adjacent modules that do not meet at a 90^0 angle, but at 180^0, a connecting solution is required in order to ensure interlocking between adjacent modules (Figure 7). When necessary, the connector can be delivered un-weld, as single side of the square connector unit.

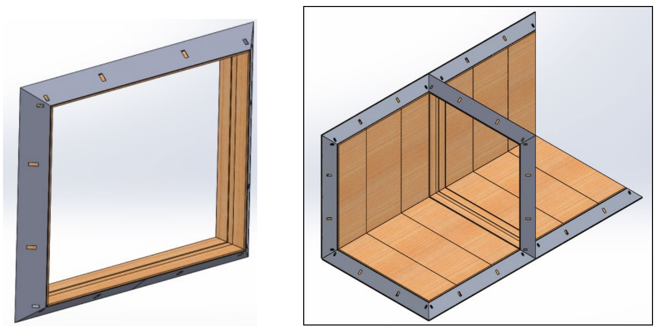


Fig. 7. *The intermediary connector unit (shown as a frame) and how it is used.*

Considering the destination of the modules as components for the construction of a living space for humans, different needs can arise. The basic requirements that a house should fulfil in order to guarantee good living conditions are electricity, a basic level of plumbing, insulation (for a rational temperature) and separation of the spaces.

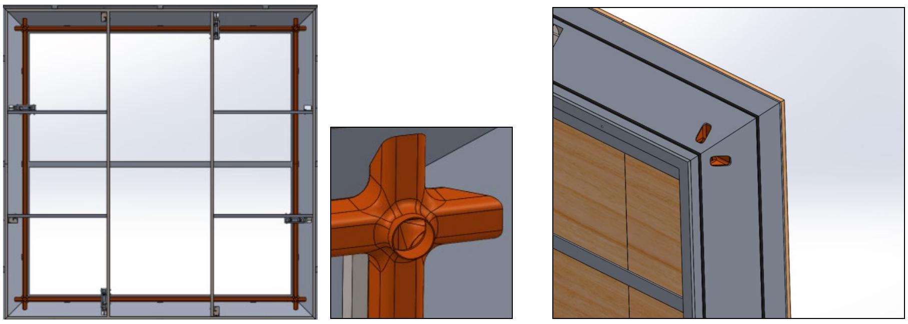


Fig. 8. *Electrical network tubes, access point and inter-modular sealing gaskets*

In order to respond to these requirements, the design process continued with objectives regarding the above mentioned facilities. The electrical grid was inserted into the module and a special connector was designed making possible the panels grid inter-connection (Figure 8). Next to the module corner, electric plugs are provided giving access to power for the user; for the roof module a mask can be removed if a pendant fitting is mounted. Following the same principle, the floor module may include the heating system.

Fig. 9. *Interior scene: bathroom, kitchen, bedroom and Exterior scene*

Along the external profile of the contact plates of each module, two sealing gasket strips have been placed (Figure 8) in order to ensure the proper sealing between each module, such as to ensure no water or external agents reach the inside of the living space or the inside of the module, where functional and critical components are situated [10]. Additionally to the sealing gaskets, between the external cover panels and the external panel support, oriented towards the exterior of the modules, has been placed a water proof tarp/foil that should completely seal the interior of each module from exterior agents such as rain water, melting snow or dust, working also as a thermal insulation layer. This ensures protection for the interior components of each module as well as for the interior living spaces between the modules.

For the interior, the design comes with a general cover panel made of wood. This provides a sensation of warmth completing the cosy friendly aspect of the spaces (Figure 9). The exterior virtual model shows one of the multiple possible configurations.

5. Conclusions

The modular building still represents a good solution because is simple to produce, is cheap and easy to build and maintain. The solution presented in this paper has all these advantages, a square panel being the basic module. The versatility of this module gives contractors large possibilities in what concerns the destination and the dimensions of the building. The design includes facilities like electrical grid, pipes for water and insulating systems permitting the building to be placed in almost any climatic conditions.

References

1. A Brief History of Modular Construction, 2009. https://deluxemodular.com/learning-center/. Accessed 06.2020
2. Abrams, A., Buchheit, J., et al.: *System for modular building construction*. https://patents.google.com/patent/ WO2008027234A2. Accessed 06.2020.
3. Barbu, A.F., Barsan, L., Lorincz, S.A.: *Graphic Modelling and Design of a Locking System Used for Modular Buildings. Journal of Industrial Design and Engineering Graphics*, Vol. 17 No. 1 (2022): Issue 1, pp.19-24.
4. Barbu, A.F.: *Modular House*. Diploma Project. University Transilvania of Brasov, 2020
5. https://adria-home.com/modular-homes. Accessed 09.2022
6. https://modsteel.com/en/container-homes-containers-house/ Accessed 09.2022
7. Morel, J.C., Mesbach, M.A., et al.: *Building Houses with Local Materials: Means to Drastically Reduce the Environmental Impact of Construction.* 2001. https://www.researchgate.net/publication/223275169. Accessed 06.2020
8. Quarante, D.: *Elements de Design Industriel. Economica 3-e Edition,* 2001
9. Stagon, S.P., Hanchen Huang.: *Airtight metallic sealing at room temperature under small mechanical pressure,* 2013. https://www.nature.com/articles/srep03066. Accessed 06.2020
10. The Brunel Museum: *Pioneer of Prefabrication-Brunel's Hospital at Renkioi*. https:// www. thebrunelmuseum.com/hospitalatrenkioi/ Accessed 06.2020.