

THESIS BOOKLET

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**EXAMINATION AND DESIGN OF INNOVATIVE,
MODULAR TIMBER BUILDING SYSTEMS
BASED ON GEOMETRIC REGULARITIES**

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Abstract

The aim of the dissertation is to develop an innovative modular building system based on geometrical regularities as results of architectural history and discrete mathematical analysis, which provides an answer to the challenges associated with urbanization.

The paper examines the relationship between architectural traditions, social issues, and sustainable design. The literature analysis examines two traditional wood-based urban building types, then it analyses the new features in the urban environment in the 20th and 21st century and the designers' responses to them. During the research, the focus is on wood-based modular systems, sustainable design, gamification, long life cycles, and inclusive and adaptive design methods.

The central elements of the dissertation are the explanation of the sustainable city model, the identification of problematic areas, the planning process, and the modelling of real spatial situations. When designing the building system, he considers the principles of sustainability, urban space, and improvement in the quality of urban life. In the appendix, four case studies are described. Each supports in specifying the building system and shows a direction in decision-making situations.

The following specific results were achieved during the thesis: spatial logic games based on geometric principles serve as models for the design of modular housing units. The combined use of innovative CLT and SIP technologies enables the efficient planning and construction of wood-based modular house systems. Gamification can be successfully used in the process of participatory design, involving end users in the design process. The model of urban stratification is constantly changing with the involvement of residents and determines the character of the system. The short life cycle of flexible modular housing systems is beneficial for adaptation to dynamic urban living space. The architectural form of urban mimicry and concealment results in a long-lasting, dynamically changing building system.

The modular building system developed during the thesis can be used in many different areas. It is especially recommended in the field of urban rehabilitation due to its flexible nature. In addition, the innovative system can also be practical in the fields of architectural design, urban design, and design education as it may contribute to sustainable urban development.

Keywords: adaptive design, design thinking, environmentally conscious design, hiding architectural form, housing problems, inclusive design, lightweight house system, long life cycle, modular architectural system, polycubes, process design, sustainable design, urbanisation, urban stratification model, wood-based modular systems

The topic of the doctoral thesis

Introduction

As a result of the expansion of human civilization, significant changes have occurred in our immediate environment. The impact of the expansion of human civilization is not only visible in the processes of urbanization, but they are also responsible for the environmental and social changes occurring in individual regions. According to the UN, in 2012 about half of the world's population already lives in cities and urban areas, whilst countless solutions are still waiting to be discovered to offset the harmful effects of urbanization. One of the central problems of today's urban planning currents is dreaming up a home that meets the challenges of the urban environment and a building system that provides a home.

The built environment

The impact of urbanization can be traced in the everyday life of city dwellers, both structurally and qualitatively: due to the reduction of time spent at home, the creeping land prices and the changing social structure, small-sized apartments come to the fore, which must satisfy the increased needs. Among some of the well-known examples for relatively small-scale, modular, wooden townhouses examined, three traditional solutions are presented:

- The traditional wooden Japanese townhouse (kyōmachiya) is an excellent example of early modular wooden houses based on a columnar frame structure. A big advantage is that the wooden column system spanning the interior spaces replaces the load-bearing role of the walls, so they become thinner and can even become mobile. With the wall panels formed in this way, the space can be divided easily and quickly, which, in addition to its speed, enables a high degree of mobility and variability. Nowadays, Japan answers the urban life questions of our time not so much with its wooden houses, but rather with its town houses with a small floor area, which rarely exceed 20m².
- The second highlighted type, the "shotgun house", is a well-known North American example of a wooden structure (modular, if you like) urban residential house that can be quickly assembled anywhere, has a uniform size, and has a varied appearance. After the Civil War, its basic type became popular

with usually 3.5m width and 11m length, consisting of three rooms, placed on piles. This type is spread mainly in the southern areas of the USA.

- To contextualize these modern challenges within a broader historical framework, we examine the evolution of apartment buildings starting in the early 20th century. This historical overview explores both international and domestic architectural innovations that have responded to the pressing urban issues of their times. The presentation of contemporary efforts is also marked by the four directions related to the research topic: sustainability, reinterpretation of the urban space, socially committed architecture and social shaping character.

Examination of wood-based modular systems

The research primarily focuses on exploring and refining the unit module by addressing specific technological challenges such as material selection and manufacturing processes, structural issues including load-bearing capacity and durability, and design aspects like aesthetics and functionality. While primarily focused on architectural design, our project also intersects with principles from classical design and incorporates insights from social sciences and engineering. In addition, we also meet other interdisciplinary fields of science, mainly from the fields of social sciences and engineering.

The investigations begin with the analysis of the variation possibilities of the elements obtained by sorting and joining the plane and then spatial solutions suitable for filling the space. The starting point of the design is a line element and the simple body assigned to the line element - in our case, a column, or a cube. Although the system is built by sorting and varying similar elements, it has a high degree of freedom and flexibility due to its geometric nature.

Examining the compact sized dwellings of metropolises, one possible conclusion may be that the standard size of the shipping container (2.44x2.58x6.06m) reflects the size of the "minimum living unit" of the urban environment. This modular unit offers countless variation possibilities for space organization, thanks to its self-supporting structure it can be easily transported by ship, train, tractor, etc.

Through clarifying requirements and through geometric modelling, the original objective was changed: the height of the 2.44x1.60x6.06m column

proved to be oppressive and its width narrow, while its length of 6.06m was excessive for the creation of basic functions (e.g.: water block, kitchen, bedroom). At the same time, the column shape is far less variable than the spatial element solution built from cubes. Thus, the size of the basic unit was changed to 3.00x3.00x3.00m gross (along with this, the mesh forming the framework of the system was also modified). The matrix formed by the arrangement of the cube spaces and the variation possibilities of the space elements obtained in this way, assigned to the "tetragonal" (square) grid type, is already suitable for solving many different urban problems.

Putting into context

Finally, the research results and the lessons learned from the case studies in the appendix show the compatibility, flexibility, and validity of the selected system in a real context.

Case studies

Socialist Family House Construction: This case study delineates the evolution of single-family housing in socialist contexts, focusing on the prevalent 'Kádár-cube' and the later large homes of the 1980's and 1990's. It assesses both the dominant designs and the lightweight holiday home alternatives, examining their construction materials, functional limitations, and architectural characteristics. The self-supporting small-panel solution named "Varia" weekend house was covered by aluminium corrugated sheet, while the small floor area and the inestimable building physical characteristics is only suitable for a limited period and for limited purposes. When assessing the condition of an "Egervár" type holiday home with a floor area of 15m², which was built almost 40 years ago and has undergone several renovations since then, several typical phenomena appeared, such as: unprofessional renovation, inadequate wood protection, subsequent (partial) insulation, biotic and abiotic damage.

Housing Problems Study: This study provides an analysis of the housing conditions of disadvantaged groups in Hungary, placed within an international framework. It avoids discussion of religious and ethnic affiliations or homelessness. By drawing on examples from 20th-century and contemporary

architecture, it addresses the intersections of economics, sustainability, functionality, sociology, and psychology, and proposes design-oriented solutions to these complex social issues.

Urban Panel Rehabilitation: This case study evaluates a specific rehabilitation program in the Rákoskeresztúr city center, focusing on the challenges and opportunities of revitalizing housing estates built with large-panel technology. It emphasizes that renovation and enhancement of living conditions are generally preferable to demolition.

Housing Estate Perception Survey: This involves an analysis based on a 15-question survey about perceptions of prefabricated/large-panel housing estates. It investigates the social and urban implications of these housing solutions and explores potential strategies for urban district reconstruction.

Research methods

The research employs an interdisciplinary approach, drawing from fields such as sociology, climatology, urbanism, and more, underlining the necessity of a holistic perspective. Data gathering is conducted through qualitative methods, like detailed questionnaires and interviews, complemented by secondary data analysis for broader statistical insights. The methodologies include both deductive and inductive reasoning, supported by grounded theory, field research, and content analysis. Technology, particularly in modelling and 3D design, plays a crucial role in simulating and refining modular housing designs.

The objective of the doctoral thesis

The thesis aims to develop an innovative modular housing system informed by geometrical regularities and historical architectural insights. This system seeks to address urban challenges such as overpopulation and rapid demographic shifts, with a focus on sustainability and environmental consciousness.

Summary

The literature analysis reveals that by the turn of the 21st century, the traditional role of the architect has transformed. Today, architects incorporate local, cultural, and social contexts, acting as social catalysts and educators within their design work. This new approach aims not just to improve living conditions broadly but to effect positive, tangible change in spatially defined situations through careful, conscious, and responsible planning, independent of political constraints. The approach can be divided into two partially overlapping areas: one focuses on local and social contexts, while the other maintains a sensitivity to global issues. An exemplary case of local context exploration involves integrating local materials, technologies, and methods.

The research also identified that regulations concerning building materials and technologies increasingly prioritize modern findings from human-centered sciences (such as human ecology, sociology, and psychology) and health protection. It has been noted that current life cycle analysis systems in architecture are providing increasingly accurate data on the environmental and health impacts of construction materials. Therefore, priority must be given to selecting health-safe materials (like building materials, furniture, home textiles, adhesives, coverings, and mechanical units) in line with the model of a sustainable city. People should be guaranteed the fundamental right to health safety in their homes and immediate environments, while architecture must take on a community-shaping role, raise new questions, and develop innovative solutions, adhering to high ethical standards, to significantly impact future society shaping.

The modular space system discussed in the thesis offers flexibility, adaptability, and a discrete character, making it suitable for addressing specific issues. By continuously rethinking spatial organizing elements and reinterpreting formal and functional nodes, the system helps transform buildings into vibrant, active components of the urban fabric, creating dynamic visual and social spaces, thereby influencing the life of communities and the built environment.

The system also facilitates the integration of diverse social strata within districts, residential areas, or blocks, potentially counteracting ghettoization, catalyzing urban rehabilitation programs, and fostering positive social processes. Moreover, the flexible modular systems provide a new type of

social platform, with units that can adapt in size and material to cover various social functions, thus fostering social interaction and local community building.

In addition to the standard "polycubes" system, the thesis supports the distortion of basic units (such as rectangular blocks, trapezoidal blocks, rhombohedra, etc.) and the use of other geometric systems.

By strategically leveraging this innovative system, the dissertation presents forward-looking implications for architects, urban planners, and educational centers.

Theses

1. The spatial logic games based on the geometric principle serve as a model for the design of modular housing units and house systems.

The spatial structure based on this principle is infinitely expandable within the system's boundaries. The configuration, which starts from a line element and a body (e.g., column, cube) assigned to it, allows for a high degree of freedom and flexibility by sorting and varying these elements. The system can perform the main residential functions and accommodate new functions depending on the number of elements, their size, and groupings.

Source:

- *Katona, V., Palócz, K. (2019) Applicability of Geometrical Games in Designing Modular Housing Solutions. In: Symmetry: Culture and Science, Symmetry in Architecture 2, Vol. 30. pp: 025-041., Budapest: Symmetry Kiadó. ISSN 0865-4824*
- *Palócz, K. (2018) Geometriai elven alapuló téri logikai játékok alkalmazhatósága moduláris lakóegységek, házrendszerek tervezésekor. In: Demográfiai változások, változó társadalmi kihívások, SOE, Sopron: SOE Kiadó. ISBN 978-963334-0904*
- *D.5.2. Céloknek megfelelő moduláris rendszer kontextusba helyezése (pp. 110-113.)*

2. *Combined application of wood-based innovative technologies provides a basis for the design of house systems based on the geometric principle and for its execution.*

The combined application of innovative wood-based technologies, such as Cross Laminated Timber (CLT) and Structural Insulated Panels (SIP), provides a strong foundation for designing and executing house systems based on geometric principles. This integration allows architects and design engineers to optimize each part of the building for specific tasks, effectively leveraging the benefits of different technologies for more flexible and efficient planning and construction.

Source:

- *Palócz, K. (2017) Lakhatási problémák és alternatív megoldásjavaslatok tervezői szemszögből. In: Geopolitikai Stratégiák Közép-Európában Nemzetközi Tudományos Konferencia NYME, Sopron: NYME Kiadó. ISBN 978-963359-0911D7. Faalapú moduláris házrendszer alkalmazhatósága (pp. 108-114.)*
- *Palócz, K. (2018) Geometrai elven alapuló téri logikai játékok alkalmazhatósága moduláris lakóegységek, házrendszerek tervezésekor. In: Demográfiai változások, változó társadalmi kihívások, SOE, Sopron: SOE Kiadó. ISBN 978-963334-0904*
- *D.2.5.2. A fa, mint építőanyag reneszánsza (pp. 40-46.)*
- *F4. Esettanulmány IV: Kérdőív (pp. 153-158.)*

3. *Gamification can be successfully implemented in participatory (inclusive) planning process.*

This innovative approach, using game elements and democratic software, engages end-users in the planning process, thereby fostering conditions that are reflective of and responsive to real needs. This method is suitable for modelling real planning scenarios and decision-making processes in architectural design.

Source:

- Palócz, K. (2019) *A gamifikáció alkalmazása a tömeges lakástervezési folyamatban*. In: *Modern gazdaság, okos fejlődés, SOE, Sopron: SOE Kiadó. ISBN 978-963334-3470*
- D.2.5.4. *A városi tér újraértelmezése* (pp. 49-63.)
- D.4. *A gamifikáció alkalmazhatósága* (pp. 95-104.)
- D.5. *Faalapú innovatív moduláris házrendszer alkalmazhatósága* (pp. 105-114.)

4. *In the model of urban stratification, the character of the building system, consciously planned with the involvement of the residents, is constantly changing, reflecting the emerging needs.*

This process, based on collage-building nature and self-initiated developments by residents, allows the community to continuously rearrange spatial elements and reinterpret functional and formal nodes, creating dynamic visual power fields that shape the environment and community life. (Adaptive design)

Source:

- Palócz, K. (2017) *Lakhatási problémák és alternatív megoldásjavaslatok tervezői szemszögből*. In: *Geopolitikai Stratégiák Közép-Európában Nemzetközi Tudományos Konferencia NYME, Sopron: NYME Kiadó. ISBN 978-963359-0911D7. Faalapú moduláris házrendszer alkalmazhatósága* (pp. 108-114.)
- D.2.5.4. *A városi tér újraértelmezése* (pp. 49-63.)
- F4. *Esettanulmány IV: Kérdőív* (pp. 153-158.)

5. *The short life cycle of the residential units of the flexible modular housing systems is beneficial in terms of adaptation to the dynamic urban living space.*

Rather than planning a static building system, this approach focuses on planning the transformation process of the building system, which continuously reorganizes and reinterprets itself in response to constant changes. (Process design, Adaptive design)

- *Palócz, K. (2017) Lakhatási problémák és alternatív megoldásjavaslatok tervezői szemszögből. In: Geopolitikai Stratégiák Közép-Európában Nemzetközi Tudományos Konferencia NYME, Sopron: NYME Kiadó. ISBN 978-963359-0911D7. Faalapú moduláris házrendszer alkalmazhatósága (pp. 108-114.)*
- *Palócz, K. (2018) Geometriai elven alapuló téri logikai játékok alkalmazhatósága moduláris lakóegységek, házrendszerek tervezésekor. In: Demográfiai változások, változó társadalmi kihívások, SOE, Sopron: SOE Kiadó. ISBN 978-963334-0904*
- *D.2.5.4. A városi tér újraértelmezése (pp. 49-63.)*
- *D.5.2. Céloknaak megfelelő moduláris rendszer kontextusba helyezése (pp. 110-113.)*

6. *Urban mimicry, or the hidden architectural form, results in a long-lasting, dynamically changing building system despite the short life cycle of residential units.*

By designing for hidden architectural forms, long-term use, high value stability, and potential value growth are achieved through the collective input of investors, designers, and spontaneous user developments. This approach outlines criteria for a sustainable building system that anticipates the changing needs and urban environment.

- *Palócz, K. (2018) Geometriai elven alapuló téri logikai játékok alkalmazhatósága moduláris lakóegységek, házrendszerek tervezésekor. In: Demográfiai változások, változó társadalmi kihívások, SOE, Sopron: SOE Kiadó. ISBN 978-963334-0904*
- *D.2.5.4. A városi tér újraértelmezése (pp. 49-63.)*
- *D.5.2. Céloknaak megfelelő moduláris rendszer kontextusba helyezése (pp. 110-113.)*