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GROUP FORM RECONSIDERED: PHYSICALITY AND HUMANITY OF COLLECTIVE SPACES

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Abstract. *In 1964, Japanese architect Fumihiko Maki presented the need for investigation in housing collective form. The need was explained through his sensitivity towards the dynamic change of society and simultaneous inadequacy of architectural static and fragmented respond. This paper presents the contemporary view on the theory of collective form and its investigation into why and how the group of buildings stands together. It brings forward the need for renewed architectural focus on group form, one of Maki's collective form types, and the social and human reasoning of design decisions. The theory of linkages in group form is related to more recent socio-spatial analytical theories and interpreted as an analytical tool for understanding housing morphologies, configurations, and ~~its~~ social capacity of group form. It is proposed that the morphological and configurational approach can be used in combination for reading and understanding the historical and contemporary housing ensembles and their relation to an urban whole. The aim of the theoretical research is the identification of the analytical framework and design principles of group form based on architectural and configurational elements and their relations, as socially and culturally relevant.*

Key words: *collective space, group form, housing, configurations, linkages, interface*

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1. GROUP FORM AND SOCIAL REASONS FOR BUILDINGS TO BE TOGETHER

> "If we accept the hypothesis (advanced since 1992) that it is the collective condition that defines urbanity and that, therefore, the collectivization of spaces and homes, people and institutions, economic movements and activities, is the supreme effect entailed by urbanity, then we would have to think that all the places of the city, public and private, individual or corporative, are partly public spaces since they share the way in which they are appropriate for the citizens (de Sola-Morales 2013)."

The contemporary urban landscapes encompass an uncountable variety of individuals and groups, in so many ways. Even if they do not come from different cultural backgrounds and speak different languages, as if they do in London or Berlin, city dwellers are confronted with a wide range of differences and incompatible views on lifestyles, beliefs and values. Nevertheless, these diverse people share the same urban space and their co-existence has a practical spatial dimension in everyday life. This *physicality* of collective life is an essential part of urbanity. In the context of the thesis of a collective condition of urbanity, the paper will focus on the dwelling culture and the architectural design perspectives on housing ensembles.

Shared and collectively used urban public places are places where proximity with others, diverse urban dwellers, comes to its practical terms. Urban dwelling culture is not only about privacy and about individuality, usually associated with a dwelling unit or home but also about the constant negotiation between private and public domain, individual and collective use of space. Architect Manuel de Solà-Morales brought forward the theoretical and practical confusion resulting from the conventional use of term *public space* to designate the places of these negotiations. "The city is the very place where the private domain can be, and often is, a social domain, just as much as or indeed even more than the public domain. Private buildings as public elements, radiating social meaning and value that extend beyond the actual buildings embody their urban character. Collective spaces are not strictly public or private, but both simultaneously. These are public spaces that are used for private activities, or private spaces that allow for collective use, and they include the whole spectrum in between (de Sola-Morales 2008, p.18)." If we follow this thesis, that urban space is continuous collective space, sometimes used by one, few or many for different activities, the architectural question is what are the spatial elements and appropriate relations between them that define collective space qualities? The specific focus of this research is on the qualities within the dwelling environment, emphasizing social and visual experience.

Continuousness of collective space requires the different design approaches to housing ensembles, or urban space generally, compared to the dominant approach of urban fragments or building oriented approach. Our contemporary design culture keep designers committed to the idea of public space as a precise, delimited place of certain typology. As Solà-Morales points out, architects are losing perspective on collective space as a basic urban structure and giving priority instead to the morphological or environmental singularity of each site as an autonomous urban lot and an occasion for independent formalization (de Sola-Morales 2013). Even in the wider architectural (self) criticism, as noticed by Bill Hiller and Julien Hanson, space is usually considered through surfaces that define the space, rather than space itself. Moreover, it is usually considered at the level of

the individual space, rather than at the level of the system of spatial relations that constitute the building or settlement. "As a result, a major disjunction has developed not only between the public pathology of architecture and the discourses internal to architecture but also between the practical design and experience of buildings and these discourses (Hillier and Hanson 1984, p. 3)."

However, after the experience of 20th-century modernism and in the conscious consideration of urbanization processes of today, it is not possible to conceptualize and construct the urban whole as a unitary model. On the contrary, there is a need to think about the urban whole as adaptable to change and time, and as such, designed and constructed from smaller elements. This paper starts from the collective form considerations by Japanese architect Fumihiko Maki that put forward the new light on the question of urban form as a relationship between architecture and the city. Architects confronted with the "issue of great numbers" after the Second World War or with the problem how to conceive and built housing for a large number of people, considered this question highly relevant (Maki 2008, p.40). How should the collection of buildings stand together? How to start with individual elements and arrive at an urban whole? The one of the collective form paradigms, *the group form*, evolved in the traditional design of settlements, has a strong potential for understanding and resolving these questions.

1.1. Research methodology

Considerations of group form are bringing forward the very essential issues of spatial order through which we can design the continuity of collective space. Maki's investigation in collective form was urged by humanly experienced errors of economically and technologically driven design and construction, especially visible in the dwelling production, even more, today. "… [I]n our inability to order experience, we merely suffer the city and long for some adequate means to comprehend it as a product of human creation—a product of intelligent, ordering forces… At such moments, when one sees only the results of mechanical and economic processes controlling the form and feeling of place, one feels estranged and excluded (Maki 2008, p.58)." Therefore, the group form is not a spatial aesthetic exercise on its own means. Adaptability to change is a very important aspect of urban form, but it is not the purpose of the design as well. As Fumihiko Maki concisely wrote, it is *a humanly significant spatial order* that should be in the center of the architectural design (Maki 2008, p.58).

This paper is bringing together two approaches to the research of housing ensembles: morphological and configurational approaches. The premise is that both are offering conceptual and analytical means for understanding the urban form through the continuity of collective space. Moreover, continuous collective space and the integrity of urban whole is analysed through the traditional housing group form in Bosnia and Herzegovina - Mahala. Criteria for case study selection were defined according to Maki's principles of housing group form. *Mahala* was constituted of small and similar structures of residential architecture, developed spontaneously during the course of time. The layout of the *mahala* settlement was consistent with the topography and is seen as the open-ended composition able to preserve the properties of the whole during the settlement growth.

The *morphological approach* to group form by Fumihiko Maki is based on interpreting the unity of human experience. It is the theory of spatial order rooted in the

necessity of perceptible understanding and reading the urban form by city dwellers, as a basic mean of connectedness with dwelling place. The *configurational approach* by Bill Hiller and Julien Hanson, putting forward the social logic of spatial ordering (Hillier and Hanson 1984).

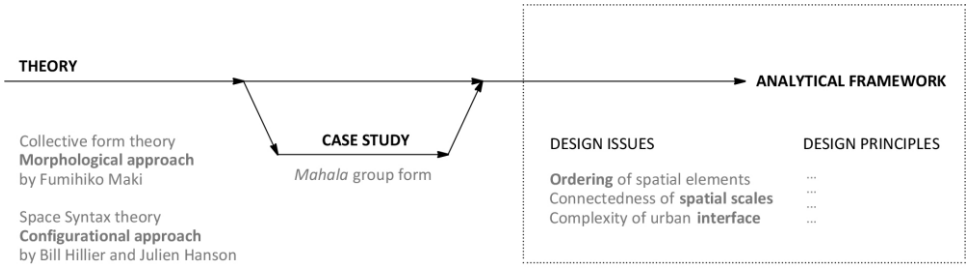

Fig. 1 Research diagram

The main theoretical research hypothesis states that linking of two theories is enabling the setting of an analytical framework for a more comprehensive analysis and design of the housing group form (Figure 1). Three important design issues of the group form are recognized from the theoretical overlapping as the first level of the analytical framework: ordering of spatial elements, connectedness of spatial scales and complexity of urban interface. These are discussed through the next three chapters. Further, the research result is an open-ended set of the design principles for the housing group form, based on the design intentions towards continuity of collective space and the integrity of the urban whole.

2. HUMAN ACTIVITIES AND LAYOUT OF BUILDINGS AND OPEN SPACES

This chapter discusses the first design issue – ordering of spatial elements. Human activities and movement through urban space are vital elements of urban living and there is a need to understand them as generators of housing group form analysis and design. These elements and principles of connection can be used for better understanding of the ordering logic in dwelling ensembles and their collective space.

2.1. Morphological approach: three paradigms of collective form

In his influential text *Investigations of collective form* (1964), Fumihiko Maki introduced his morphological and human-oriented approach to urban design. He saw a city and its parts as a morphological unity, as a collective form. Collective form addresses the importance of the whole over the individual buildings or separate open spaces. Spatial, visual and movement linkage is the ordering act of spatial elements into the logical unity from the human perspective.

Maki defines three types of collective form based on different relations or linkages between the single element and the whole (Figure 2). The first one is *the compositional form*. The structure of the compositional form is based on the arrangement of separate buildings and their geometry, so the linkage in composition they form is dominantly on a two-dimensional plane. It is the common way in urban design, starting from the Le

Corbusier's architecture up to today. Compositional form as such is static, because the separate elements, their function and their arrangement are not supposed to change over time.

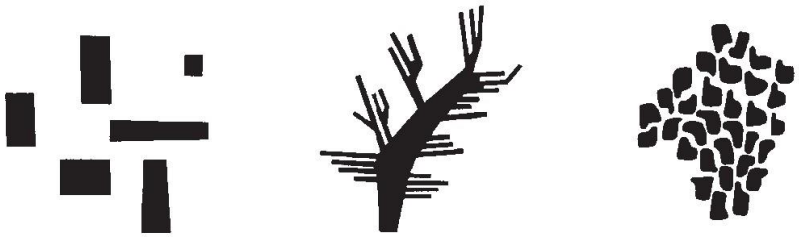

Fig. 2 Fumihiko Maki's paradigms of collective form: compositional form, megastructure, group form (Maki 2008, p.46).

The other two collective forms are based on organic principles of growth. *Megastructure* paradigm became relevant in the sixties, very much disseminated by the post-war Japanese architecture movement called *Metabolism.* The overall technological advances made possible design of the megastructure as a large spatial frame in which all the functions of a city or part of a city are housed. World Design Conference held in Tokyo in 1960, discussing the issues of mass urbanization in Japan, recognized the relevance of megastructure for environmental engineering, as design of multifunctional complexes and infrastructure. Rayner Banham's book *Megastructure: Urban Future of the Recent Past* (1976) is one of the influential books about the megastructures' design methods and meanings. In spite of Metabolists' aspiration for organic growth, Maki indicates megastructure as rigid, because it allows the infills change, but the main structure itself can fall into disuse and then the entire system becomes obsolete (Lin 2010, p.164). More organic and more flexible alternative Maki finds in the third collective form - *the group form*.

Group form "evolves from a system of generative elements in space" (Maki 1964, p.14). This type of collective form Maki recognised in the existing examples of buildings and spatial elements distribution in traditional settlements. According to Maki, several factors determine the spatial organization of historical towns seen as a group form: spontaneous, but minor variations in physical expression, the use of geography and topography in a wise and dramatic way, and sequential development of the open-end composition. The authors of this research interpret the group form as a totality structured by small elements on proportionally small distances. Through the layout of houses and open space is possible to accomplish the sequential development of the open-end composition. Moreover, sequences are the result of repetitive use of certain visual elements, such as walls, gates, and towers.

In the group form one can recognise the clear relation between the elements and the whole, between the human activities, movement and the form, between the time passage and the form. "There exists unquestionably a clear structural relationship between the village and the houses, between village activities and individual family life, and between the movement of villagers and cows. Here the house unit is the generator of the village form, and vice versa. A unit can be added without changing the basic structure of the village. The depth and frontage of the unit, or the size of the court or barn, may differ from unit to unit, but an understanding of basic structural principles in making the village prevails (Maki 2008,

p.52)." In conclusion, there are two important criteria concerning the collective form according to Maki: clear reciprocal relation between the human activities, movement and form, and the ability of collective form to grow over time according to same structural principles. The compositional form is fulfilling neither criteria, the megastructure only the criteria of movement compatibility and the group form fulfils the both.

2.2. Configurational approach

Bill Hillier and Julienne Hanson developed the analytical theory that formulates the principles of the social logic of space. According to this theory called Space Syntax, architecture and urban structures are spatial *configurations*. The relationship between the parts in configuration and the way we link them together are much more important than any individual part, from a social point of view. There is a clear idea about the urban whole, as much as in the Maki's approach.

The theory of space syntax assumes that buildings are not just physical objects or artefacts, composed of single elements that together define a particular form. Buildings also form and organize empty volumes of space in between. The spatial distribution of buildings and empty volumes mediate relations between people in the area, namely groups, separates and connects them. According to the theory, buildings are sociological objects in two ways: they form a social organization of everyday life through a spatial configuration we live in and are moving through, and they represent a social organization as the spatial configurations and elements that we see. Buildings are, therefore, social objects through their own forms and not only through their role as visual symbols (Hillier and Hanson 1984).

Interdependence between spatial configuration and patterns of use Hillier explains for the case of three buildings with courtyard (Figure 3). Each building has the same number of spatial units, morphologically distributed in the same way. The only spatial difference is the position of openings, the position of connections between the spatial units. The difference is sufficient to produce various patterns of use of the space within three buildings. These patterns of uses are schematically presented by justified graph (j-graph) that shows sequences of use (third column in Figure 3). A starting point is marked by *x* sign within the circle. The circle is a sign for each spatial unit and simple line signs each connection. The first configuration shows a linear sequence of use, the second configuration is a tree-like and the third one contains multiple possibilities even for circular movement.

The conclusion from this configurational analysis is that *the permeability pattern* driven from the position of entrances is a critical point in the creation of different patterns of spatial use. Configuration with multiple use possibilities (moving and wayfinding options) also offers various scales of privacy and publicness. The value we can read from the j-graph is *the configuration depth* and presents distance between the base point of departure and end spaces. Each cell within configuration belongs to first, second, third…n^{th} level of depth related to the configuration base. Beside configuration depth, there is a possibility to identify another value from the same configurational way of urban space's analysis, and that it is *the integration value*. The space that has the shortest distance to all other spaces within configuration has a highest integration value (Hillier 2007). This is the place where the most paths meet.

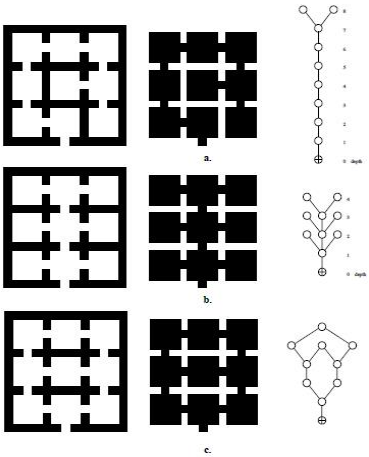

Fig. 3 Architecture and space as the configuration (Hillier 2007, p.22).

According to the theory, encounters, gatherings, avoiding, interactions, and dwelling are not individual acts, but patterns or configurations formed by a group of people. Urban space from the configurational point of view can be organized in a way to offer more possibilities for a variety of social group interactions instead of separating the individual territories (Hanson and Hillier 1987, p.251-273). The spatial precondition for that to happen is the complexity of configuration. Variety of configuration depths and the existence of the spaces with higher integration value are desirable conditions for the higher social value of urban space. The spatial linkage in the urban whole understood as a configuration, is constituted by the permeability pattern – number and distribution of direct spatial connections between the open and closed units of space. Therefore, the space syntax theory directs us towards the importance of the architecture of the boundary, as well.

2.3. Learning from the historical context: *mahala* as a group form

> „...architecture from our close past...its principles, which are ours, good and modern, and to transfer them to today's life. Why? Because they are human, because they strive for a connection with nature, because they respect the neighbour, because they are democratic, smooth and unpathetic (Grabrijan and Neidhardt 1957, p.13). “

Further inquiry into group form ordering principles is done by analysing the collective space of traditional dwelling groups in the local context – Bosnia and Herzegovina's cities. As relevant example, the traditional residential part of the city named *mahala* was chosen. *Mahala* is the model of the earliest urban neighbourhoods in Bosnia and Herzegovina and is dating to the times of the Ottoman Empire rule. Unfortunately, they are rarely preserved in their original urban layout and architectural structure. Juraj Neidhardt and Dušan Grabrijan, Yugoslavian architects, have done an extensive survey on the traditional architecture of Bosnia and Hercegovina with a focus on living in and building the cities. They aimed to understand the qualities of heritage for creating possibilities of incorporating them in contemporary architectural design. Neidhardt makes

specific reference to the city of Sarajevo and identifies three functions with corresponding urban and architectural principles: buildings with social functions spread over *as points* of gatherings (sacral buildings), production and retail organised in *row* buildings (*čaršija*) and residential buildings arranged *in groups* intertwined with nature (*mahala*). Similar to results of Maki's analysis of traditional Japanese village group form, Neidhardt finds that mahala reflects two important principles of architectural and urban design: (1) building for human "who hears, feels and is capable of watching" and (2) building with the awareness that one human cannot do anything if he does not connect with the other (Grabrijan and Neidhardt 1957, p.149-150).

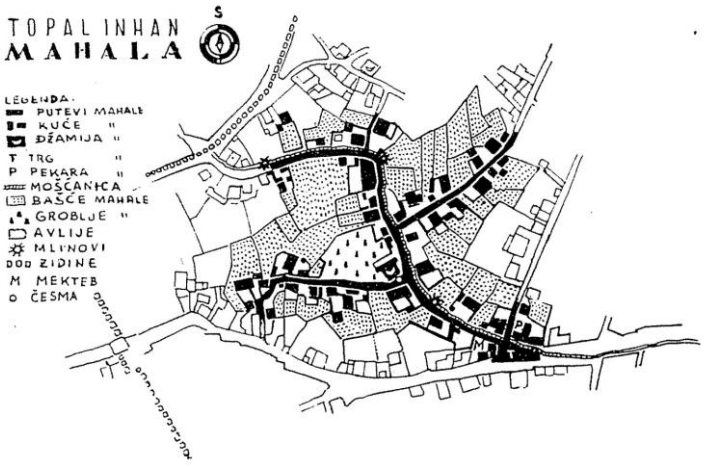

Fig. 4 Group form of *mahala. Topal inhan mahala* in Sarajevo, drawing by architect Juraj Neidhardt. Drawing categories in order of appearance: roads in mahala, houses, mosque, square, bakery, water channel, gardens, graveyard, house yards, mills, walls, Islamic school, and fountain (Grabrijan and Neidhardt 1957, p.144).

Interrelation of houses and other spatial elements is important in a *mahala*. Each house has a fence around it (with the house surrounded by the garden), that makes a plot basic element of the *mahala's* group form. The households are dispersed in several buildings and even more than one courtyard according to oriental cultural understanding of relations between the man and women, inhabitants and strangers, and between the neighbours. It is possible to recognise the great virtue of design in human scale done by small distances between buildings but with enough privacy for everyone and with, as much as possible, an open view towards the street and landscape.

There is a hierarchical differentiation of roads following the terrain configuration. Justified graph of the *mahala's* collective space is usually a tree-like (Figure 4). Public life happens mostly on crossroads as places with higher integration value. Sacral buildings, grocery store and bakery are built around the main crossroad. The street is the *mahala's* backbone. The street curved like meander creates a series of sequences in motion, a change of vision from a pedestrian perspective. The meandering street makes easier to capture the good view from surrounding buildings' first floors, as well. One can

monitor the street life and simultaneously enjoy the beauty of the open landscape view. A layout of the buildings is an equally important element that creates three-dimensional meander like shape of the street. Such relations of the houses and other buildings with open spaces make a mahala worth calling the group form in the Maki's sense. Mahala also grows over time according to same structural principles. If we add the honest respect to neighbours in a spatial sense (distances, privacy, right to the view) that makes the *mahala* dwelling group form deeply related to the notion of collective life.

3. Connectedness of Spatial Scales: Architecture and City Scale of the Group Form

The housing ensembles were dominantly conceptualized and constructed as *the compositional form* in the second half of the 20th century. The same concept was applied in the Bosnia and Herzegovina in the renewal after Second World War. Already after the first phase of the massive construction, real-life problems began to emerge. Universal spatial principles applied around the world were confronted with a different social-political and cultural context, and consequently produced the various complex relationships between urbanism and the social environments (Urban 2012). It seemed that the practical application of the concept of *the neighbourhood unit* and its compositional form has not always succeeded in generating community ideal and, contrary to that, it contributed to social fragmentation at the city level (Legeby 2010).

The basic thesis of social and planning criticism formulated after the sixties is that rational, comprehensive planning model for collective housing gives an advantage to a static and hierarchical spatial form over social processes (Jacobs 1992[1961], Lefebvre 2003[1970], Sennett 1991, 1992). Starting from the neighbourhood unit concept developed in the USA, to the planning of post-war neighbourhoods in Europe, the spatial order of urban and architectural elements that together define the neighbourhood community we can see as an instrument of establishing the desired social order and organization. However, the relationship between urban form and social relations was conceived as a very simplified, one-way oriented and insensitive to future change.

In the same period, the sociological concept of *community*, established as a political imperative of social stability and prosperity in after war renewal in different socio-political systems, will go through critical rethinking as well. The theoretical model of opposite categories rooted in the theory of German sociologist Ferdinand Tönnies from 1887 (Tonnies 2011[1887]), will be reconsidered in the intellectual discussions of the second half of the century. The discourse will be developed around the question of whether *urban sociability* is coming from close community ties (*Gemeinschaft*) or arising from the rich social diversity of modern times (*Gesellschaft*)? What spatial implications does this social dichotomy bring to the design of the dwelling group form?

3.1. Urban sociability in relation to spatial scale

The concept of urban community is often stigmatized as a dangerous myth of social unity and integral identity, in the recent rethinking of urban sociability (Sennett 1992, Sennett 2003[1977], Harvey 2005, Young 1986). As opposed to the social relations of close neighbours brought forth by the sense of personal affiliation and close connection,

researchers and theoreticians of a heterogeneous urban society find anonymous and distant relations as a basis of urban sociability. These theories are based on the empirical experience of the social and cultural diversity of contemporary large cities - diversity in class, gender, age, race, and lifestyles.

These theories give special attention to the relations between people who do not know one another, between strangers. Strangers are in direct visual and physical contact in collective space, with the option to stay strangers to each other, but with the awareness of the potential interaction. For sociologist Richard Sennett, one of the essential political, sociological and psychological values of the city is a project of *collective coexistence with strangers* or urban coexistence outside the community. In this context, the public space of the city is recognized as a place of mixing of the group and individual differences, the "culture of the city" as defined by Sennett, and as such is offering the perspective on the various possibilities of personal reinvention (Sennett 1991). Thus, within sociological theories that reject the normative social relations of the community and embrace the social and cultural diversity as the basis for the advancement of social relations, public space or in Sola Morales terms collective space is defined as an important place for generating the modalities of urban sociability. In that sense, collective space is a highly important spatial structure for the social life of dwelling group forms.

Sociologist Steven Brint leaves a significant theoretical possibility according to which the positive features of urbanity as diversity - constant variability, diversity in contacts, possibilities, and opportunities, mental freedom, are not opposite to the positive characteristics of community - feeling of belonging, safety, and solidarity (Brint 2001, p.1-23). The author advocates "more relaxed, occasional and ad hoc" social ties that he sees as possible in *communities of place* that show a combination of close relationships, with few restrictions on personal freedoms and low levels of resistance to people outside the community. This thesis is particularly important for housing ensembles shared as a dwelling territory by a group of people brought together by minimal spatial distances of a dwelling place. At the same time, housing ensembles are part of the larger urban landscape, dependant on many other global urban systems. In the context of Brint's thesis, the dwelling group form could be conceptualized as one of the basic social-spatial forms that have the potential to put in practice this kind of urban sociability - *a community within diversity*.

The configurational theory of urban space is based on the tendency to overcome the model of corresponding relations between spatial territories and social groups (the correspondence model), usually applied in the design of communities of place (Hanson and Hillier 1987). Urban space understood as the configuration can be designed in a way that increases the likelihood of encounters between people of different social groups, rather than to give them the corresponding territory, and to separate them. Accordingly, Henson and Hillier state that the relationship between the local organization of space and the global structure of the city, which is producing the probability of encounters, is a basic spatial issue in the context of vitality, sociability, and safety. According to the authors, it is important to create a spatial strategy for the design of local configuration and properly integrate it in the global urban system, rather than to localize space to the enclaves.

If we put the graphic representation of cells and connections in *Figure 3* in the context of the relations between neighbours (spatial groups connected with the proximity) and strangers (those who pass and visit), we can establish sociological references for all spatial elements of the configuration. Spatial unit or cell is the category of urban space that belongs, or it is

controlled by someone who is an inhabitant. The spatial boundary forms the cell and at the same time, it is a spatial mean of control and discretion. The space outside the boundaries is the domain of strangers and the entrance is the liminal area of potential social relations between inhabitants and strangers. The entrance thus becomes a mean of establishing the identity of the inhabitants, as well as a mean of transforming the stranger into a visitor. The more integrated is the outside space into a global system of urban space, the more strangers potentially will be present. The more permeable the boundary, the more potential there is for outside space to become a negotiating place of inhabitants and strangers.

The general argument of space syntax theory is that urban sociability is the product of a global spatial order that organizes the presence of inhabitants and strangers and that it is not exclusively the product of local spatial patterns. Considering the dwelling group form as a distinct spatial-social unit, at the same time a local dwelling space and part of a wider urban area, it demands the simultaneous local spatial identification and integration at the global level of the city.

3.2. Co-presence in collective urban space

The key sociological concept within the configurational theory of space is the concept of the simultaneous presence of people in space. The *co-presence* is much closer to the desired design outcome because it is a necessary condition for the occurrence of interaction, communication and the formation of social relations (Marcus and Legeby 2013). The theory of space syntax points out that the patterns of co-presence, (its size in numbers and inhabitants/strangers ratio), are largely a result of architectural and urban form, and therein lies the importance of this concept, as the essential link between space and social capital.

The space syntax theory recognizes the principle of convex and axial organization of space. In most cases, strangers are moving through the settlement, while the inhabitants have a much more static attitude towards the local system. Axially elongated segments of public space introduce and let strangers into the system, while convex public space is static area overlooked by inhabitants. This principle of the spatial relationship between the inhabitants and strangers is the basic determinant of settlement growth during the time, according to configurational theory (Hillier and Hanson 1984, p.17).

The issue of safety in a collective space closely relates to the same principle. The spatial system is letting strangers into the public area of settlement. At the same time, closeness of housing units' layout provides visual control over strangers in public areas. In this way, strangers oversee the collective space, and the inhabitants oversee strangers. The sense of safety in the collective housing form derive from the routines of everyday movement and the co-presence, with the possibility of an encounter with both the neighbours and strangers.

The size of co-presence (number of people in collective space) and the constitution of co-presence (inhabitants/strangers ratio) we can directly relate to different modalities of urban sociability (Marcus and Legeby 2013). Researchers are proposing the use of space syntax techniques for measuring the size and the constitution of co-presence as an indicator of the potential type of social capital. Collective spaces of dwelling ensembles with fewer strangers refer to spatial isolation or even the social segregation of the neighbourhood, where the inhabitants are more directed to local social and economic resources (Marcus and Legeby 2013). Therefore, the spatial distribution and connection of axial and convex open spaces and their relation to indoor spaces have a crucial role in the formation of the social life of the dwelling ensembles.

4. COMPLEXITY OF AN URBAN INTERFACE

Elaborated two-dimensional plan of spatial configurations is necessary, but not sufficient for a design of a meaningful environment. Therefore, if we observe the configuration in three dimensions, we come to the importance of individual spatial elements on a local scale, not only their integration into the global urban system. Following the Maki's argument that the city as a physical place and social system depends on the autonomy of individual elements and search for possibilities for every single element to participate in the whole (Maki 2008, p.42). As mentioned above, spatial boundaries play a very important role in the structuring of continuous collective space. Architectural modelling of the boundary is the potential way to control physical and visual connection between the spatial units and at the same time the issues of safety, transition and overlapping of private and public domain. In that context, spatial boundaries are the interface of urbanity, as Miloš Bobić called them (Bobić 2004).

Three of five Maki's linkage acts in group form we can relate to the architecture of interface: to mediate, to repeat, and to make a sequential path (Maki 1964). Coming from configuration theoretical discussion and *mahala* considerations, the two most relevant principles for interface design are physical and visual connectedness between the exterior and interior and changes in sequence. However, there is a need for a more physically specific way of defining the interface and more related to patterns of use.

One can contribute to the continuity and use of collective spaces in housing ensambles through shaping the space in the scale of the interface. "Any form of configuration contributing to a gradual transition between the street and a group of houses may be seen as a collective interface (Bobić 2004, p. 77)." The physicality of division between interior and exterior space plays important role in giving more privacy to individual space, connecting it with the collective and providing the higher level of people co-presence in collective space, all at the same time. How to define this transitional form and what are the principles for designing it? "In general, collective transition areas are combined with individual interfaces of the buildings, and together they maintain a gradual transition. Superimposition of these two levels of scale throughout the design maintains both a livable housing environment and desirable level of urban character (Bobić 2004, p. 78)." According to Miloš Bobić, there are two important factors for defining the space and location of the transition from city to house, from collective to individual space. Those are the building's position relating to public space and the definition of a transitional area in location and size. Spatial, visual and psychological claims upon private and public domain are not simply overlapped with each other territories. There are bigger chances for social complexity or higher level of collectivity if common claims arise upon the transitional area. The space of interface is a spatial difference between street room and street profile (Bobić 2004, p. 63).

The coherence of the interface in the *mahala* arises from the defined relationships of spatial elements on a larger scale. Street meandering as a design principle at the level of the whole results in the specific physical appearance of the interface. A meandered street room in *mahala* creates a layered interface between the individual and collective space. The physicality of the interface is manifested both in the horizontal and vertical plane. Relations between the house and the street are defined with multiple architectural elements resulting in pervading and separating of the static domain of privacy (house and garden) and dynamic domain of public street life (Figure 5). According to Neidhardt,

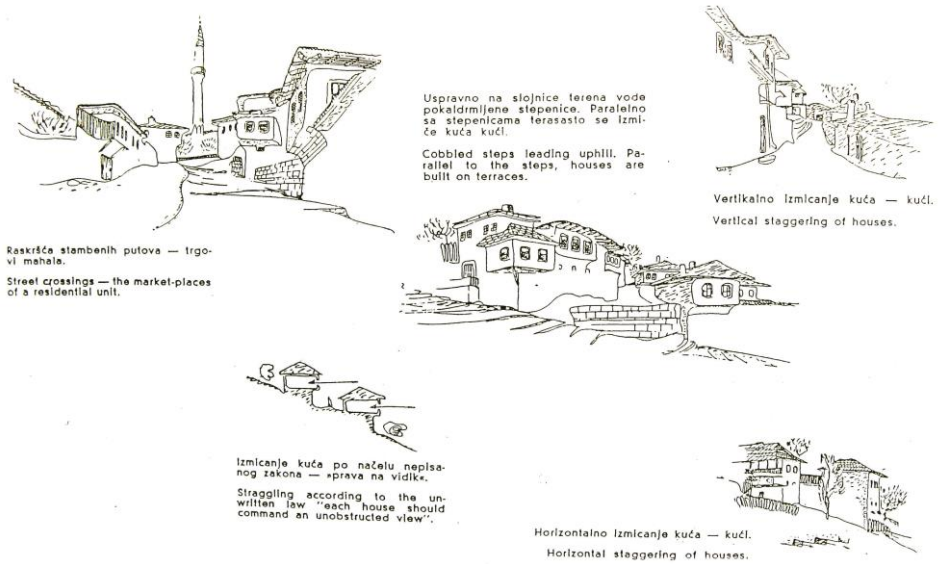

Fig. 5 Juraj Neidhardt's drawings. Relations between houses, street, and landscape in *mahala* (Grabrijan and Neidhardt 1957, p. 151).

there are gates, ramps before the gates, green lines between the wall of the house or fence and the street, *doksat*, loggias, roof terraces, among other examples (Grabrijan and Neidhardt 1957, p. 145-146). *Doksat* is the element of the house that visually connects the individual and collective space. It is on the first floor of the house and enters into the street room. Architectural composition of *mahala* show us that the interface needs to be designed as a three-dimensional physical space and as such, it will result in the richness and the integrity of the experience. From one side, visual continuity could be the result of a unified approach to the street-house border. On the other side, the layout of the complete housing area with backbone roads that are curved and meander like shaped, brings a variety of sequences for pedestrians.

5. Design Principles for Making Housing Group Form

The group form is reaffirmed as the adequate framework for design thinking in todays fragmented city and its dwelling and public space. The paper emphasise the Fumihiko Maki's explanation of the group form as the basis for designing continuous collective spaces and meaningful dwelling environment.

Considerations of group form are bringing forward the very essential reasons for spatial order through which we can design the continuity of collective space. What are the architectural elements and their relations that define the quality of continuous collective space? Can we define that quality by identifying the basics of spatial language? Human experience and social logic (of collective space) are generators of such design process. To make everything more comprehensive and more design applicable we found useful to emphasise measurable principles grounded in the Space Syntax theory. Furthermore, for

identifying specific values rooted in context and culture of living, we find important to recognize and analyse the local group form – the *mahala* as a traditional housing area of the city. Both addings together, with reconsidered Maki's concept of group form, made possible the identification of design principles set for humanly appropriate dwelling environments (Figure 6). Each of proposed design principles is addressing one or more primarily defined design issues: ordering of spatial elements, connectedness between spatial scales and complexity of urban interface.

design principle	**design issue**
use of geography and topography wisely and dramatically	connectedness between spatial scales
layout of small elements on proportionally small distances but with sufficient privacy for everyone and with, as much as possible, open view	ordering of spatial elements complexity of urban interface
respect to neighbours in a spatial sense (distances, privacy, and right to the view)	ordering of spatial elements complexity of urban interface
right to view for everyone	ordering of spatial elements connectedness between spatial scales
variety of configuration depths	ordering of spatial elements complexity of urban interface
higher number of spaces with higher integration values	connectedness between spatial scales
local configuration integrated with the global urban system	connectedness between spatial scales
visual connectedness between the exterior spaces and between exterior and interior spaces	ordering of spatial elements complexity of urban interface
serial vision - sequential changes in pedestrian's experience	ordering of spatial elements
complexity of transitional area between building and public space	complexity of urban interface ordering of spatial elements
interface as three-dimensional physical space	complexity of urban interface ordering of spatial elements
sequential development of open-end composition or growing architecture	connectedness between spatial scales ordering of spatial elements

Fig. 6 Housing group form design framework

6. CONCLUSION

The analysed theories, their linkage and the case study resulted in setting of an analytical framework for comprehensive understanding and design of the housing group form. Three important design issues of group form are recognized from theoretical overlapping as the first level of the analytical framework: ordering of spatial elements, connectedness of spatial scales and complexity of urban interface. The second level of the analytical framework is an open-ended set of the design principles for the housing group form, based on the design intentions towards continuity of collective space and the integrity of urban whole.

Theoretically, this paper has contributed to expand the existing theories about urban form and spatial configurations by elaborating on them from the design perspective. Methodologically, research is conducted by overlapping the findings from theoretical research with the case study related to specific social and cultural context. The findings are instructive for urban theory and urban design practices when designing urban dwelling environments and its collective spaces. Some limitations of results are obvious when building the research based on single case study. Therefore, with the aim to generalize or contrast these findings further researches are recommended. More case studies in other cultural and social contexts would surely provide useful insight in proposed housing group form design framework.

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ZNAČAJ I ULOGA GRUPNE FORME: FIZIČKA I LJUDSKA DIMENZIJA KOLEKTIVNOG PROSTORA

Japanski arhitekta Fumihiko Maki je 1964. godine ukazao na potrebu za istraživanjem kolektivne forme u stambenoj arhitekturi. Potreba je proizašla iz arhitektove osjetljivosti prema dinamičnim promjenama u društvu i istovremeno neadekvatnim statičnim i fragmentarnim reakcijama arhitekture. Ovaj tekst predstavlja savremeni pogled na teoriju kolektivne forme i istraživanje o tome zašto i kako zgrade treba da stoje zajedno. Tekst naglašava važnost ponovnog fokusiranja arhitekture na grupnu formu stanovanja i odluke u dizajnu uslovljene društvenim i ljudskim aspektima. Teorija veza u grupnoj formi je povezana sa novijim društveno-prostornim teorijama i interpretirana kao analitičko sredstvo za razumijevanje morfologije, konfiguracije i društvenog kapaciteta stanovanja. U tekstu se predlaže kombinovanje morfološkog i konfiguracijskog pristupa prilikom tumačenja tradicionalnih i savremneih stambenih ansambala i njihovih veza sa širim urbanim prostorom. Cilj teorijskog istraživanja je identifikacija analitičkog okvira i principa dizajna grupne forme zasnovanih na društveno i kulturološki relevantnim relacijama arhitektonskih i konfiguracijskih elemenata.

Ključne reči: *kolektivni prostor, grupna forma, stanovanje, konfiguracije, veze, interfejs*

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IMPLEMENTATION OF ENERGY EFFICIENT PRINCIPLES OF TRADITIONAL VOJVODINA HOUSE ON THE CONTEMPORARY FACILITY OF LOCAL MONOCULTURE FARMING SYSTEM

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Abstract. *The research is concerned with the current problem of depopulation and devastation of rural areas in Vojvodina, which are slowly disappearing as more and more young people turn to cities and urban lifestyle, looking for more comfortable working conditions not related to agricultural activities. These villages, along with their unique rural architecture, represent the identity of the area and by destruction of their communities Vojvodina would lose on its significance and identity. On the other hand, the paper considers one of the problems of today's research practice that relates to the constant attempts and needs of interpolating agricultural production into already overbuilt and polluted urban surrounding, making the villages even more neglected. Therefore, there is a need to establish a single strategy that would enable the revival of valuable rural communities in Vojvodina and make these areas better and more advanced places to live, retaining agriculture within the rural boundaries, as well as preserving the authenticity and tradition of the Vojvodina region.*

This paper presents the study project of Local Monoculture Farming System as a concept of a visionary model for the new type of facility in villages of Vojvodina whose construction could prevent further departure of young people from these areas giving them the possibility of education and employment within buildings instead of working on the land, since this is one of the reasons why they leave. Relying on energy efficient principles of traditional Vojvodina house in the construction, but also adapting some new, modern sustainable technologies, this future-oriented farming system would enable the connection between traditional and modern in rural areas of Vojvodina. The project links agriculture, energy efficiency, heritage and architecture to recover and use local resources of Vojvodina villages as a cultural approach in contemporary research for sustainable modern solutions.

Key words: *energy efficiency, agriculture, rural areas, Vojvodina, heritage, contemporary architecture*

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1. INTRODUCTION

For more than two decades villages in Vojvodina have been exposed to depopulation under the influence of modern processes of urbanization and industrialization. Rural population recognized salvation from hard work on agricultural land in urban areas, where they expect more comfortable working conditions in activities related to economy, industry and technology. As a consequence, more than half of the total population of Vojvodina lives in cities today, although almost 90% of its territory are villages [1]. The results from two last population censuses, which have been conducted in 2002 and 2011, reveal a constant decrease of rural population in the region. In 2002 rural population of Vojvodina comprised 43.27% of the total population, and in 2011 this number was already reduced to 40.64% [1]. According to Estimates of the population in the Republic of Serbia on 30th of June 2017, the percentage of rural population in Vojvodina has even more decreased to 39.66% [2]. Certain sociological characteristics and patterns of behavior, typical for the traditional rural society in Vojvodina, like stability of relations, unity and equality, represent greatest values of this area. By moving to cities people have lost their social relations that represented an important support for them, while they lived in villages. The identity of Vojvodina is defined by its rural communities and the unique rural architecture. If these local communities disappear, Vojvodina will lose its identity.

"*The village was an inexhaustible source of power for the mankind, throughout the history. Much was taken from it and a lot less returned. The village has never been the subject of serious care and work. The main part of spiritual and material efforts and activities was intended for cities. Science and art, the highest domains of man's creation, have not given anything to the village*."[3]

The problem of today's research practice is that most of the attention is devoted to trying to solve the problem of overpopulation in cities. Besides many proposals for "insertion" of new facilities in order to solve the housing issues in towns, there are also intentions to move and interpolate agriculture within the polluted city cores, e.g. the project “Farming the city” [4]. Not much effort has been invested in the development of rural communities and returning people to the village, which would also solve the problem of overcrowded cities. Abandonment of agriculture is also one of the consequences of depopulation of rural areas in Vojvodina. However, since it has always been main economic activity and source of income in this region, it is necessary to keep it within the boundaries of rural areas, whose environment will provide natural and sustainable farming conditions. Agriculture requires consumption of large amounts of energy, so the rationality of its production and consumption has a major influence on economic development of rural areas. The need to incorporate environmental protection and application of sustainable development principles in new directions of agricultural and rural policy in Vojvodina is growing.

Traditional rural houses in Vojvodina, which represent bearers of its culture, are specific in certain characteristics that make them sustainable and are built according to energy efficient principles. Unlike contemporary architecture, these houses did not use large amounts of additional energy because everything that was needed for their functioning was found in the local environment, in the natural and the renewable resources. Comparing modern architecture with the traditional, it can be concluded that it’s not as sustainable today as it was before. For this reasons it is necessary to examine and reconsider old principles and building technologies of traditional architecture and apply them in new, contemporary

solutions, which would all together enable us to see old architecture in a new light, in the conditions of modern society.

This paper presents the project study proposal of Local Monoculture Farming System (LMFS) as an original idea of the author Jovana Stanišić[1]. LMFS shows the concept of the proposed strategy for improving economic and social situation in villages of Vojvodina by recovering and reusing its local resources and applying modern sustainable technologies. This strategy reflects a new approach in contemporary research of sustainable solutions for the future generations. As a future-oriented visionary model of a new type of facility in the villages of Vojvodina, the study project of LMFS would establish a rural-urban synergy by making these rural communities sustainable and more advanced places to live. The purpose of constructing this facility is to preserve agriculture within the rural boundaries in order to improve and facilitate working conditions for the rural population, by giving them new opportunities of employment and education in the villages. Simultaneously accommodating five different functions under the same roof of this facility: farming, manufacturing, promotion and sale of one particular crop, as well as agricultural education of young people, work in agriculture would be greatly simplified. The village would be "urbanized" in a certain way and would adopt a more urban lifestyle. By reusing the old principles of energy-efficient construction of traditional Vojvodina house, but also by applying some of the modern, sustainable technologies, LMFS study enables the reconciliation between traditional and modern in rural areas. Within this paper the study of LMFS construction and functioning system is explained, as well as implementation of energy efficient principles. In order to maintain authenticity of Vojvodina rural communities and not to disturb ambient values of the area, the paper explores the possibilities of adjusting this new facility to the existing environmental conditions of Vojvodina villages: its morphology, urban structure, plots and houses shape, features of traditional architecture etc. Since the aim is to integrate this new type of building in the wider framework of the neighborhood, the analysis of its adjustment is based on one of the existing typologies of Vojvodina houses, typology depending on the relationship between the house and the plot [5]. As a result of these analyzes, several model types of this facility will be formed as a new building typology of LMFS in rural areas of Vojvodina.

[1] The LMFS study project is one of the element of the PhD thesis "*Urbanistic and architectural principles of energy efficiency of traditional Vojvodina houses - application in contemporary architecture*" by author Jovana Stanišić. The important issue that the PhD research is considering relates to the process of depopulation of rural areas in Vojvodina and the degradation of traditional Vojvodina rural houses. Within the theoretical part of the PhD thesis, the problem and reasons of depopulation of the villages were analyzed and defined. The basic goal of the PhD research is to prove that the urbanistic and architectural principles of designing traditional rural houses in Vojvodina are energy efficient, in order to stimulate awareness of the need to return the old principles of construction and their application in contemporary architecture, as a strategy that would enable the revival of these rural communities. The LMFS model is an experimental study of a contemporary architecture project on which these traditional principles are applied in order to examine and demonstrate the possibility of their application. The paper presents the initial phase of the LMFS project development, which includes the formation of general LMFS model types. Further research that involves the implementation of the LMFS concept on specific examples of Vojvodina houses is planned within the PhD thesis.

2. METHODOLOGY

The LMFS project is an experimental study model for examination and demonstration of the possibility of applying the traditional principles of sustainable Vojvodina architecture in the contemporary one. First part of the paper describes the predicted functions of the LMFS project, using the descriptive research method. The second part presents the study of possible architectural features of the LMFS model, through the presentation of an extensive typology and its shaping process, which was carried out using the modeling method, based on previously performed analyses. For example, general plan types of LMFS model have been developed based on previously analyzed types of one of the existing typology of traditional Vojvodina houses. All LMFS model types are designed by applying the examined energy efficient principles of traditional Vojvodina architecture. Finally, all applied principles are schematically shown on the model's figure. The methodology of this paper implies a research-by-design approach, the result of which can be considered more practical than theoretical.

3. LOCAL MONOCULTURE FARMING SYSTEM STUDY PROJECT

LMFS represents an example of BIA (building-integrated agriculture) practice application that explores synergies between the built environment and agriculture by locating greenhouse farming systems on buildings. The BIA system is usually considered in urban areas due to the lack of farmland in cities [6]. Implementation of this practice in the villages of Vojvodina, urbanizes them and brings them closer to the city lifestyle by providing new opportunities of employment and education to young people within the built structures. This method would change the rural tradition and the established rule that in villages only land serves for work, and not buildings. Applying the energy-efficient principles of traditional Vojvodina houses in the construction, these facilities preserve the local tradition and maintain sustainability of its communities. LMFS building involves the production, processing, consuming and trading of one specific agricultural product and its seedlings at the same time. In addition, the agricultural education of young rural population is organized within the facility, in order to enable them to apply their knowledge in their one household later on. Agriculture is integrated inside the building in such a way that all four phases of the agricultural goods life cycle (production, processing, consuming and trading) are carried out within it and the order of these phases is organized according to the levels of the facility, so life cycle of the culture and the building make an inseparable union (Fig 1). That is one of the reasons why the priority is given to the production of agricultural goods within the boundaries of LMFS, instead of using the land. There would be several facilities of this kind built in one village of Vojvodina and each of them would enable the

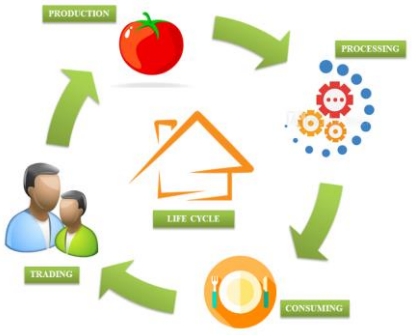

Fig. 1 Agriculture life cycle in Local Monoculture Farming System building (Source of illustration Fig. 1: author's drawing (Stanišić J.))

production of one certain type of agricultural product. Each of these buildings would function as a small, self-sustaining, energy-efficient farming system in rural areas.

3.1. Farming system functioning

Employment of young rural population in these new facilities of LMFS in the villages gives them an opportunity to get a job, to learn activities related to production, processing and trading of agricultural products and its seedlings and, later on, to become independent and start manufacturing within their own households. New young people would come to take their place afterwards and so the whole process of "a social program" would be rounded: employment, training and independent entrepreneurial development. In order to ensure that the project is successful, different key players should be engaged, experts in farming and manufacturing. Young people are the ones who are currently employed and trained, but later on, when they start an independent manufacture, other family members would also be hired. In this way the problem of unemployment of rural population in general would be diminished, regardless of the age of participants. In order to simplify the whole process of production and processing, the plan is to establish a number of such facilities in one village, with only one crop produced within each of them. The LMFS makes it easier for employees to master one particular job and to specialize about the production process of one product. This system allows easier equipping of the space for manufacturing cultures because it is necessary to purchase equipment for processing only one product. Young people who want to learn about the agricultural production of more than one type of product can be educated in several different LMFS buildings. In this case, they are educating for a while at one workplace and then referred to another. Although it is only one culture that is produced inside the building, the processing would yield a variety of products. These products are promoted in a restaurant, which can be located on the ground floor of the facility allowing visitors to consume and familiarize with the final products of a particular culture promoted in that building. At the end, these manufactured products are being sold on the markets that are organized at the back of the plot or in public market in the village. Due to the small production area in these facilities, the sale of raw and processed agricultural products is not a wholesale. However, each of them also produces seedlings of the same plant that can be sold wholesale and, if necessary, distributed to neighboring villages and towns. The highest income comes from the sale of these seedlings. Money earned from the sale of raw, manufactured products and seedlings, restaurant and market is again invested in production, and so the whole system becomes sustainable. All the local agricultural products, which are cultivated in this region and under the described conditions, come into consideration for production in LMFS facilities. The owners themselves choose the type of product to be produced in the facility, based on the general regulation that determines the production schedule for each part of the village within the rural community. This arrangement defines the broader context of specialization, including all the types of plants that can be produced. Each of these buildings behaves as a self-sustaining, energy-efficient farming system, so no major investments are required in their maintenance. LMFS building is basically organized so that all five functions are under the same roof, arranged in 4 different sectors: Farming (Production) on Farm Field; Manufacturing (Processing) in a Farm Lab; Promotion

(Consuming) in the Farm Restaurant; Sale (Trading) on the Farm Market and Education (Learning) carried out in all the four above mentioned sectors (Fig 2).

Fig. 2 Local Monoculture Farming System functions
(Source of illustration Fig. 2: author's drawing (Stanišić J.))

3.1.1. *Farming*

Production of agricultural crops and their seedlings - Farming, takes place in the context of green roofs located below the greenhouse in a terraced designed facility. The building is terraced so that the roof area would be as large as possible in order to obtain maximum production space. This part of the facility is called the **Farm field**. In addition to excellent thermal insulation, the installation of extensive green roofs allows the cultivation of various seedlings and agricultural products of low growth whose processing would be conducted in the building. It is also a way of returning back what was taken from the nature - a piece of land occupied by the building itself. This reuse of land as a renewable resource from the immediate local environment for roof gardens is one of the applied sustainable principles of traditional rural Vojvodina architecture in the modern building solution of LMFS. Green roofs are organized on terraces of the buildings and are situated within greenhouses. In order to save electricity for heating and lighting, greenhouses are built with reflective surfaces. Reflective surfaces are the cheapest source of energy, and in addition to thermal radiation, they reflect light as well. For faster growth and maturation of plants, a reflective surface is attached to a glass of a greenhouse. The thermal

effect is achieved by less dissipation of heat on the north side because of reflective surfaces installed, and in addition to that, insulation is doubled in the cheapest way. Each greenhouse has its own heating and led lighting system providing optimal farming during winter months.

3.1.2. *Manufacturing*

Processing of agricultural products and their seedlings is carried out in the enclosed spaces of the building, located below the production areas of green roofs. This part of the facility, with the necessary equipment for manufacturing and packaging the certain type of product is called the **Farm Lab.**

3.1.3. *Promotion*

The promotion of manufactured products is organized in a **Farm Restaurant** that occupies a front part of the ground floor. The restaurant is intended for potential customers to become familiar with the primary and secondary processed products. This area functions as an exhibition space. It is possible to organize festivals, which will draw attention to a specific plant. These festivals would attract residents of neighboring villages and towns and so stimulate the development of tourism in rural areas of Vojvodina. Neighbors would have the opportunity to get familiar with the final products, consume them and buy on the markets.

3.1.4. *Sale*

The sale of raw and processed products is carried out in the context of the last part of the plot in Vojvodina villages, where, at a certain part of the day, **Farm Market** is organized. The stands on which the products are presented are cube-movable containers that are "pulled out" from the building. These movable containers are an integral part of the ground floor of the facility, but not a necessary part of the building because the skeletal system of the construction allows the facility to be maintained without them. Each container is a functionally independent unit for itself. The building changes its shape and appearance of the ground floor thanks to the mobile containers. Their mobility allows them to be "pulled out" of the building to the inside of the plot where they unfold and set so they become sale stands at the market (Fig. 3). In the hours when the market is closed, cubes are drawn to the ground floor of the building where they fit perfectly so they become a part of it and then the facility is "closed" toward the street which ensures its

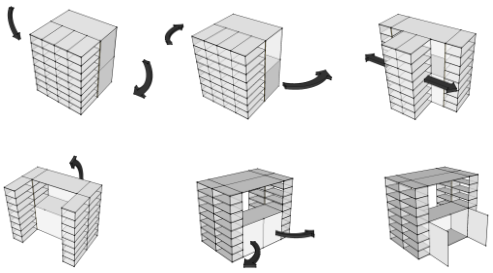

Fig. 3 Unfolding system of the cubes
(Source of illustration Fig. 3: author's drawing (Stanišić J.))

privacy. When the market is open, the part of the ground floor, which is designed for cubes, becomes an open, fluid area which allows visitors access to the market from the street. Due to a specific linear form and a large length of parcels in Vojvodina villages, containers are assembled within the last part of the plot so as to allow for the maximum use of the area to display as many products as possible.

3.1.5. *Education*

Education and employment of young rural population in LMFS facility takes place in all four sectors. Since the primary idea of the project is to reduce the unemployment of the young people in villages of Vojvodina and educate them about agricultural production, it is necessary for them to learn all phases of the agricultural good's life cycle so that they can later assign knowledge to their own household.

4. ARCHITECTURAL FEATURES OF THE BUILDING – EXPERIMENTAL STUDY

Architectural features of the LMFS building will be defined based on an analysis of the possibility to interpolate it within the existing structure of rural Vojvodina settlements. The analysis will be carried out in the plan and the model, based on one of the existing typologies of Vojvodina houses. As a result of these analysis, more possible variations of the new facility will be formed, that is, its typology. By integrating these different types of buildings into a wider neighborhood, the residential areas of Vojvodina villages would become multifunctional, without changing its appearance and structure. Using the benefits of traditional Vojvodina houses construction in design, new type of facility remains in accordance with the environment and ambience of this rural areas. Appearance and variations in the model of the new building will depend on these analyses and applied energy-efficient principles, both traditional Vojvodina's and modern technologies.

„*The spirit of heritage is to be expressed in other ways-not going back to heritage and tradition but starting with them. As heritage is a tested experience of previous generations it should not be ignored but it should transpose the inherited and develop it to meet modern needs.“*[7]

4.1. Environment and plan study

Based on analysis of one of the existing typologies of Vojvodina houses and specific sustainable principles organizing their environment, different types of the new building plan are formed.

4.1.1. *Terrain configuration*

Flat terrain, continental clime, which provides a lot of sunny days per year, and a relatively small altitude, are the advantages of Vojvodina's territory which contribute to the benefits for utilization of solar, geothermal and other renewable energy sources. In addition, the physical-geographic environment and geological composition of land in Vojvodina most of all influenced the choice of construction material, since the residents of this area have always used material that they had close to the hand. They were mainly using material from the immediate surrounding such as rammed earth, adobe, cane, etc.

For the needs of the roof production areas, project LMFS also uses the ground from the immediate environment, land taken from the nature by building the facility itself. This provides returning to the nature what has been taken away from it, and the land is again used (reused), as a renewable source, in the contemporary interpretation of Vojvodina landscape - roof gardens.

4.1.2. *Housing and plot organization*

Traditional villages in Vojvodina have particularly formed housing organization which represents the result of an orthogonal urban scheme from the time of Theresian space planning. The existing concept of typical housing organization with placing different content along the depth of the plot is very suitable for the use of solar energy as a renewable source. The new LMFS facility, with its structure and organization, respects the basic and essential aspects of the Vojvodina house: linear organization, shape and dimensions of the plan and placing the side facade, gable, on the street regulation line, which is one of the symbols of the traditional Vojvodina house. One of the principles of the Theresian planning determined the distance between the neighboring houses, which had to be at least 17 meters long, due to the risk of fire. This ensures uninterrupted sunshine on the south side of the plot and greater use of solar gains.

4.1.3. *Plan shape and form*

Different plan types of the LMFS facility will be formed according to the existing typology of Vojvodina houses, based on the relationship between the house and the plot (Fig. 4). The differences between these types are reflected in the possibilities of applying traditional energy efficient principles precisely because of the different relationship between the house and the plot. In order to fit the building into the environment of residential zone in Vojvodina villages, without compromising its physical structure or traditional ambient values, for each type of existing typology possible models of a new facility are being developed (Fig. 5). All types of the new LMFS building observe the basic characteristics of the Vojvodina housing organization: shapes and dimensions of plans correspond to the types of existing typology, and the organization of the Local Farm Market within the last part of the plot complies with the contents of the plot of Vojvodina houses. Dimensions of houses from the analyzed typology range from 5-6 m x 12-18 m. LMFS building is designed according to the principle of modules that can, if necessary, easily be "reproduced" without violations of its construction and function. The simple shape and design of the facility allows for its expansion or for increasing the square footage of its surfaces with an aim of getting larger production areas in case it needs to produce more plants and seedlings. Also, in case a larger production and sales areas are needed, it is possible to connect two neighboring plots, multiplying the module of the facility form (Fig. 6). Types of the existing Vojvodina house typology, based on the relationship between the house and the plot, from which different plans of the new building were formed are: Furrow house, Long house, Front house, Corner house and Turn-key house.

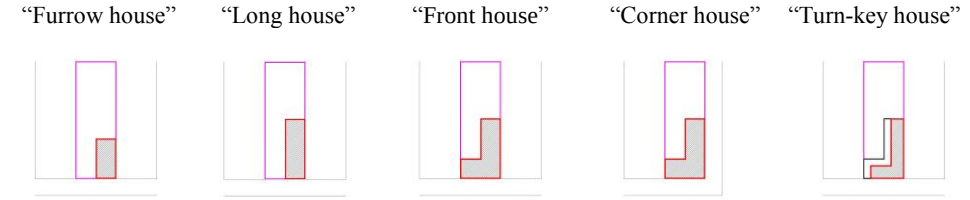

Fig. 4 Traditional Vojvodina house typology depending on the relationship between the house and the plot

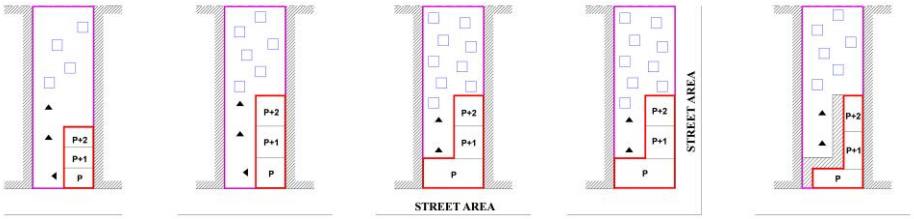

Fig. 5 LMFS typology – single plots
Legend: P=ground floor (Parterre-French); P+1=first floor; P+2=second floor

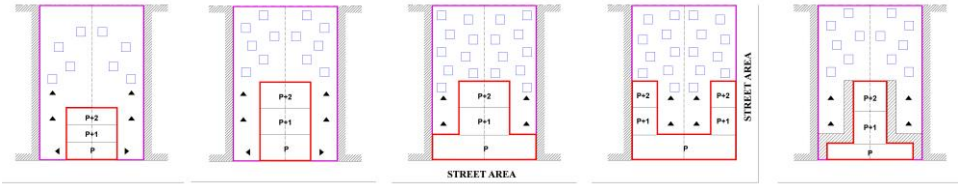

Fig. 6 LMFS typology - joined plots
Legend: P=ground floor (Parterre-French); P+1=first floor; P+2=second floor
(Source of illustrations Fig. 4,5,6: author's drawings (Stanišić J.))

4.1.4. *Plot landscaping*

The existing concept of housing organization in Vojvodina villages enables the formation of favorable landscaping on the plot in order to establish better bioclimatic conditions, improve the energy efficiency of the house itself and reduce heat losses during winter months. In this regard, the vegetation has a double function: it regulates the heat and light effect of the sun and the influence of dominant winds.

1) Vegetation as a temperature regulator (sun protection)

Adequate arrangement of vegetation on Vojvodina plots can greatly contribute to the regulation of temperature, that is, the thermal and light effect of sunlight. Placing deciduous trees on the south side of the plot makes a shadow, or protection from the sun during summer. In winter, when the leaves fall, these trees filter the sunlight rays and allow them to get to the building. This increases the heat gain during winter months. Also, vegetation reduces the need for artificial cooling in the summer because the absorption of sunlight lowers the ambient temperature and reflection.

2) Vegetation as wind protection

The dominant winds in Vojvodina, Kosava and Severac, have a double effect: they provide a favorable cooling effect during summer, while in winter they increase heat losses. Planting the coniferous trees on the north side of the plot provides adequate wind protection throughout the year. Deciduous trees on the south side of the plot turn the direction of dominant winds, toward the building in the summer, and from it during winter (Fig. 7).

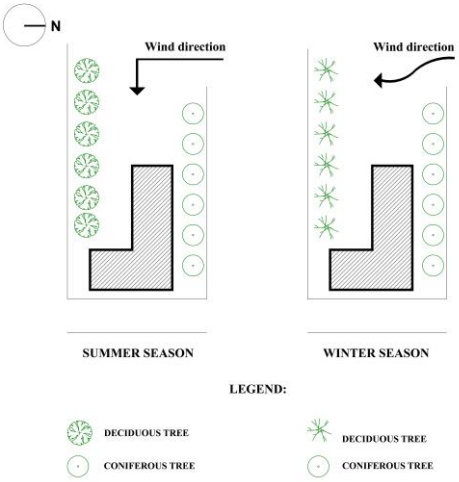

Fig. 7 Plot landscaping
(Source of illustration Fig. 7: author's drawing (Stanišić J.))

4.2. Design and model study

Different types of the LMFS building model are formed based on the analysis of the existing typology of traditional Vojvodina houses. The design and shape of these models represent the result of this analysis and applied traditional and modern energy efficient principles in construction.

4.2.1. *Model design*

These models are studies of contemporary architecture design which can be developed according to the location and context of Vojvodina villages by applying traditional construction principles of their houses. The LMFS facility is terraced designed for the needs of the production areas of green roofs, which is not typical for traditional Vojvodina houses. Compliance with the environment is achieved with implementation of the greenhouse whose design shapes the models in such a way that they receive a simple archetypal form of the Vojvodina house. When observing the LMFS model from the pedestrian perspective, the feeling of existence of the terraces is lost and the building fully gets the appearance and form of the Vojvodina house (Fig. 13). The modular structure of the facility allows expanding its area to neighboring plots, in case of need for larger production areas. Construction of the greenhouse covers only the front part of the plot during the summer months. In winter, it can be extended to the back of the plot, covering the Local Farm Market. For each of five types of the existing

typology of Vojvodina houses, four different types of LMFS structures have been formed, depending on their size and construction of the greenhouse. So there are four models for each type of building: on single or multiplied-joined plots and with greenhouse on the front and the back of the plot (Fig. 8, 9 10, 11, 12). Since the LMFS facility has a larger number of floors than the typical house in Vojvodina, the storey height is reduced so the continuity and skyline of these villages would not be disturbed. By applying the same arrangement and windows shape as in the Vojvodina house, natural ventilation in the building and compliance with the existing environment is achieved. The application of traditional, gabled roof of Vojvodina houses on the LMFS facilities enables the installation of solar collectors that supply the entire facility with the necessary energy from the sun as a renewable source. Type of solar collectors, used in the building, is made in the form and color of traditional tile roof cover, so that the new LMFS facility remains in compliance with the environment, in this segment too.

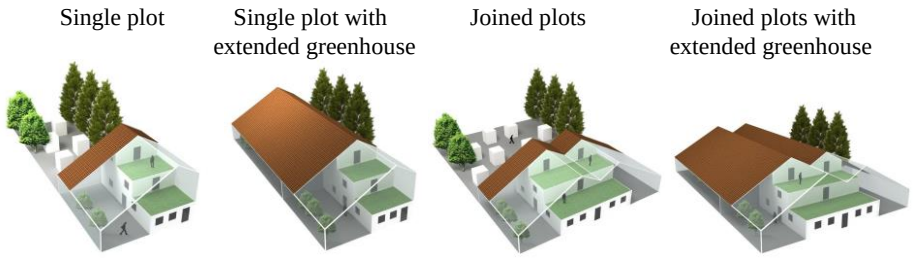

Fig. 8 LMFS model typology – Traditional "Furrow house" variations

Fig. 9 LMFS model typology – Traditional "Long house" variations

Fig. 10 LMFS model typology – Traditional "Front house" variations

Fig. 11 LMFS model typology – Traditional "Corner house" variations

Fig. 12 LMFS model typology – Traditional "Turn-key house" variations

Fig. 13 LMFS model elevations

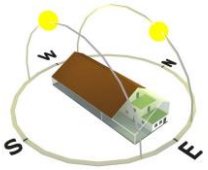

Fig. 14 Model orientation

(Source of illustrations Fig. 8,9,10,11,12,13,14: author's drawings (Stanišić J.))

4.2.2. *Orientation*

The roof, solar panels in the form of tiles and glass surfaces of greenhouses are mostly open and oriented towards the south thanks to the favorable position and orientation of the plots of Vojvodina houses (Fig. 14). This results in good day lighting and solar radiation gain throughout the whole year. In case of extension greenhouse construction on the last part of plot, the Farm Market, roof area for installation of solar collectors is increasing. Regulation of temperature within the building and protection from the wind, sun and other exterior factors is achieved with adequate orientation of traditional Vojvodina landscape design as previously explained in the paper.

4.3. Functional organization study

LMFS building is designed and functionally organized in such a way that it fully meets the needs of production, processing, promotion and sale of agricultural goods. The ground floor of the building is divided into three sectors. The processing of products is carried out in the Farm Lab in the last part of the ground floor, while the part of the ground floor which is oriented toward the street is reserved for the Farm Restaurant-

exhibition space and mobile containers that serve as stands for the sale of products on a Farm Market. At the time when the market is open, cubes are taken out of the facility, unfolded and placed on the inner part of the plot (Fig. 15). The indoor part of the first floor is a space for the processing of products, Farm Lab, while the open terrace - green roof is a Farm Field for the production of a specific plant and its seedlings (Fig. 16). The last (second) floor of the facility is also divided into two parts: the Farm Lab and terrace garden for production, Farm Field (Fig. 17). Each individual model of the LMFS building typology has the same functional disposition regardless of its size, shape and model type.

Fig. 15 LMFS model example – ground floor function

Fig. 16 First floor function **Fig. 17** Second floor function

(Source of illustrations Fig. 15, 16, 17: author's drawings (Stanišić J.))

5. APPLIED PRINCIPLES

Design, shape and appearance of the LMFS facilities depend a lot on applied energy efficient principles, both traditional Vojvodina and modern technologies. Thanks to this reconciliation between traditional and modern, the building represents a contemporary solution as a reinterpretation of the traditional rural architecture and principles. Reviewed traditional, urban and architectural, energy efficient principles of Vojvodina houses construction, which are implemented in the design of an LMFS building are:1) Reuse of land; 2) Terrain configuration; 3) Housing organization; 4) Plot and plan shape and dimensions; 5) Landscape design and vegetation; 6) Orientation; 7) Compact archetypal model shape; 8) Fenestration; 9) Traditional gabled roof shape; 10) Traditional construction materials; 11) Water from local wells. Some of the modern sustainable technologies applied, that are convenient for the use in the conditions of Vojvodina villages environment are:1) Green roofs; 2) Greenhouses with reflective surfaces; 3) Solar panels in a form of traditional tiles; 4) Geothermal energy production; 5) Biomass energy and CO_2 production; 6) Rainwater and Wastewater collection. All the applied energy efficient principles and the system of their functioning are shown on the example of one type of LMFS facility (Fig. 18).

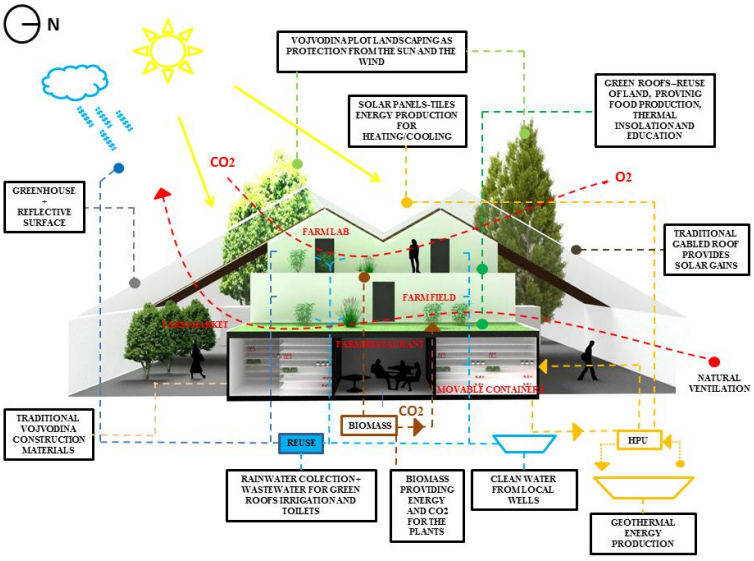

Fig. 18 Presentation of applied traditional and modern energy efficient principles (Source of illustration Fig. 18: author's drawing (Stanišić J.))

6. CONCLUSIONS

Abandonment of rural areas represents a current problem for the entire world. People are increasingly turning to cities under the influence of modern urban processes. The LMFS study project is an opportunity for preventing further departure of people from rural areas and an attempt to improve the economic and social situation, not only in villages of Vojvodina, but also in the entire country. Construction of several such facilities in one village in Vojvodina creates new employment opportunities for the rural population, and changes the rural tradition that in villages only land serves for work and not buildings. It gives an opportunity to the rural population to shift from agricultural land to man-made facilities and find employment in them. The village is "urbanized" in a certain way and becomes "closer" to the city lifestyle. The LMFS offers reconciliation between the traditional and the modern and establishes a rural-urban synergy. Cherishing rural tradition and re-using the energy efficient principles of traditional Vojvodina construction in the contemporary architecture of the LMFS facility, we preserve traditional local rural communities from decline in a new form that is in accordance with the conditions of modern society. Taking into account conditions of local environment during construction of these facilities and without compromising traditional architecture and urbanity of rural areas, the identity of Vojvodina can be preserved.

Acknowledgement. *The LMFS research project is a part of the doctoral dissertation "Urbanistic and architectural principles of energy efficiency of traditional Vojvodina houses - application in contemporary architecture" by author Jovana Stanišić, which is in the process of preparation.*

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PRIMENA ENERGETSKI EFIKASNIH PRINCIPA TRADICIONALNE VOJVOĐANSKE KUĆE NA SAVREMENOM OBJEKTU LOKALNOG MONOKULTURNOG POLJOPRIVREDNOG SISTEMA

Istraživanje pristupa aktuelnom problemu depopulacije i devastacije ruralnih područja u Vojvodini, koja polako nestaju, jer se sve više mladih ljudi okreće gradovima i urbanom načinu života, u potrazi za komfornijim radnim uslovima koji nisu u vezi sa poljoprivrednim aktivnostima. Ova sela, zajedno sa svojom jedinstvenom ruralnom arhitekturom, predstavljaju identitet područja, čiji bi nestanak doveo do gubitka identiteta i značaja Vojvodine. Sa druge strane, rad razmatra i jedan od problema današnje istraživačke prakse koji se odnosi na stalne pokušaje i potrebe interpolacije poljoprivredne proizvodnje u ionako već preizgrađena i zagađena gradska područja, čime se sela još više zanemaruju. Iz navedenih razloga se javlja potreba za uspostavljanjem jedinstvene strategije koja bi omogućila oživljavanje vrednih seoskih zajednica u Vojvodini, i učinila ove prostore boljim i naprednijim mestima za život, zadržavanjem poljoprivrede unutar ruralnih granica, kao i očuvanjem autentičnosti i tradicije vojvođanskog regiona.

Rad prezentuje projekat "Lokalni Monokulturni Poljoprivredni Sistem" kao koncept vizionarskog modela za novi tip objekta u selima Vojvodine čija bi izgradnja mogla da spreči dalji odlazak ljudi sa ovih prostora, pružajući im mogućnosti obrazovanja i zapošljavanja unutar objekata umesto rada na zemlji, budući da je to jedan od razloga zašto odlaze. Oslanjajući se na energetski efikasne principe tradicionalne vojvođanske kuće u izgradnji, ali primenjujući i neke moderne, održive tehnologije, ovaj futuristički model poljoprivrednog sistema omogućio bi povezivanje tradicionalnog i modernog u ruralnim sredinama Vojvodine. Projekat povezuje poljoprivredu, energetsku efikasnost, nasleđe i arhitekturu kako bi se oporavili i ponovo koristili lokalni resursi vojvođanskih sela kao kulturni pristup u savremenim istraživanjima za održiva moderna rešenja.

Ključne reči: *energetska efikasnost, poljoprivreda, ruralna područja, Vojvodina, nasleđe, savremena arhitektura*

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HISTORICAL AND STRUCTURAL SURVEY OF 19TH AND EARLY 20TH CENTURY BUILT HERITAGE IN NORTHERN VOJVODINA

UDC 624"18/19"(497.113)
691"18/19"(497.113)

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Abstract. *Studies of the historical development of construction and applied building materials have so far mainly focused on the most important architectural and engineering achievements that had a major impact on further developments. This paper focuses on the development of structures and building materials in a region that has not been the subject of previous researches, as the buildings studied belong to the narrow geographical area of northern Vojvodina during the period when it was part of Austro-Hungarian Empire. The research includes a detailed analysis of the preserved archival material, review of the literature, as well as analysis and research on individual buildings during restoration works. The results shown in the paper reveal the appearance of exceptional design solutions for individual structures and architectural achievements in the seemingly uninteresting and stalled provincial environment.*

Key words: *building materials, building structures, historical development, reinforced concrete, architecture*

1. INTRODUCTION

The 19th and early 20th centuries saw increased building construction as well as a widening range of applied building materials throughout Vojvodina.[1] The rammed-earth walls and timber roofs of the simple rural houses were gradually augmented by more modern structures and materials, such as cast iron and concrete, in the construction of

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[1] During the 19th century the territory of today's Province of Vojvodina belonged to the Habsburg Empire, and from 1867 to the Austro-Hungarian Dual Monarchy. After the First World War it became a part of newly formed Kingdom of Yugoslavia and after the Second World War of the Republic of Serbia.

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public, religious, and multi-storied residential buildings [1]. The example of Subotica in the region of northern Vojvodina is significant because a large number of original building designs have been preserved in the city's Historical Archive and most of these buildings still exist. Therefore, the research could be conducted more thoroughly than in other regions.

The research on the development of construction and the application of building materials was carried out by examining all the blueprints that were found dating from before 1875, as well as all the blueprints kept in the Fund 2 of the Historical Archive of Subotica, covering the period between 1875 and 1918. Fund 275, which contains the blueprints for public, industrial and religious buildings was also examined. This paper examines the structure and materials of the most characteristic buildings. The research on certain buildings was carried out during their restoration or adaptation. Some buildings call for further *in situ* examination for this research to be complete, but such an examination has so far proved impossible due to property access restrictions and insufficient financial support. The collection of data was carried out using empirical methods, desk and *in situ* research. In processing the data collected from various types of research (field research of material sources, legislation and planning documentation) methods of artefact analysis and comparative and contextual analysis were used. To obtain the results, methods of synthesis and result interpretation were used.

The historical overview of the development of construction and materials in the region around Subotica covered in this study is divided into three periods. The earliest period was marked by the use of traditional materials, including rammed-earth walls, mud brick and masonry structures, timber roofing and flooring, and thatched, caned, or shingled roofs. The second period saw the beginnings of the application of iron structures combined with masonry structures, whereas the last period introduced the use of concrete and composite materials, although most buildings, especially residential ones, continued to use masonry.

2. TRADITIONAL MATERIAL IN BUILDING CONSTRUCTION

At the beginning of the 19th century, Subotica had the status of a free royal town within the Habsburg Empire and was at a time called Maria-Theresiopolis. The town developed slowly throughout the 18th century after the territory had been deserted and ransacked by the retreat of the Ottoman Empire and the area returned to the Habsburg Empire [2]. The population that moved into the area during the 18th century usually built modest three-room rural houses of rammed earth walls, timber roofing, and thatched or caned roofs.[2] In the 18th century, brick was only used for religious and public buildings, such as churches and town halls. At the beginning of the 19th century, brick started to be used in the construction of two-story town houses of the wealthier townspeople. The first multi-storied residential building with traditional brick walls was constructed around 1815 on the Main Square (Republic Square 10), for the owner Jovan Milinović [4]. This occurred in the period that saw attempts to establish the "inner town" of Subotica, the

[2] The most widespread type of rural house was one with three premises: two rooms and the central area of a kitchen with an open fireplace. The fireplace, in addition to cooking, served as the source of heating for domed mud stoves positioned in the rooms. [3]

borders of which were finally defined in 1820 at the request of and by the instructions of the royal commissioner Ferenc Scultety [5].

Unlike other free royal towns within the Habsburg Empire, at the beginning of the 19th century, the Magistracy[3] of Maria-Theresiopolis did not have a building regulations book [6]. New houses were built without prior official notification or request for a permit from the Magistracy, so in early 1820 Commissioner Scultety asked for a decree to be issued by the Magistracy forbidding unlicensed building and rebuilding of houses until the city's urban plan was completed [7].[4]

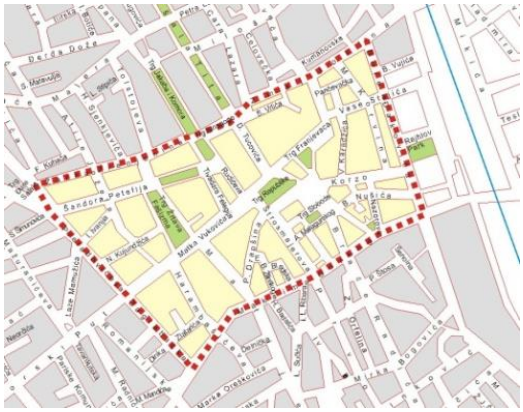

Fig. 1 Borders of the "inner town" of Mária-Theresiopolis
(author's drawing on the contemporary chart of Subotica)

In July 1820, the Commissioner issued instructions containing a number of clauses, all of which insisted on the separation of the "inner town" of Maria-Theresiopolis from the outskirts, prescribing that the houses in the "inner town" be built on a street alignment, with their longer side turned towards the street, constructed from solid material (brick) with tile or shingle roofing, unlike the houses on the outskirts, which might be constructed from rammed earth or adobe, with thatched or caned roofs, their triangular gables turned towards the street [7]. At the initiative of Commissioner Scultety, a Commission for town arrangement, appointed by the Magistracy, developed the Plan for Urban Development, which defined the zone of the "inner town" by means of six border streets. (see Fig. 1) [5]. The building regulations defined by the Plan for Urban Development also provided incentives for the application of brick and the construction of multi-storied houses in the "inner town".

After the Milinović house, similar houses were increasingly being erected on the Main Square and surrounding streets, in accordance with the established building regulations. These houses were constructed with masonry walls, their flooring made of timber, with parallel half-cylindrical or square timber beams. The blueprints dating in 1907 for the facade redesign of the previously mentioned Milinović house, shows a ceiling cross-section constructed with timber beams.[5]

[3] The town was ruled by the town council, which replaced the external Magistrate of the eighteenth century, the town Magistracy, judge, mayor, town captain, town attorney and town lawyer. [6]
[4] Historical Archive of Subotica (hereinafter HAS), F:13, 9.A.46./1820. Scult.
[5] HAS, F:2, ép. eng. VII kör 19/1907.

In 1827, a two-storied Inn was built at today's No. 8 Štrosmajer's Street, by Andreas Winkler. In 1841 Magistracy intended to purchase the Inn. An agreement was made on the price and submitted to higher administration levels for approval [8]. Engineer Sándor Tóth was engaged to design the extension of Inn, the design shows what the original Inn looked like [9] (see Fig. 2).[6]

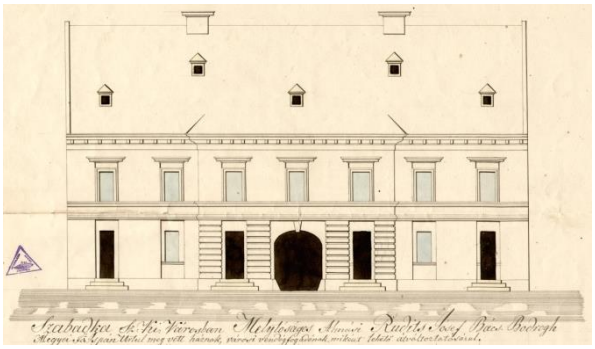

Fig. 2 Adaptation design for Inn, made by engineer Sándor Tóth (HAS, F:272, 13.A.20./aec.1843.)

The Inn was a two-storied building in the late-Baroque style with a large arched gate and gateway in the middle of the ground floor. The second adaptation design for Inn was made by János Scultety, commissioned by the town. Cross-section drawings show that the existing ceiling joists were made of parallel timber beams. The narrower rooms and the hallways had brick vaulted ceilings.[7]

The town owned only one Inn - "Nagy Vendégfogadó". This building was, in fact, a modest single-story house with rammed earth walls, built in the late 1770s [9]. As there was a need for a new town Inn, it was debated, for several years, whether new facilities should be built on the town-owned lot where "Nagy Vendégfogadó" was located or on the site of Inn originally owned by Andreas Winkler. It was finally decided that a new Inn, together with a theatre, should be built on the lot of the existed "Nagy Vendégfogadó".

Engineer János Scultety was commissioned in 1844 by the Magistracy to design the new Inn and the theatre. Scultety made the design for the Inn and theatre in 1845, and the foundation stone was laid in 1848 (see Fig. 3).[8] The revolutionary events of that year in Hungary [10] delayed the building's construction and work was not resumed until 1853, when the hotel wing of the building was completed, while the part containing the theatre hall was finished the following year.

The building of the hotel and theatre "Pest Városhoz" (as it was called then – today it bears the name of "Narodno pozorište – Népszínház" (National Theater)) had a V-shaped floor plan, with one wing featuring hotel facilities as the building's primary purpose at the time, and the other containing the theatre hall. The exterior facade was designed in a strict

[6] HAS, F:272, 13.A.20./aec.1843.
[7] HAS, F:272, 13.A.20./aec.1843.
[8] HAS, F.275, box 1.

and modest classicist style, whereas the front oriented towards the square was adorned with six monumental Corinthian columns with a tympanum above. The columns were made of brick and decorated with plaster flutes. Behind the columns, the main entrance and grand staircase led to the first-floor ballroom. In addition, the building also contained a restaurant and a confectionery. It was the first monumental public building, offering facilities yet unseen in the town, all located within a single building.

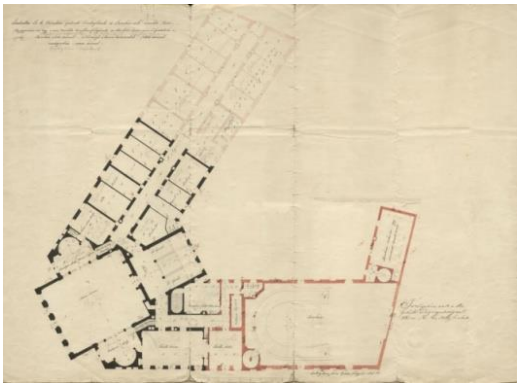

Fig. 3 Design for the ground floor of the Inn and theatre "Pest Városhoz", made by engineer János Scultety in 1845 (HAS, F.275, box 1.)

The theatre hall was built with horseshoe-shaped interior walls made of brick instead of timber, as was the custom for theatre halls at the time. Loggias and galleries constructed from timber abutted against the brick wall. The central part of the building and the hotel wing were masonry structures. The ground floor fascia had a vaulted structure (see Fig. 4), while the loft structure on the first floor was flat and made of timber. The roof structure was also made of timber. The central part of the building, oriented towards today's Republic Square, was roofed with tin, and the lateral parts with flat clay tiles [9].

Fig. 4 Photograph of the vaults on the ground floor of hotel facilities in the "Pest Városhoz" building (photograph author: Photonino, www.subotica.info)

An example of the ceiling structure made of timber half-cylinders split from round logs, characteristic of this period of construction in Subotica, was discovered in 2011 during the adaptation of the ground-floor premises of the house located at No. 5 Trg Žrtava Fašizma (see Fig. 5).

The space between the half-cylinders was filled with construction rubble, brick debris and mortar. This two-story building was constructed in 1880 as the hotel "Hungaria", for the owner Bela Jakopčić, designed by the Szeged architect Mihály Tóth.[9] The ground-floor gateway is vaulted, and so are the hallways and basements. Two years later, as an extension to the hotel, a ballroom was built in the courtyard, designed by Géza Koczka, a Subotica architect.[10] The ballroom building was constructed with brick walls, and its long span was bridged with a coffered timber ceiling supported by massive beams (see Fig. 6).

Fig. 5 Photograph of the ceiling made of timber half-cylinders on the ground floor of the former hotel "Hungaria" (photograph author: Viktorija Aladžić)

Fig. 6 The cross-sectional design of the hotel "Hungaria" ballroom, built in 1882 (HAS, F:2, ép. eng. IV kör 10/1882.)

Few original blueprints completely survived with floor plans, elevations and cross-sections, from the earliest period of construction of multi-storied houses in Subotica, a period that lasted from 1815 to the 1880s. Three of the most complete designs of the kind are: the 1859 design for the two-story house of Adolf Geiger (Štrosmajer's Street No. 6);[11] the 1873 design for the two-story house of Marko Batić (Dimitrija Tucovića Street No. 5);[12] and the 1880 design for the two-story house of Béla Váli (Matka Vukovića Street No. 5).[13] All three buildings are characterized by solid brick walls, floors made of timber beams, and semi-circular barrel vaults in the basements and kitchens with open fireplaces. Ceramic ovens in the rooms were grouped around common stacks fuelled from hallways, utility rooms, or the kitchens' open fireplaces. Although the construction and materials were identical for all three buildings, they differed in the stylistic features of

[9] HAS, F:2. ép. eng. jelz. nelk. 6/1880.
[10] HAS, F:2, ép. eng. IV kör 10/1882.
[11] HAS, F:2, 899/polg. 1859.
[12] HAS, F:2, 1770/polg. 1873.
[13] HAS, F:2, 128/polg. 1880.

their facades. Adolf Geiger's house was built in Baroque style, with arched openings on the ground floor. Marko Batić's house was built in the Romantic style, whereas Béla Váli's house was Neoclassical. Consequently, we can conclude that architectural styles did not influence the application of building materials in this case.

Preserved examples of industrial and agricultural buildings from the first half of the 19th century are rare in Subotica; however, the latest research has shown that the courtyard building located at today's No. 13-13a Jakaba i Komora Street actually was once a three-story barn, built in 1869 and owned by Salamon Halbrohr.[14] The barn was constructed with solid perimeter brick walls and four wooden columns longitudinally aligned along the middle of the barn, supporting a floor of load-bearing timber beams. The single-pitch roof was constructed from timber beams and covered with shingles. The interior wood structure is now damaged by the fire, but the exterior walls have been preserved, as well as the vent shafts on the facade and the metal screens that cover them (see Fig. 7).

Fig. 7 Photograph of the interior of Salamon Halbrohr's barn, built in 1869. (photograph author: Viktorija Aladžić)

3. Use of Iron Elements in Building Structures

The development of Subotica was rather slow until the arrival of the railway in 1869. Since the town is not situated on a river that would facilitate the transport of goods, it was the railway that enabled the development of the trade, export of the multitude of agricultural products which Subotica had at its disposal due to the vast areas of fertile farmlands, as well as the development of the industry. The sudden progress of the town's economy began in the 1880s, coinciding with the beginning of the application of the new iron construction. The progress was reflected in the population growth, but also in the sudden rise in the number of multi-storied apartment buildings and residences being built: during the 1880s, Subotica witnessed the construction of 26 two-storied residential buildings, as many as in the preceding 65 years altogether.

Iron construction elements in floor structures, as well as cast iron support columns, were being introduced gradually with the simultaneous ample use of the aforementioned

[14] HAS, F:2, 1019/polg. 1869.

traditional methods of constructing floors of timber. Out of approximately thirty multi-storied houses built throughout the 1880s and at the beginning of the 1890s, only four made use of iron I-beams in floor structures.

The turning point in utilizing new materials and construction methods was the return of the architect Titus Mačković from his studies to Subotica [11]. His initial designs included what was a local novelty: a floor structure supported by iron I-beams with shallow brick arches between them (referred to as the "Prussian vault") [12]. This design was first used in a two-story apartment building owned by Luka Aradski, located at No. 4, Štrosmajer's Street.[15] Mačković's next design comprising an iron beam floor structure and shallow brick arches was a two-story apartment building owned by Petar Radišić, designed in 1882 and located at No. 9 Matka Vukovića Street;[16] followed by the two-story apartment building of Ferenc Sümegi, designed in 1885 and located at No. 25 Maksima Gorkog Street.[17]

In the house owned by Petar Radišić, iron I-beams were utilized only in the ground floor ceiling, while the ceiling below the attic remained of timber, and the basement ceiling had brick vaults. In the house owned by Ferenc Sümegi, the "Prussian vault" was also used in the basement ceiling. Simultaneously, Mačković was also designing houses with timber ceilings, just like all other architects in Subotica. Timber floors were predominantly used for another decade and a half, probably because of the high price and limited availability of iron beams throughout the 1880s.

According to our research, the first structure which utilized vertical iron elements, i.e., cast iron columns, was the railway station passenger platform roof erected during the expansion of the station building. Towards the end of the 19th century, the existing railway station building was becoming too small for the increased traffic. A significant expansion of the building was ordered, including the extension of the roof over the passenger platform, made of an iron lattice structure supported by 18 cast iron decorative columns. The design of the extension of the Railway Station was developed in 1891 in Szeged by the engineer signed as Kurt.[18]

The wide use of iron I beam supports in ceiling structures started in Subotica in the second half of the 1890s and, as evidenced by the preserved blueprints, all multi-storied buildings constructed in that period had their ceilings made of the "Prussian vaults". However, the ever faster economic development of the town towards the end of the 19th century brought in its wake new materials and construction methods for erecting multi-storied houses and public buildings, namely, the use of concrete.

4. USE OF CONCRETE AND OTHER COMPOSITE MATERIALS

Developments in the use of new materials and building methods, propelled by the industrial revolution all over Europe, thoroughly transformed the general appearance of the world and influenced the less advanced European regions, such as northern Vojvodina, that found themselves on the fringes of industrial progress.

The oldest record of the fact that Portland cement was available in Subotica originates from 1864, when the Portland cement factory in Perlmoos (Austria), owned by a certain

[15] HAS, F:2, ép. eng. I kör 5/1880., ép. eng. I kör 6/1881.
[16] HAS, F:2, ép. eng. I kör 8/1882.
[17] HAS, F:2, I – 232/1885.
[18] HAS, F:2, ép. eng. VIII kör 17/1891.

Angelo Saulich (Portland-cement Landesfabrik von Angelo Saullich im Perlmoos)[19] sent a notice to the Town's Construction Department to advertise the production of this building material. At the time, however, a factory of Roman cement had already been opened in Beočin (Belcsény), near Novi Sad, in 1855, owned by József Csík [13]. The production of Portland-cement commenced in Beočin around 1870 [14] after Csík returned from the World Exposition in Paris in 1867. The cement used to produce concrete in Subotica most probably originated from the Beočin cement factory which was much nearer to Subotica than the factory in Perlmoos.

The earliest known application of concrete in Subotica occurred in 1898, when this material was used in building the pool of the first steam bath owned by Dezső Joó and Emánuell Fürst, in what today is No. 12 Dimitrija Tucovića Street [4]. The first building of the steam bath, with two smaller cold-water pools, two dressing rooms and a line of rooms with individual baths, was built in 1879, by expanding an older building of unknown purpose.[20] This bath house building was rather unimposing and built of traditional materials. In 1893 and 1894, two small-scale upgrades were made to the building by the design of Nándor Wagner.[21] In 1898, Dezső Joó engaged a young architect named Lajos Fazekas to design another, bigger pool, to be built on the plot of land behind the existing bath house.[22] Realization of this design involved the use of contemporary materials and construction methods. Lajos Fazekas, just like Titus Mačković, was a forerunner in utilizing state-of-the-art building techniques and materials in Subotica. The pool was made of some type of concrete, this being the oldest documented use of concrete in Subotica. The ceiling was constructed with "Prussian vaults" supported, via iron I-beams, by the two rows of iron columns stretching longitudinally on both sides of the pool (see Fig. 8). Exterior walls were of brick, while the single-pitch roof was of timber. (see Fig. 9).

Fig. 8 Photograph of the bath house owned by Dezső Joó, shot in 2013. (photograph author: Viktorija Aladžić)

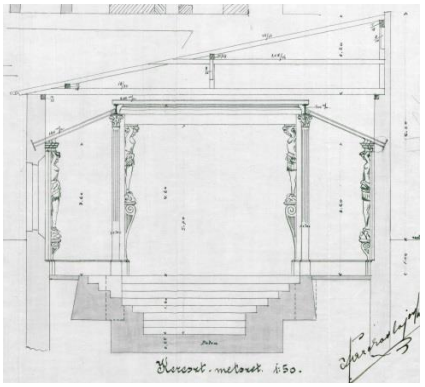

Fig. 9 Design of the cross-section of the pool in Dezső Joó's bath house dating from 1898 (HAS, F:2, ép. eng. VII kör 20/1898.)

[19] HAS, F:2, 1743/polg. 1864.
[20] HAS, F:2, 4823/polg. 1879.
[21] HAS, F:2, ép. eng. VII kör 24/1893, ép. eng. VII kör 17/1894.
[22] HAS, F:2, ép. eng. VII kör 20/1898.

The next year, Titus Mačković designed a three-story apartment building for the architect Lajos Fazekas, currently at No. 13 Age Mamužića Street [8]. This was not only one of the earliest buildings in a town built in the style of Secession, but it was also planned to utilize reinforced concrete for the floor structure, instead of the commonly used "Prussian vaults". It is yet to be examined whether concrete was actually used. This was the first design of a residential building which envisaged the use of reinforced concrete.[23]

4.1. Synagogue structure

The most famous building in Subotica that was built with the use of concrete is the Synagogue. Its structure was a pioneering work of two Budapest architects: Marcell Komor and Jakab Dezső [15]. The Synagogue was built in 1902 in the style of the Hungarian Secession, with rich floral ornaments inspired by Hungarian folk art. However, its greatest value is the unique structure made of iron columns and beams, supporting the vaults and the dome made of concrete and wire mesh. [16]

The central eight-sided space in the Synagogue is created by eight iron columns arranged along the edges of a square with truncated corners, the longer sides being 10.6 m long and the shorter ones 3m long. These columns are the base for the building's exquisite structure. At their tops, the columns are connected with horizontal iron beams 80 cm high, which in turn support a regular octagon-shaped brick wall called a tambour. The octagonal base for the brick tambour was created by staggering the iron beams at the angles of the truncated square inwards. Above the tambour stretches a concrete dome 8-10 centimetres thick, reinforced with wire mesh [17]. Its rigidity and bearing capacity are provided by 50-centimetre-high ribs arranged in the shape of a star. There are eight of these ribs near the apex of the dome, while they multiply to a total of 32 separate ribs near the base [18] (see Fig. 10). The interior height of the dome is between 15 and 23 meters. Above the interior concrete dome rises the timber structure of the outer roof dome, which shields the interior dome from the weather while simultaneously emphasizing the dome's position viewed from the outside.

Fig. 10 Dome of the Synagogue
(photograph author: Viktorija Aladžić)

[23] HAS, F:2, ép. eng. I kör 6/1899.

The main nave of the Synagogue, as well as the transept, are vaulted by concrete and wire mesh vaults, also stiffened by ribs below the timber roof structure. As the central dome is supported by the iron columns, the exterior walls are unburdened, turning into curtain walls, while the interior dome itself mimics the structure of a tent. Four smaller towers above the corner areas of the Synagogue, which house the stairways to the galleries, serve to achieve the balance of the masses, as well as to emphasize the verticals of the four stairways. The central top outer roof dome of the Synagogue, as well as the four smaller towers, were covered by zinc sheet, while the quarter-domes above side entrances at the corners of the Synagogue were roofed by lead sheeting. However, during the building's restoration, the roofing on all domes and quarter-domes was replaced with copper sheets [19].

The main binding component of the concrete used in casting the vaults and the dome of Subotica Synagogue was gypsum [17]. No cement was used in making this concrete mixture. Since gypsum is water-soluble and has a corrosive effect on iron, i.e., the wire mesh, it appears that the concrete used in building the Subotica synagogue was not an entirely reliable material, even though it has persevered for more than 110 years now. The structure made of it certainly represents a pioneering engineering achievement in concrete structures. It remains unclear why cement was not used in producing this concrete. At the time of the Synagogue's construction cement had been produced for a long time in the Beočin factory. In any case, the beginning of the 20th century was a period of exploring the possibilities of new materials and types of structures, especially concrete. Since no material testing or static calculations were undertaken at the time, the design of concrete structures and concrete mixes was performed experimentally and empirically.

Compared with other early reinforced concrete structures, which are considered as the world's first reinforced domes in history, namely domes of Armeemuseum (1902–1904) and Anatomie (1905–1907) in Munich, the dome of the synagogue in Subotica can also be considered as a very important early pioneering work, although the application of material was not the same. Reinforced concrete as elective subject appeared at the Budapest University in 1903/04 in the lectures given by Szilárd Zielinski. Other reinforced concrete domes in Hungary dated from a later period, reaching intensive development between the two World Wars [20].

4.2. Szilárd Zielinszky's intervention on the theatre building in Subotica

The introduction of concrete into building practice was quite slow, conditioned by two main reasons: the unavailability of high-quality aggregates and cement, i.e., their high price, and the lack of confidence in modern structures made of concrete.

The next important building in which concrete and reinforced concrete were used is the National Theatre ("Narodno pozorište – Népszínház"), reconstructed in the period between 1904 and 1907. During the reconstruction, a new reinforced concrete roof structure was built (see Fig. 11) above the auditorium of the main theatre hall. The structure was designed by the well-known engineer Professor Szilárd Zielinszky (1860–1924), who is considered to have been one the best constructors of concrete structures in Europe at the time, especially for the structures of water towers [14]. In 1900, he had the opportunity to meet François Hennebique at the Paris World Exhibition, get acquainted with his methods of construction using reinforced concrete and obtain the rights to use this French patent in Hungary. Dr. Zielinszky manifested his exquisite engineering

abilities and knowledge in several dozen large buildings throughout Austria-Hungary, and the structure above the "Great Hall" of Subotica's National Theatre is a typical example of magnificent concrete construction at the time, carried out according to the Joseph Monier and François Hennebique construction system [21].

The reinforced-concrete roof structure above the theatre hall was built during the reconstruction of the building between 1904 and 1907, replacing the old timber structure. The new RC roof structure was three-dimensional and made up of six transverse frames spanning 17.3 m connected with concrete blocks resting on solid brick walls. The roof end RC frames were enclosed with 8-cm-thick RC walls. Each RC frame had horizontal ties, partly hanging from the frames by means of 20x25 cm trussed beams reinforced with 30 mm ø iron reinforcing bars. Trussed beams with 35x40 cm cross section were reinforced with 30 mm ø vertical reinforcing bars and 30x1 mm ties (following Hennebique's armoured concrete system) spaced at 30 to 50 cm. Across the roof frames, at a 35^{o} of inclination, a Monier RC slab was formed, 10 cm thick and reinforced in both directions with 8 mm ø bars spaced at 25 cm. This slab was longitudinally supported by RC beams and transversely by the frames. The longitudinal beams were supported by the frames and had cross-section of 12x15 cm, reinforced with 20 mm ø bars. The lower horizontal Monier RC slab hung from 16x20 cm RC longitudinal beams supported by the ties. The slab was 5 cm thick and reinforced in both directions with 8 mm ø bars spaced at 25cm. The frame closest to the Great Hall stage had a vertical RC wall constructed within the frame, which together with the RC gable wall constituted the firewall [22].

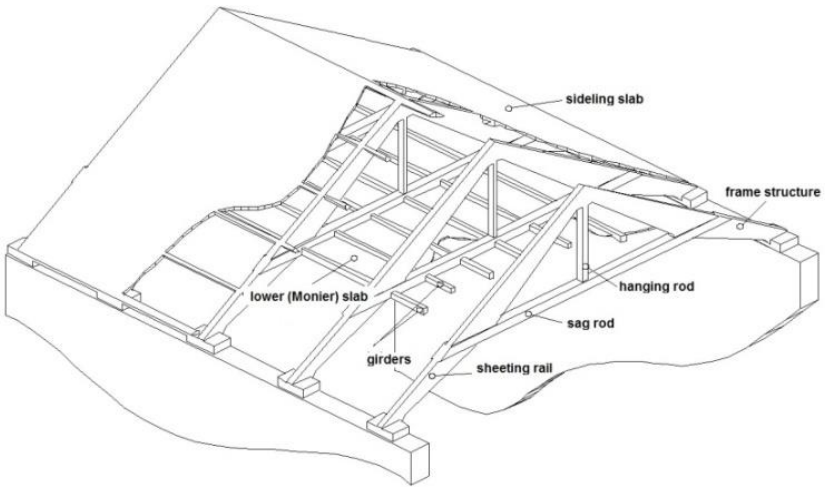

Fig. 11 Spatial reinforced-concrete roof structure on the "Nationa Theatre – Népszínház" building, a masterpiece of Dr. Szilárd Zielinszky (author's drawing)

In 1915, a fire broke out in the auditorium and completely destroyed the stage and the adjoining part of the building, but thanks to the RC structure it did not expand to other parts of the building. As it was the time of World War One and the ensuing post-war period, activities on the reparation of the fire-damaged building only began in 1924, with Prof. Đorđe Mijović from the Faculty of Civil Engineering in Belgrade making a condition

evaluation of the theatre structure. In his report from 1924, he concluded that the RC structure, as well as the walls it leaned on, were in satisfactory condition, but that it was necessary to repair the lower slab, for which he also suggested repair solutions [23]. The reconstruction was made in 1926 when the lower RC slab was replaced, while other parts of the structure remained in their original state. This exceptional structure was unfortunately demolished in 2007 when work on the reconstruction, adaptation and extension of the Subotica National Theatre building began.

4.3. Other examples of concrete structures

The next building which had reinforced concrete flooring and ceiling was not constructed until 1907. It was a two-story apartment house owned by Antal Morvay, built by design of engineer Milan Zarić and located at No. 18 Vase Stajića Street.[24] Its walls were made of solid brick. In the same year, Titus Mačković designed the two-story administrative building of the Subotica electrical tramway company, commissioned by the *Compagnie de Services Urbains Bruxelles*, also built with solid brick walls and reinforced concrete flooring and ceiling and is located at today's No. 22 Segedinski put Street.[25]

The beginning of the 20th century was marked by experimentation in house construction methods and materials including the use of different materials as concrete aggregates. Among other things, a new version of concrete came into use, with slag as the aggregate. This material was used in the construction of the foundations and base walls of János Bébecz's house at No. 104 Braće Radića Street, designed in 1908 by Miklós Zakaria, a railroad engineer.[26] This house is today in a bad state. The surfaces of the slag concrete mix exposed to atmospheric conditions are now crumbling, and cracks have appeared in the base walls. Analyses of this concrete mix and structure are certainly called for, in the first place for safety reasons, but also for the purpose of making a comparative analysis of the durability of the concrete, since this house represents one of the early examples of buildings constructed with the application of concrete.

Fig. 12 The Grand Terrace by Palić Lake
(photograph author: Viktorija Aladžić)

[24] HAS, F:2, ép. eng. VIII kör 16/1907.
[25] HAS, F:2, ép. eng. 0 kör 66/1907.
[26] HAS, F:2, ép. eng. II kör 2/1908.

The Grand Terrace, at the lake Palić, was also constructed with a concrete roof structure, designed by Komor and Jakab [15] (see Fig. 12). In the late 19th century Palić was a spa and favourite resort of Subotica's townspeople. Central to the Palić tourist complex was the "Grand Terrace", built between 1909 and 1912 in a version of the Hungarian Secession style, as a multipurpose building containing halls and two large terraces where balls, parties, theatrical performances, sports competitions and exhibitions were held. A special part of this building is a vaulted concrete structure above the first-story great hall. This vault is supported by the lateral solid brick walls and suspended from the iron roof structure positioned right above it. The structure is built with concrete-mortar of an average thickness of 10 cm and has iron reinforcement with 10 mm and 14 mm ø bars, spaced at 20 cm and 30 cm. The vault is additionally reinforced with wire mesh in its middle plane. Since the vault is suspended from the iron roof structure, this iron structure has the role of bearing a greater part of the load from the vault. The suspension system was achieved by means of wire ropes tied directly to the elements of the roof structure or indirectly to transverse iron "I-220" cross-section beams leaning against the rafters. An integral part of this structure is also a pair of iron "2xI400" beams that bridge the span above the middle side entrance to the great hall in the middle longitudinal wall. A vault was built right above this entrance from the same material as the structure above the great hall [24]. At the beginning of 2006, the Government of Serbia and the City of Subotica initiated the reconstruction and restoration of the building that was completed in 2012.

The Town Hall in Subotica is the most monumental building constructed at the given period, between 1908 and 1912. It was built according to the design of Marcell Komor and Dezső Jakab [15]. In the construction of the Town Hall, a plenitude of modern materials and structures were used in combination with traditional ones, but in situ analysis of this building was not possible due to its idiosyncratic features; furthermore, the designs for the Town Hall preserved in the Historical Archive do not provide precise insights into its construction and it was therefore not examined as a subject of this research. Examination of the Town Hall construction and the applied materials will be possible during the next restoration of the building, since it is protected by law as one of the cultural monuments of exceptional importance, and thus not available for partial research outside the official restoration works.

5. CONCLUSIONS

Buildings in Subotica that incorporated new developments in construction and materials had both local and international significance. Although South-East Europe at the beginning of the 19th century largely lagged behind the rest of the world with respect to the development of construction materials, the spreading of the railroads allowed for a fast connection to the world, as well as the exchange of new ideas. Thus Subotica, which in the 18th century was an extremely underdeveloped area, by the end of the 19th century had made great strides in the development of building materials, construction and technology.

The purpose of this research has been to point out that provinces should not be overlooked in favour of large cities, especially capitals, since the provinces can also boast important constructors who leave their legacy, sometimes producing more daring building achievements there than those in the capitals and other centres of growth. Although there are

not many buildings in Subotica that represent significant achievements in terms of novel materials and structures at the end of the 19th century, these buildings are still relevant and unique pioneering works of architecture and construction. Their significance is recognized primarily in the case of the Subotica Synagogue, which has been listed by the World Monuments Watch organization as one of the world's one hundred most endangered monuments (in 1996, 2000, 2002 and 2006), and in 2014 it was included in the Seven Most Endangered Monuments program by the Pan-European organization Europa Nostra.

Regarding the fact that the construction of the Synagogue was a forerunner of modern concrete structures, and it is currently facing restoration works, the process of designing the dome and vault structure deserves to be exhaustively explored. It is not known yet how Marcell Komor and Jakab Dezső developed the synagogue structure and why they applied gypsum instead of cement as a building material. These questions might never be answered, but more efforts have to be put into the research of a synagogue structure through cooperation between engineers and researchers from Serbia and Hungary.

In addition to research on this topic, we propose further studies of the oldest concrete from the beginning of the 20th century in this region, because in this way their characteristics of durability and strength can be recognized even today.

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ISTRAŽIVANJE ISTORIJE I KONSTRUKCIJE OBJEKATA GRADITELJSKOG NASLEĐA 19. I POČETKA 20. VEKA U SEVERNOJ VOJVODINI

Dosadašnja istraživanja istorijskog razvoja izgradnje i primene građevinskih materijala uglavnom su bila usmerena na najvažnija arhitektonska i inženjerska dostignuća, koja su imala presudni uticaj na daljnji razvoj. Ovaj rad se fokusira na razvoj građevinskih konstrukcija i materijala u regiji koja nije bila predmetom ranijih istraživanja, a istraživani objekti pripadaju užem geografskom području severne Vojvodine u razdoblju kada je ona bila u sastavu Austrougarske. Istraživanje obuhvata detaljnu analizu sačuvanog arhivskog materijala, pregled literature, kao i analize i istraživanja pojedinih objekata tokom restauratorskih radova. Rezultati prikazani u ovom radu otkrivaju pojavu izuzetnih projektantskih rešenja pojedinih struktura i arhitektonskih dostignuća u na izgled nezanimljivom i zaostalom provincijskom okruženju.

Ključne reči: *građevinski materijali, konstrukcija objekata, istorijski razvoj, armirani beton, arhitektura*

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ADDITIONAL INSIGHT INTO CREATIVE CONTRIBUTION OF LE CORBUSIER

UDC 72.036MODERNIZAM

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Abstract. *Social turbulences and discontinuities of the 20th century, have as always reflected upon scientific and creative achievements, most visible in changes in architectural thought and relation to space. First half of the 20th century was shaped by the modernist movement, represented through technical and technological achievements of building into economy, social context and culture giving an overall sense of units and spirt of urbanism and architecture of the modern era.*
In architecture there is a special place for the architect of the new era Le Corbusier whose narrative shaped and dominated the urban and architectural medium. Through research one can draw an analogy conceived by Le Corbusier between a typical serial housing unit and his functionalist urban and regional planning. He was at the same time praised and despised, but has definitely shaped the urban landscape as we know it today.
Through research into his essence and paradigms and contribution, this paper aims to reflect his urban design process that originated in multiplication and standardization of single units (family or collective) combined with his visions for an expanding cityscape.

Key words: *Le Corbusier, XX century, modernism, architecture, urbanism, urban planning*

1. INTRODUCTION

The entire 20th century was shaped by tumultuous social upheavals characterized by bustling social flows, increased individual comfort and prosperity, as well as numerous crises and turmoil. This is the age of incredible human achievement and development science and technology, but also an era marked by the unseen possibility of destruction [1].

Sizzling social currents of the historical stages of development, including the twentieth century, have been reflected in the most visible area of man's activity, architecture and art. They always reflect on man's cognitive and creative achievements, as answers to

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discontinuities in civilization. Many architectural orders were mirrored in the field of other arts, literature and often in conjunction, reflected on architectural thought and sense of space.

The architecture of the XX century is characterized by the emergence of numerous movements and in the entire history of civilization it has never been so autonomous. By linking technological opportunities, economics, social context and culture, more than ever before, architects have influenced the formation of the tastes and habits of its investors, but also of the society. Nevertheless, the twentieth century, was marked by a modern movement that, in its more than three decades of its active phase, created a large number of followers. Architects have developed and experienced the movement, building their creative philosophy to support or resist modern doctrine. The orders have been replaced by aesthetic codes, and utopian spatial and urban visions have played a key role in its development. The Spirit of Modernity became the "cement" of the twentieth century [2].

This cement was shaped by life and work of architects, as embodiment of new brave era of architecture heading into a new world. Their visions of space became technological, economic, social and cultural fundamentals to entire nations. Among them, the name of an exponent of the New Age, a composer of complex processes in urbanism and architecture – Le Corbusier, is especially emphasized.

Starting from the thesis that Le Corbusier urban theories were ultimately shaped by his visions of architecture; the goal of the article is to analyze the structural and functional meaning of his work and influence. His architecture appears to provide rational solutions, but is essentially derived from technical calculation and/or a complex sense of spatiality within the process of emergence and development of Le Corbusier's urban and architectural concepts starting from single housing units, repetitive patterns, followed by the collective and its transposition into urban schemes. Since the architect's polyvalent work requires a concise approach and interpretation, sometimes eluding a firm conclusion, it is important to emphasize that the aim of this analysis is not to change the order in the existing division in Le Corbusier's work, but essentially to point out the different perspectives – a critical overview of his urban and architectural paradigms as a contribution to the general theory of the urban architectural design – as Le Corbusier himself has said, "There are no small and large inventions; there are only small or big consequences" [4].

2. METHODOLOGICAL APPROACH

In order to indorse the initial argument of this paper – Le Corbusier's urban theories were based on his architectural premises – one must understand the context, the zeitgeist that shaped his perceptions which is reflected in his urban and architectural opus. It is therefore necessary to reiterate the essential overview of prominent influences and substantial experience of his predecessors, as well as the socio-economic circumstances and cultures with radical new attitudes towards built space. The analysis of structural and functional meanings of this new standardized architecture, considered by Le Corbusier as his ultimate accomplishment can be translated into urban form and scale. Furthermore, the paper will present three urban theoretical models of the era demonstrating Le Corbusier's ability to create urban space variations based on minimal number of elements and using a strict building code in all scales starting from a single house, to a city and then a region. This analytical reflection will incorporate both, positive and negative connotations that

stemmed from his ideas, and that this paper will be one more contribution, an integral perspective on a legacy that still affects architectural and urban practice.

2.1. Methods

The research within this paper derived from the description model methodology that involves the process of simply describing or reading facts, processes, and objects in nature and society, and empirically validating their relationships, but without scientific interpretation and explanation [5; 6; 7]. In the initial phase of the research, the application of the descriptive method allowed us to identify important features of facts and processes in the zeitgeist in which Le Corbusier created, their causal connections and relationships.

In the further course of the research, we applied the inductive and deductive method. Induction is the initial, and deduction is the final process in scientific knowledge. One without the other method is not possible, that is, it is inefficient, as are their results if used separately.

The inductive method is the systematic application of the inductive method of inference, which, on the basis of an analysis of individual facts, leads to the conclusion of in general, i.e. it is based on the inference procedure from single to general. There are several types of induction, namely: complete, incomplete, predictive, analogous, universal and causal [5; 6; 7]. For a complete analysis of the structural and functional significance of Le Corbusier's theoretical settings of architecture and urbanism, we applied causal, predictive, and analogous induction. Causal induction analyzes the causal relationship between the phenomena that precedes and the phenomena that follows, thus determining the cause and effect relationship. Predicative induction is a thought process that takes place through inference from one class of phenomena to another class, whereby only inference is based on their similarity. Analogical induction is based on inference by analogy, with thinking moving from a single to a general phenomenon [5; 6; 7]. By causal induction, we analyzed the influence of the predecessor on Le Corbusier's attitude to spatiality, while the predictive and analogous inductions were applied in the analysis of Le Corbusier's actions as architect at all scales (house-city-region).

The deductive method is the systematic application of the deductive inference by which specific and individual extrapolations are drawn from the general rules. In science, it is used to explain facts and laws, predict future events, discover new facts and laws, test hypotheses, and make scientific presentations. As in the final stage of research, the deductive method relates to inference based on the results of observations or experiments [5; 6; 7], so in this paper it was applied in the formation of specific results and final conclusions in order to confirm the basic starting point of the research.

In the part of the research that deals with the understanding of Le Corbusier's new standardized architecture and the three theoretical urban settings of a modern-day city, we applied methods of analysis and synthesis. Generally, in science, these methods have a common research object and are mutually assumed.

The breakdown of complex concepts, judgments and conclusions into their simpler constituents, and the study of each part for itself and in relation to other parts, is called the method of analysis. The opposite process of scientific research, through the fusion of parts or elements into a whole, of assembling simpler thought creations into more complex ones, is called the synthesis method. According to the gnoseological function, both methods are divided into: descriptive, when describing the elements of a whole and explicative, when explaining a whole based on its parts [5; 6; 7]. In this part of our research, we applied a

descriptive method of analysis and an explicit method of synthesis in order to achieve logical and consequential, as well as controversial aspects of his ideology.

3. SETTING THE CONTEXT

In order to establish a relation between Le Corbusier's theoretical tenets of architecture and urbanism, it is necessary to determine a contextual framework from which it is possible to obtain a critical and comprehensive review of his work.

3.1. The origin of Le Corbusier's ideas of the city

Scientific achievements, technological and industrial progress, wars, social, economic, and cultural environment of the 20th century proclaimed the dominance of the new technical culture. Industrialization led to a large demographic influx of rural population into cities, allowed the machines to replace handcrafts, caused the transformation of family and, in general, social customs. In the field of construction, revolutionary constructive and technological novelty was made possible by the use of new materials - reinforced concrete, steel and glass. In the „era of machine/mechanical civilization "[4], these achievements adapted architecture to the world of machine production and included the constructive system of the object among the expressive elements of the architectural vocabulary. The objects themselves become machines that serve and man's needs are shaped according to economic criteria. Requiring bare minimum in terms of accommodation, only free space, they could stand anywhere, in the country side or within a tissue of the city [8]. Multiplication of them in a free space, the city could be created. Thus "the realized architectural revolution offered its means to the urbanization of modern cities" [4]. The era of machine civilization embodied "the most progressive forms of its era, and the mission of architecture, as the driving force of material progress, was to adapt, even to master these forms" [8].

In such an environment, the image of the creator of Le Corbusier is, to a large degree, a product of the time. It was a time when architectural creation was divided into technical processes, as a result of rational thinking in accordance with the mechanical era; and on emotions, as a reflection of an irrational feeling and achieving the spiritual well-being of a man of the new age. The unified, technical and spiritual component, in his entire opus, made the synthesis through which he sought for the universality of spatial values. Being often in a position to defend his ideas, even at the time of their emergence, Le Corbusier said that "architecture is conditioned by the spirit of time, and the spirit of time is the in depths of the past, the knowledge of the present and the perception of the future" [9].

The origin of Le Corbusier's ideas of the city was precisely the spirit of the time in which he lived that determined his beginnings and overall output. *Nothing creates nothing* (lat. *Ex nihilo nihil fit*, Parmenides), that is, the logical process of the evolution of one idea is always preceded by the embryo, i.e. an idea that existed before and which enabled this further development. The design of Le Corbusier's creativity was prepared by the work of the predecessors, by the action of various ideological movements and technical achievements in the field of architecture. The material and spiritual culture of the West has become so fertile for the evolution of its ideas of architecture and urbanism. Accumulating everything: ideas, substance and experiences of the predecessors, as well as

European society, economics, sociology and culture, he shaped the modern movement and formulated it with clear principles.

3.1.1. *From August Perret to Dom-ino house*

The experience he gained while working with August Perret started Le Corbusier's pathway. At the time they met (1908), Perret was already known as the pioneer of reinforced concrete structures and claimed that the new material and new constructions would produce new architectural forms. By absorbing Perret's ideas and experiences, Le Corbusier has generated his own understanding of architecture, and indirectly urbanism, based on the technical, technological and design possibilities of this new material.

As a result, a design was created with clear signs of preference by Le Corbusier for reinforced concrete, the constructive skeleton of *Dom-ino* (1914). House *Dom-ino*, in terms of architecture, is actually a constructive system based on a special skeleton as a constructive phenomenon, which is completely independent of the functionality of the layout itself [9] (see Fig. 1a). Its embodiment in urban planning was conveyed by matching the required number of houses in the space, as tiles in the game of domino, it contributed to the rapid reconstruction of war-torn homes and, in the short term, provided a cheap accommodation for a large number of rural inhabitants who rushed to cities (see Fig. 1b).

It has already been stated here that Le Corbusier advocated the idea of multiplying a type of housing unit in order to establish housing estates. That is, the idea of connecting individual architectural structures into a unified functional urban system is visible, but without referring to immediate or wider urban environment – place and context.

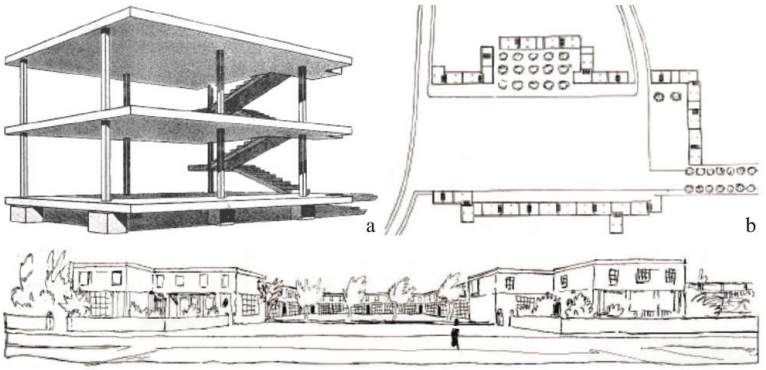

Fig. 1 a) structural system *Domi-no*; b) stacking of houses *Domi-no* on a site; Source:[10]

In addition to the constructive direction in architecture, August Perret introduced the idea of building high-rise buildings as a tool in the urban reconstruction of chaotic cities. At that time, he also began to point out that decorating buildings was wrong and he carried it into the work of "direct architectural nudity" [11].

And here Le Corbusier bowed to Perret's attitudes. On these foundations, in the era of new materials, constructions and machines, he developed the tendency to structural and functional rationalisation of urban structures and simplification of lines. In order to overcome

the admiration and mystification of ornamented structures he became an advocate for purism[1], further developing these tendencies.

3.1.2. *From Tony Garnier to Athens Charter*

Within the same year (1908), Le Corbusier met Tony Garnier when he carefully studied and accepted his ideas about the Industrial City (*Une cite industrielle*). An industrial city was an attempt to adapt urban structures to the needs of society in the era of industrialization and represented a pioneer vision of a rational city. By clearly separating various urban functions, determining the space for future expansion of the city, creating free park surfaces, separating pedestrian traffic from roads and constructing reinforced concrete structures, raised from the ground on pillars, the Industrial City was envisaged to satisfy the material and spiritual needs of the individual (see Figure 2). By looking at these settings, it can be concluded that Garnier's principles of modern city organization are actually the anticipation of Le Corbusier's Athens Charter[2].

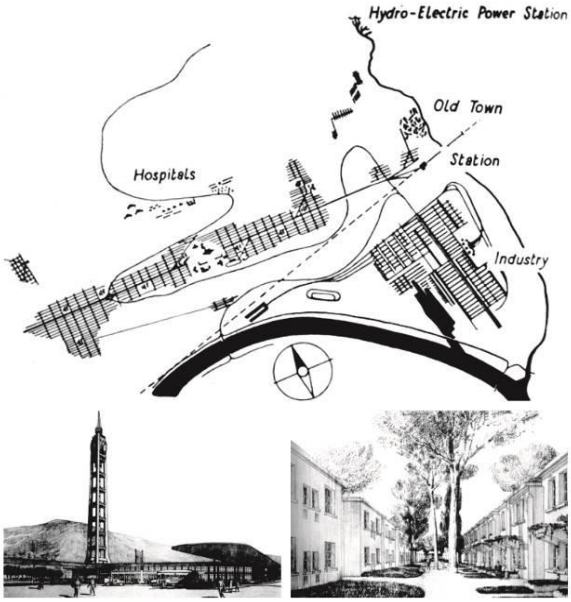

Fig. 2 Tony Garnier, *Une cite industrielle*; Source: [12]

[1] The problem of the conflict of inherited cultural values and modern technology has significantly influenced the emergence and development of a "pure" architectural style – a purger only since the publication of the magazine for architecture and urbanism, *L'esprit nouveau*, published by Le Corbusier and Amédéé Ozenfant from 1921 to 1925.

[2] Athens Charter (*La Charte d' Athénes*, IV kongres CIAM-a, 1933) – except in architecture, the application of the principles of functionalism and urbanism: a clear distinction between urban zones (housing, work, recreation and traffic = the association of a man with housing, leisure time and workplace), denial of tradition (anti-textualism, ie the rejection of national cultural urbo-architectural characteristics) , the scale of the human body (urban design standard), the freedom to dispose of urban land (regulation line / private and public property), regional planning [14; 15; 16];

Once again, one can reflect upon the origin of his work – adapting the visionary attitudes of Perret and Garnier, and suggesting that Le Corbusier was skilled in using the ideas and efforts of the predecessors in order to contribute to his own understanding of architecture and urbanism. Immediately after the First World War, he started with the idea that "the new spirit is the spirit of construction" [11], in which he saw a means to change the social state and active force for further development, unlike all forms of restoration. To construct for him meant to think technically, that is, to be deprived of all speculative artistic considerations. On the same track, he saw the apartment as a cell of a city that was waiting for transformation in accordance with the new, material and spiritual, needs of man. Starting from the reform of the dwelling house and from the construction economics, there has been a clear distinction between urban functions on housing, work, recreation and traffic and to the right line as the basic characteristic of modern urbanism, to the principles he later used in his urban plans [13].

3.2. Le Corbusier-urban theory

The demographic expansion, conditioned by the consequences of the war and sudden urbanization, required the consideration of the economic and social aspect of architecture. Relocation the rural population towards the peripheries of the capital cities, looking for permanent earnings and cheap accommodation, for architects meant finding a method of construction that would "adapt new homes to new optics and a new social life" [17]. Conceiving new types of housing to solve housing problems at low cost, it was the architects who were supposed to remove the class divisions between existing and new urban units. In order to achieve this, it was necessary to enable users to understand the new architectural design, and in this respect, understanding their own needs.

On the basis of its earlier experiences and adopted attitudes, and in the light of the described social circumstances, Le Corbusier developed the idea of a serial-produced housing unit. Without sacrificing the series his belief that architecture is a means of establishing a social equilibrium, a tool with which it is possible to build a harmonious, more just and humane world, he claimed that the standard is created "on a secure basis (...), a logic that relies on analysis and experiment" [17] (see Figure 3). This theory, Le Corbusier, transformed into the innovations of housing typology, which he based on the concept of *Dom-ino* (1914).[3] These innovative residential typologies provided the comfort of living space with a terrace-garden, and their free internal organization meant a break with the previous cultural setup of life indoors – separate rooms of the apartment. He claimed that "the houses as machines" [17] can be reduced to a measure of social needs, and which allows him to lead a more organized and better life. For Le Corbusier, the house-machine (*machine à habiter*) meant "the source of a new ethics of life on the verge of utopia" [9].

[3] This is how the idea for the *Citrohen* house (1920), a model of a cheap single-family house with a garden-garden, a simple and rational design, was adapted to mass production. Almost simultaneously (1922), he designed the multi-story multi-residential building *Immeubles-villas*, with 120 apartments-villas, combining the comfort of individual housing (apartment = house with terrace-garden) with the advantages of common services in the building and later applied in plan for the Contemporary City (*Ville contemporaine*).

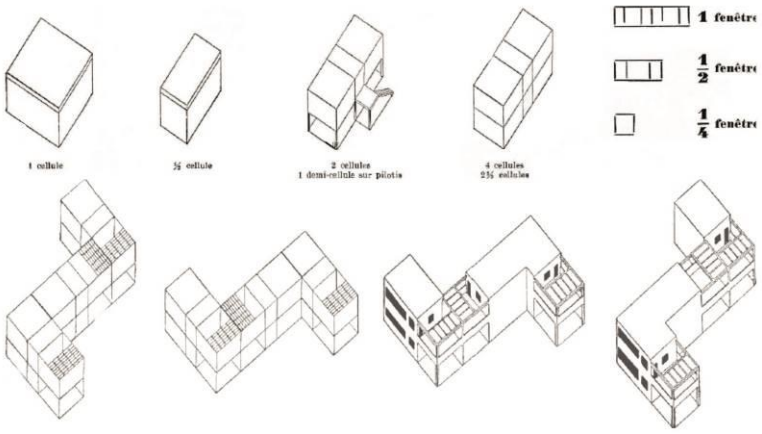

Fig. 3 Standardization of a housing unit; Source: [10]

Ideas on the new order of the material and spiritual life of an individual within the collective system, Le Corbusier improved over time and confirmed in formal and adopted principles. The program ideas of the innovated housing units were finally formulated in Five Points (1923)[4], which defined the principles of modern architecture and gave a complete picture of the new balance of reinforced concrete structure, the purpose of the building, the economics of construction, the freedom in the formation of foundations and façade panels, and the associated aesthetic experience of the inner and external object design. For him, this was a feat because the prospects of the new standardized architecture could be transferred to urbanism and thus to solving the problems of modern cities. Thus, the ways of involving separate units into urban life and the distribution of the common spaces of the city within the limits of acceptable economic parameters, prompted Le Corbusier to reflect on theoretical urban settings.

3.2.1. *Contemporary city for three million inhabitants (Ville contemporaine de trois millions d'habitants)*

Critical analysis of the relationship between old town centres and new peripheries and the need to address the problems of their aggregation into a complete urban system led Le Corbusier to make suggestions, visions, based on functional principles and derived from social, economic and cultural context. He believed that the time had come to accomplish great works that will undo the remains of the dead and promote the era of a new collective spirit and civic pride.

This idea was presented for the first time in the design for the *Ville contemporaine de trois millions d'habitants* (1922) and saw it as a model for designing all cities for modern society. The plan represented the release of the constraints that emerged as a result of decentralization and uncontrolled expansion of urban structures. It was a theoretical attempt

[4] Five points of new architecture: 1. Pillars - free ground floor, garden is located beneath the house and above the house, i.e. on roof, 2. Roofs-terraces-gardens – usable flat roofs, replacement for the space taken from the ground, 3. Free formation of the base – with fixed pillars, partition walls are installed as needed, 4. Lateral window – horizontally continuous, maximum façade and 5. Free façade design – vary according to need, in accordance with the free base plan [17; 11];

to form a city organized on the parameters of the central core ripple, the rapid circulation of traffic along its entire linear plane. The increase of the density of population in high buildings, in conjunction with the increase of green areas sublimated all Le Corbusier's ethical, aesthetic, technical and sociological theses.

The basic cell of the *Ville contemporaine* was a standardized residential unit with a terrace-garden. In opposition to the scattering of the urban phenomenon, Le Corbusier placed vertically individual units on the periphery and concentrated them in the complex of high-rise buildings called *Immeubles-villas*. It was a vision of a vertical garden town that allowed the undisturbed spread of park/green surfaces beneath the skyscraper and all around them in large open spaces. In the central city zone, administrative and cultural facilities lay around the administrative core that was characterized by skyscrapers. With skyscrapers and tall buildings, he wanted to bring the city to the smallest possible area[5]. The hierarchical distributive norm regulated at various levels the city's auto-routes, which were entwined below the spacious surface for aerotaxis, and the fast roads diagonally crossing the linear base of the city [4; 9; 11; 3] (see Fig. 4).

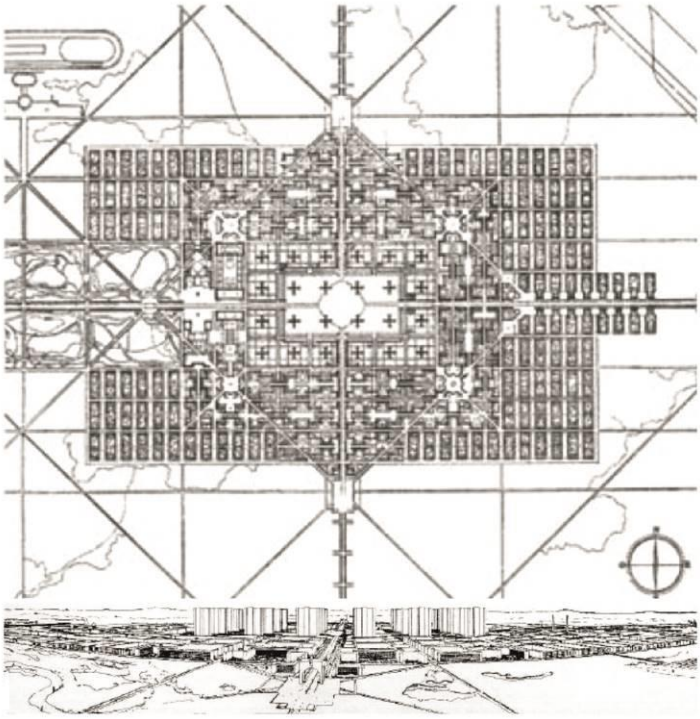

Fig. 4 *Ville contemporaine de trois millions d'habitants*, 1922; Source: [10]

[5] In a vertical garden town, with a population density of about 1000 inhabitants/ha, 3 000 000 inhabitants could have lived. Green and park surfaces occupy an area of about 1.5 km². The administrative center is planned with a density of 3200 inhabitants/ha and each of the 24 skyscrapers couldv accommodate from 10 000 to 50 000 employees [10].

In the *Ville contemporaine*, Le Corbusier created urban space based on from free-standing objects as basic units of measure in the dimensioning of urban space, he expressed principles of a new urbanism, i.e. the principles of a clear differentiation of the primary city functions connected by the network of fast communications. With this logic, he established a connection between the central and peripheral parts of the city and linked them into a coherent system. The plan clearly reflects his architectural ideology, which is to think radically technically means to be in close relation to the interests of capital and to adapt to social order and social conditions. For this reason, Le Corbusier argued that "the great city – the metropolis, as a phenomenon and design symbol of spatial articulation will remain in all social systems as a justified phenomenon" [11].

3.2.2. *Radiant city (Ville radieuse)*

Ville radieuse (1930) was a perfect plan of the *Ville contemporaine*. The main difference was that Le Corbusier moved the business centre of the city outside of its geometric centre, and kept the idea of concentrating high buildings and skyscrapers in order to minimize the city's area as much as possible[6]. Everything in the *Ville radieuse* was symmetrical and standardized, differentiated functional zones connected by underground traffic, and walking communications, positioned at different levels above the terrain, in lush greenery [18]. The main characteristic of the *Ville radieuse* was the possibility of infinite expansion, making Le Corbusier overcome the closeness of the *Ville contemporaine*. The isolation of the business centre and the organization of city functions around the central axis made the city's central model seem more like a linear one (see Figure 5).

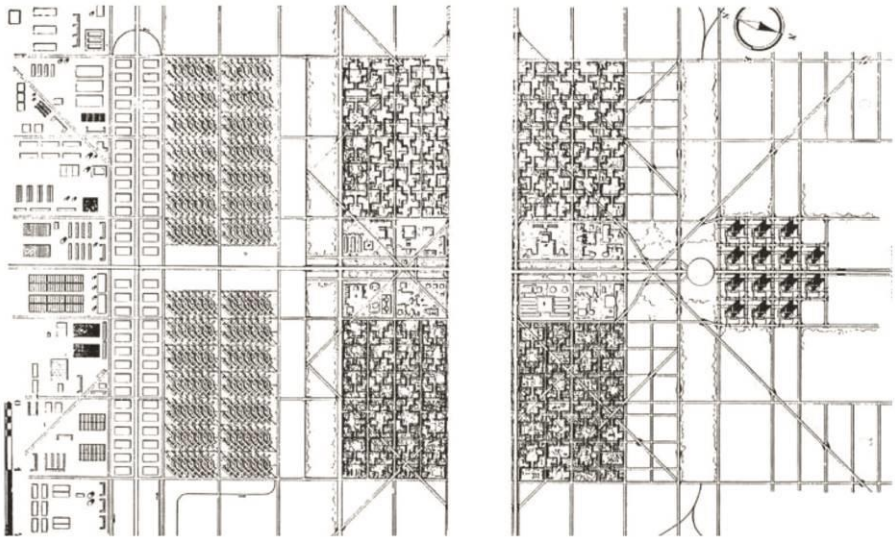

Fig. 5 *Ville radieuse*, 1930; Source: [18]

[6] And in *Ville Radiuse*, freestanding objects are units of measure in the dimensioning of urban space. Their number is indicative, for which there is no data to come from calculating the need for housing or work space.

And in this plan, Le Corbusier resolutely stood on the point of view of urbanization. In his view, the (necessary) evil of big cities should have turned into the good of the majority, and the industry and technology that caused such a state of affairs brought about the possibility of implementing the social transformation of modern society. His position that primary geometry, both in architecture and urbanism, is suitable for machine production, and therefore possess the qualities of purity, economy, modernity and sociological imagination, has been declared by opponents as a technological-ideological dialectic. On the other hand, many critics pointed out that Le Corbusier in *Ville radieuse* has reached the greatest extent of the idea in the theory of the construction of cities, the concept he is most famous for.

3.2.3. *Linear industrial city (La cité linéaire industrielle)*

After the Second World War, Le Corbusier once again faced the challenges of industrial and economic reconstruction of cities, which enabled him to influence the essence of modern society and once again anticipate post-war reconstruction problems. In that period, without departing from his theoretical urban planning, based on the differentiation of primary urban functions connected with network of fast communications, the organization of an entire country, on the enhancement of industry and agriculture, was also affected. In the aspiration to establish a synergy, as well as harmony between man and nature, exchange, agricultural exploitation, position and justification of industrial and radial-concentric cities, he developed the idea of linking a linear industrial city and a cooperative rural unit.

In *La cité linéaire industrielle* (1945), Le Corbusier conceived the dual zone as horizontal and vertical gardens, composed of typical residential units, dimensioned according to the needs of one family and with the possibility of multiplying in space. This concept provided a zone of common services connected with network of fast communications. The protective shade of greenery, in which the city's highway was located, separated the apartment from the zone of industrial plants. In the wider region of the region, the village, as a unit of agricultural exploitation, connected the radial-concentric network of roads with the existing city as a place of trade, administration which was further accented with a linear industrial city as a place of production. There is a green industry, an example linear city, replaced the black industry from the first period of the mechanical era, introduced the work into the environment of natural conditions and restored dignity and joy to human life. Based on the real conditions of nature, Le Corbusier argued that this concept of regional organization of life and labour could be further consolidated into an organic and balanced structure of the continental and intercontinental systems [19; 17] (see Fig. 6).

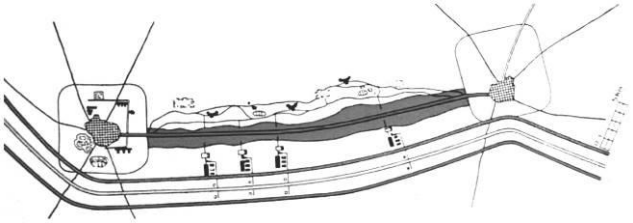

Fig. 6 *La cité linéaire industrielle*, 1945; Source: [19]

3.3. Accepting and challenging Le Corbusier's ideas

In addition to numerous theoretical reflections on space transformations in all scales, Le Corbusier left behind numerous works that promoted the "internationalization of architectural practice around the world"[7] [20]. He was fully confident and expressive about his ideas and achievements, and therefore acquired the entire army of followers. Many theorists of modern architecture claim that it had a beneficial effect – referring to open principles of construction, rather than on the ready solutions. His associates, as well as the architects with whom he gained professional contacts, did not take over, but further developed the ideas of modern architectural language[8]. It can be said that the uniformity of ideas and deeds is actually the key to understanding Le Corbusier's successful acquisition of the sympathies of architects of all generations and in all the climates, because he did not put them before the dualism of contradictory claims and the intractable inconsistencies.

However, in parallel with the acceptance, Le Corbusier's ideas have been exposed to fierce denunciations. Although he always accompanied functionalist explanations and claimed for himself that he was a rationalist and a scientist, his critics saw his architectural and urban solutions as partially rational, mostly dogmatic and uncritical [21]. Considering the reformer of the society, the rational urbanist and the prophet of the mechanical era, he saw the building as an instrument of social action, the conduct of politics, the seduction of morals and the development of the economy. The paradoxes in the space that originated from it were estimated as the result of simplified interpretations of these ideals. Still, without giving up on his principles, he once said: "It takes thirty years to be accepted, fifty years to come into practice. With daily fighting, terrible stubbornness, unwavering confidence and complete self-determination, you will achieve victory. But others will benefit from it and that's good" [3].

4. RESULTS AND DISCUSSION

In tangible world of matter and energy, result is a reflection, an interaction of individual components, one can presume that in the immaterial world there are spiritual forces which, by the purposefulness of their movement towards a certain goal, become a symbol of meaningful realization of ideological engagement. In this paper, we dealt with the observation of the material and metaphysical forces directed towards the formation of the morphology of

[7] This is also supported by the fact that UNESCO listed 17 architectural objects on the World Heritage List in 2016, written by Le Corbusier, in seven countries and on three continents [20].
In addition, with its urban studies, Le Corbusier has made a decisive influence on urban planning for the second half of the 20th century. By developing the basic theoretical urban setting from the *Ville contemporaine de trois millions d'habitants*, the principles of the new urbanism have been incorporated into numerous plans for the cities: Paris, Geneva, Rio de Janeiro, Sao Paolo, Montevideo, Buenos Aires, Algeria, Moscow, Antwerp, Barcelona and Stockholm. Only one plan has been implemented - a plan for Chandigarh, a city of 500,000 inhabitants (1950-1960) [3].

[8] Between the two world wars, the influences of modern architectural trends in Sarajevo were among the first to be brought by the Prague student Helen Baldasar who applied them to public buildings and residential multi-story houses. Muhamed and Reuf Kadić, also Prague students, advocated the idea of functionalism in the housing culture. Juraj Neidhart, an associate at Le Corbusier's studio until 1939, with the architect theoretician Dušan Grabrijan, worked on the synthesis of traditional and modern architecture in B&H. Grabrijan is also the author of the book: Architecture of Bosnia and Herzegovina and the Way to Modern (1951), for which the preface was written by Le Corbusier. In the field of urban planning, the General Urban Plan of Sarajevo (1965-1986) is based on the principles of modern urbanism, a strict functional division of urban zones.

modern architectural thought. This provided us with Le Corbusier's architectural and urban phenomenon that was not the case of spontaneous emergence, but it is precisely the result of circumstances of diverse and turbulent events of the 20th century, which became a platform for his entire creative output. This is not about ideas that emerged in the field that were officially recognized in architecture and urbanism, but in the realm of Le Corbusier's dynamic spiritual habitus. This fact explains how one mind can at the same time conquer the peaks of architecture and become the embodiment of a modern architectural movement, and on the other hand be severely condemned for ideas that are often rated as devastating.

One can realize that the material and spiritual culture of the western civilization of the 20th century and the knowledge gathered from the experiences of the predecessors determined Le Corbusier's understanding of architecture and urbanism. He collected the most important active and thoughtful settings of the architects with whom he worked, formulated them in, strict language, principles, and thereby shaped the architectural movement. However, it is important here to point out that Le Corbusier was going to determine the actual results of the work of the predecessors, who then showed a great value of their contribution, not to take over and adopt their expression, nor to select architectural and urban elements for possible imitation.

Creating his architectural expression, Le Corbusier did not transform this knowledge into formal allusions, but for him meant a preparatory experience in designing, that is, the adoption of the attitude that inspired the revalorization of general life opportunities. In this creative moment, watching the house as a living machine, the classic temple of comfort, reliability and satisfaction joined the dialectic of resources and goals related to economic criteria, he saw architecture as a unit of serial production. Barred from all forms of decoration, it became an equivalent of mass-produced objects and subject to the laws of standardization and economics, and as such, he believed, had beneficial effects on its users.

Studying the typologies of family-built residential units, Le Corbusier elevated them to an urban dimension. In his view, the city had to provide individual freedom and benefit from a joint action on a spiritual and material basis. In order to achieve this goal, the unit of measure of everything that is being built inside the urban space had to be a standardized housing unit – the basic cell of the city. The city has thus become an enlarged architecture, which Le Corbusier has left as a reference spatial system, a monotonous repetition of a number of models and types of residential buildings. He trimmed and subdued the city to the houses.

From overview of the most significant characteristics of Le Corbusier were aspirations to unite man and nature into a unique system and to formulate norms that will enhance the city in spiritual and material terms for happiness and individual freedom, to create a space variability with few basic elements. Continuity and consistency in the cyclic repetition of these elements during the years of creation, both in architecture and in urbanism, have assumed the character of "revived beliefs" [9]. Le Corbusier remained faithful to the very end by the strict rules of construction, from home across the city to the region, ideas transmitted to forms and forms that the welfare of man had as the basic unit of measure of all interventions in space.

When it comes to the strict differentiation of the primary city functions, it is clear that the life of a city is much more diversified and fuller than the reduction to a unique formula: housing – work – recreation – traffic. In fact, this is our negative critique of the principles of the Athens Charter and the guidelines of functionalist urbanism, as well as the negative criticism of the standardized, bureaucratic environment of Le Corbusier's city.

5. TOWARDS A CONCLUSION (*VERS UNE CONCLUSION*)

From this point, it can be concluded that the analogy Le Corbusier established between architecture and serial production emphasizes the production process. When this is added to the economic category of construction, we come to a fundamental defect, that is, mass production which makes them temporary in use value and quickly obsolete. That should not be valid for the built space. Because, when these two systems are equal, primacy is taken up by production techniques, cost-effectiveness and speed of construction, and spatial and social components of life in settlements are neglected. In addition, we can say that Le Corbusier, along with a strictly defined and standardized model of housing and the concept of a community, fell into a mind-set of industrialization of society, whose aim was first demographic growth and production, and then social life. In this context, his approach, regardless of the declarative humanist views, can nevertheless be assessed as autocratic.

In solving complex urban problems with methods based on schemes verified in the context of smaller dimensions, we see the weak point of Le Corbusier's theoretical development. We conclude his internalized and rationalized views on architecture are simply not applicable in the interpretation of a complex urban phenomenon. On the other hand, the city's vision, based on the principle of multiplying free-standing objects as a unit of measure in the dimensioning of space, opened the possibility of free spatial arrangement of buildings and their construction on reinforced concrete pillars. This was appropriate only for the abolition of private land ownership, and such a radical concept was the ideal starting point for the avant-garde vision of a city separated from the ground. Although radical, we must admit that it is Le Corbusier who made a turning point in his perceptions of the planning of cities and established a clear boundary between classical and modern urbanism.

We concluded that the specialization, segregation and isolation of urban functions made the city a kind of machinery in which the free-standing objects in greenery were repeated dogmatically and persistently, and the urban space became a common place. We also saw that Le Corbusier's disdainful attitude towards place and context produced the same urban morphology, sterile cities and universal spaces. This is legible in all the benchmarks it has dealt with, from home across the city to the region and further to continental and intercontinental urban systems.

Ignorance of places and contexts, layered messages of history and tradition, as well as of social components of life, has generally proved to be an essential weakness of functionalist urbanism. Therefore, since the 1980s, the integration of functions has become a new and basic urban concept, that is, multi-functional and connected urban spaces have pushed the zoning. Contextualism led to the return of the city and strong urban identity. Otherwise, 20th century will be remembered as an era of reaction to modern architecture and urbanism, especially on the concept created by Le Corbusier, which resulted in the construction of large, unimaginable and unrecognizable urban spaces.

In this paper, we tried to present Le Corbusier's aspiration for reaching the new reality of the city, which he created and confirmed with economic, political and social connections within a well-defined urban environment. Topic of Le Corbusier’s work is omnipresent and part of our cityscapes, this paper provided a contribution in clear connection and understanding of the structural and functional significance of urban visions, based on his theoretical propositions on architecture. This was the main intent of our critical overview, as yet another layer and insight into the creative opus of this influential and controversial architect and the general urban and architectural theory.

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O STVARALAŠTVU LE CORBUSIER-A: JOŠ JEDAN PRILOG PROMIŠLJANJU

Burni društveni tokovi turbulentnog XX vijeka i diskontinualnosti koje su ga obilježile, kako to uvijek biva, reflektovali su se na polju čovjekovih spoznajnih i stvaralačkih dostignuća i uticali su na oblikovanje nove arhitektonske misli i stava prema prostornosti. Prva polovina vijeka posebno je obilježena modernističkim pokretom, čiji su predstavnici, povezujući tehnička i tehnološka dostignuća u građenju, ekonomiju, socijalni kontekst i kulturu u jedinstvenu cjelinu, utjelovili duh i označili domet arhitekture i urbanizma moderne.

Među njima se posebno izdvaja ime izrazitog predstavnika novog doba, arhitekte Le Corbusier-a, o čijim teorijskim postavkama urbanizma i odnosu prema arhitekturi i gradu ovaj rad i govori. Istražujući analogiju koju je formirao između serijski proizvedene stambene jedinice i funkcionalističke urbanističke dimenzije, kao i model regionalnog planiranja, uvidjeli smo da je Le Corbusier izvršio preokret u dotadašnjim shvatanjima o planiranju gradova. Istovremeno hvaljen i osporavan, postavio je jasnu granicu između klasičnog i modernog urbanizma.

Razmatranja o ishodištima i evoluciji Le Corbusier-ovih ideja ovdje nisu imala za cilj uspostavljanje nove periodizacije u opusu, već predstavljaju još jedan prilog brojnim promišljanjima o njegovom stvaralaštvu, za koji vjerujemo da daje doprinos opštoj teoriji urbo-arhitektonskog dizajna.

Ključne reči: *Le Corbusier, XX vijek, modernizam, arhitektura, urbanizam, urbano planiranje*

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NUMERICAL ANALYSIS OF FINITE HYPO-ELASTIC CYCLIC DEFORMATION WITH LARGE ROTATIONS

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620.1

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Abstract. *Constitutive relations which describe engineering materials behaviour during the finite elastoplastic deformations are usually presented in the form of rates of stresses and strains. One of the possible approaches in the constitutive relations formulation is the additive decomposition of the total deformation rate into its elastic part and its plastic part. The elastic deformation rate contributes to any elastoplastic deformation at any stage. Hence, its exact and well-considered formulation is of particular importance and it has to be properly predicted by the corresponding material law. This is of great importance in particular when deformation cyclic processes are considered, in which case small errors may accumulate, even if the total deformation is small.*
The implementation of the most frequently used corotational rates, i.e. the Jaumann rate and the Green-Naghdi rate, in the hypo-elastic constitutive relations regarding small and moderate rotations gives accurate results for low number of repeated deformation cycles. With increased number of cycles, however, the implementation of these rates results in different and physically non-admissible material responses. This instability in results is particularly observable during the cyclic deformations with large rotations, which is the main subject of this work. In contrast to the aforementioned objective rates, the results of the logarithmic rate implementation into the hypo-elastic constitutive relations for the case of pure elastic deformation describe a physically stable process.

Key words: *hypo-elasticity, objective rate, logarithmic rate, finite cyclic deformation, ABAQUS, UMAT subroutine, large rotations*

1. INTRODUCTION

In the contemporary Eulerian formulation of finite elastoplasticity the elastic behaviour is often described by a grade zero hypo-elastic law that requires the implementation of an objective rate instead of material time derivative. By reviewing the corresponding literature, it

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may be observed that the objective Jaumann rate has been used by many researchers and has found a wide application in developing elastoplasticity theories. However, the shear oscillation phenomenon, firstly revealed by Lehmann (1972) and Dienes (1979), has questioned the correctness of application of the Jaumann rate in the constitutive relations for finite deformations. The work of Kojic & Bathe (1987), in which the authors showed that the application of the Jaumann stress rate produces residual stresses at the end of an elastic closed strain path, just confirmed the aforementioned conclusion on the inappropriateness of the Jaumann rate implementation in the constitutive relations even for the case of small deformations of cyclic nature. These findings have contributed to the development of numerous rates, corotational and non-corotational ones, such as the Truesdell rate, the Green-Naghdi rate, the Cotter-Rivlin rate, the Durban-Baruch rate. Their implementation, however, has not completely solved the existing problems. Additionally, in the work of Simo & Pister (1984), it was shown that for the case of pure elastic deformation, hypo-elastic rate equation, considering all then known objective rates, fails to be exactly integrable, and by that, is unable to define an elastic behaviour of the material realistically.

Although the theoretical studies have shown that the classical rates produce unstable solutions for finite deformations, some of them are still incorporated in widely used commercial finite element codes for structural analysis. For example, in the software ABAQUS, depending on the element type and constitutive model, the Jaumann rate or the Green-Naghdi rate are the available options to be selected by the solver (see ABAQUS documentations, 2013).

Recently, the logarithmic rate has been in a focus of a number of studies by various researchers, who have proved that application of this rate in hypo-elastic constitutive relations successfully solves the problems related to shear oscillation and residual stresses for a closed strain path. For details, the reader is referred to references Xiao et al. (1997a, 1997b) and Meyers et al. (2003, 2006).

The present study employs one distinctive numerical problem, performed with a view toward investigating the logarithmic rate implementation in the hypo-elastic constitutive relations for the case of pure elastic deformation and verifying that this rate obeys the Bernstein's integrability condition (see Bernstein, 1960) to give an elastic relation, thus meaning that path-dependent and dissipative processes are not detected. According to the results of a present study, the logarithmic rate is proved to be an appropriate solution for the aforementioned problems, opposed to formerly-used objective corotational and non-corotational rates.

2. BASIC RELATIONS

2.1. Kinematics

If $\mathbf{X}$ denotes the position of a material particle in the Lagrangian, or reference, configuration and $\mathbf{x}$ denotes its position in the Eulerian, or current, configuration, the particle displacement can be described by the deformation gradient $\mathbf{F}$ as follows:

$$\mathbf{F} = \frac{\partial \mathbf{x}}{\partial \mathbf{X}} \qquad \text{with} \qquad J = \det(\mathbf{F}) > 0, \tag{1}$$

where J is the Jacobian determinant or shortly Jacobian. The velocity $\mathbf{v}$ of the same particle and the velocity gradient $\mathbf{L}$ are defined as:

$$\mathbf{v}(t) = \dot{\mathbf{x}} = \frac{\mathrm{d}\mathbf{x}}{\mathrm{d}t}, \qquad \text{and} \qquad \mathbf{L} = \frac{\partial \mathbf{v}}{\partial \mathbf{x}} = \dot{\mathbf{F}} \cdot \mathbf{F}^{-1}. \tag{2}$$

In the previous relations a superposed dot denotes the material time derivative or ordinary time derivative when the variable is only a function of time. Applying the left polar decomposition theorem, the deformation gradient can be decomposed into a positive definite 2^{nd}-order tensor $\mathbf{V}$, named left stretch tensor, and an orthogonal 2^{nd}-order rotation tensor:

$$\mathbf{F} = \mathbf{V} \cdot \mathbf{R}. \tag{3}$$

The square of the left stretch tensor, termed as the left Cauchy-Green tensor, is more convenient for numerical purpose than $\mathbf{V}$ and it is defined as:

$$\mathbf{B} = \mathbf{V}^2 = \mathbf{F} \cdot \mathbf{F}^{\mathrm{T}}. \tag{4}$$

The velocity gradient can be decomposed into its symmetric part, related to stretching, and skew-symmetric part, related to rotation:

$$\mathbf{L} = \mathbf{D} + \mathbf{W}. \tag{5}$$

The rate of deformation tensor, or the stretching tensor, $\mathbf{D}$ and the vorticity tensor, or the spin tensor, $\mathbf{W}$ are given respectively as:

$$\mathbf{D} = \frac{1}{2}(\mathbf{L} + \mathbf{L}^{\mathrm{T}}) \qquad \text{and} \qquad \mathbf{W} = \frac{1}{2}(\mathbf{L} - \mathbf{L}^{\mathrm{T}}). \tag{6}$$

2.2. Constitutive relations

In the case of finite deformation, constitutive relations of elasticity or elastoplasticity are usually given in rate form. The occurrence of moderate to large rotations in finite deformations requires the introduction of the objectivity concept. Since the material time derivative is not an objective quantity in the Eulerian description, adopted here, the objective rates have to be introduced in the constitutive relations. From the general hypo-elasticity model, introduced by Truesdell, the simplified form of the hypo-elastic equation of grade zero is given by the following expression:

$$\mathbf{D} = \underline{\mathbf{K}} : \overset{\circ}{\boldsymbol{\tau}} = \frac{1+\nu}{E} \overset{\circ}{\boldsymbol{\tau}} - \frac{\nu}{E}(\mathrm{tr}(\overset{\circ}{\boldsymbol{\tau}}))\mathbf{1}, \tag{7}$$

which represents the relation between the rate of deformation, i.e. the stretching tensor $\mathbf{D}$, and the objective rate of the Kirchhoff stress tensor $\boldsymbol{\tau}$ via the constant and isotropic instantaneous elastic compliance 4^{th}-order tensor $\underline{\mathbf{K}}$. Here, ν and E stand for the elastic constants, i.e. the Poisson's ratio and the Young's modulus, respectively, and $\mathbf{1}$ represents the symmetric 2^{nd}-order unit tensor. The Kirchhoff stress tensor, or weighted Cauchy stress tensor, $\boldsymbol{\tau}$ is related to the Cauchy stress, or true stress, $\boldsymbol{\sigma}$ as:

$$\boldsymbol{\tau} = J\,\boldsymbol{\sigma}. \tag{8}$$

The objective stress rate, given here in a general form by Eq. (9), implies the introduction of the so-called spin tensor $\boldsymbol{\Omega}$, whose choice divides the objective rates into

two groups of corotational and non-corotational rates (for more details see Trajković-Milenković, 2016, and the references therein):

$$\overset{\circ}{\boldsymbol{\tau}} = \dot{\boldsymbol{\tau}} + \boldsymbol{\tau}\cdot\boldsymbol{\Omega} - \boldsymbol{\Omega}\cdot\boldsymbol{\tau}. \tag{9}$$

The corotational rates that are examined here are the Jaumann rate, the Green-Naghdi rate, and the logarithmic rate (the Log-rate), whereas the tested non-corotational rates are the Truesdell rate, the Oldroyd rate, and the Cotter-Rivlin rate. The spin tensors for the aforestated corotational rates are given as:

$$\boldsymbol{\Omega}^{\mathrm{J}} = \mathbf{W}; \qquad \text{for the Jaumann rate,} \tag{10}$$

$$\boldsymbol{\Omega}^{\mathrm{GN}} = \dot{\mathbf{R}}\cdot\mathbf{R}^{T} = \mathbf{W} + \sum_{i=1}^{m}\Big(\sum_{k=1,k\neq i}^{m}\frac{b_k - b_i}{b_k + b_i}\mathbf{B}_i\cdot\mathbf{D}\cdot\mathbf{B}_k\Big); \quad \text{for the Green - Naghdi rate,} \tag{11}$$

$$\boldsymbol{\Omega}^{\mathrm{Log}} = \mathbf{W} + \sum_{i=1}^{m}\Big(\sum_{k=1,k\neq i}^{m}\Big(\frac{b_k + b_i}{b_k - b_i} - \frac{1}{\ln b_k - \ln b_i}\Big)\mathbf{B}_i\cdot\mathbf{D}\cdot\mathbf{B}_k\Big); \qquad \text{for the Log - rate.} \tag{12}$$

In Eqs. (10) - (12) $b_{i(k)}$ represent m distinct eigenvalues of the left Cauchy-Green tensor, and $\boldsymbol{B}_{i(k)}$ denote the corresponding eigenprojections of the same tensor.

For the known spin tensors the corresponding objective rates are obtained from the general form given by Eq. (9):

$$\overset{\circ}{\boldsymbol{\tau}}{}^{\mathrm{J}} = \dot{\boldsymbol{\tau}} + \boldsymbol{\tau}\cdot\mathbf{W} - \mathbf{W}\cdot\boldsymbol{\tau}, \qquad \text{the Jaumann corotational rate,} \tag{13}$$

$$\overset{\circ}{\boldsymbol{\tau}}{}^{\mathrm{GN}} = \dot{\boldsymbol{\tau}} + \boldsymbol{\tau}\cdot\boldsymbol{\Omega}^{\mathrm{GN}} - \boldsymbol{\Omega}^{\mathrm{GN}}\cdot\boldsymbol{\tau}, \qquad \text{the Green-Naghdi corotational rate,} \tag{14}$$

$$\overset{\circ}{\boldsymbol{\tau}}{}^{\mathrm{Log}} = \dot{\boldsymbol{\tau}} + \boldsymbol{\tau}\cdot\boldsymbol{\Omega}^{\mathrm{Log}} - \boldsymbol{\Omega}^{\mathrm{Log}}\cdot\boldsymbol{\tau}, \qquad \text{the logarithmic corotational rate,} \tag{15}$$

$$\overset{\circ}{\boldsymbol{\tau}}{}^{\mathrm{Old}} = \dot{\boldsymbol{\tau}} - \mathbf{L}\cdot\boldsymbol{\tau} - \boldsymbol{\tau}\cdot\mathbf{L}^{\mathrm{T}}, \qquad \text{the Oldroyd non-corotational rate,} \tag{16}$$

$$\overset{\circ}{\boldsymbol{\tau}}{}^{\mathrm{CR}} = \dot{\boldsymbol{\tau}} + \mathbf{L}^{\mathrm{T}}\cdot\boldsymbol{\tau} + \boldsymbol{\tau}\cdot\mathbf{L}, \qquad \text{the Cotter-Rivlin non-corotational rate,} \tag{17}$$

$$\overset{\circ}{\boldsymbol{\sigma}}{}^{\mathrm{T}} = \dot{\boldsymbol{\sigma}} - \boldsymbol{\sigma}\cdot\mathbf{L}^{\mathrm{T}} - \mathbf{L}\cdot\boldsymbol{\sigma} + \boldsymbol{\sigma}\,\mathrm{tr}(\mathbf{D}), \qquad \text{the Truesdell non-corotational rate.} \tag{18}$$

The Truesdell rate is originally given for the Cauchy stress instead of the Kirchhoff stress in the form given in the last Equation.

3. CLOSED ELASTIC STRAIN PATH - HYPO-ELASTIC CYCLIC DEFORMATION

In the engineering practice strain cycles and cyclic loading can frequently occur as well if the agencies are repeated in a large number of cycles. It has been proved analytically that even for small but cyclic deformations the residual stress may be appreciable even after a single cycle and it may become of quite a high value with an increasing number of cycles (see Xiao et al., 1999). Accordingly, the analysis of cyclic deformation paths takes the important place in structural analysis. For the hypo-elastic law (Eq. 7), the aforementioned objective stress rates, i.e. the Jaumann, Green-Naghdi, and logarithmic rates, as corotational rates, and the Truesdell, Oldroyd, and Cotter-Rivlin rates, as non-corotational rates, have been compared in closed single parameter elastic deformation cycles.

In the numerical calculations the commercial software ABAQUS/Standard has been used in which material behaviour can be defined in terms of a built-in or a user-defined material model. In the latter case the actual material model is defined in the originally programmed code incorporated into ABAQUS via the user-defined subroutine UMAT. Here, Eqs. (13) - (18) have been incorporated in separate material models programmed in the user-defined subroutine UMAT. The outputs have been compared mutually, also with those obtained using ABAQUS built-in material model, as well as with the results from the relevant literature.

In the studies of Kojić & Bathe (1987) and Lin et al. (2003), a four-phase plain strain cycle was considered, which consists of extension, shear, compression, and return to original unstrained state. Here, the smooth strain cyclic deformation of the square element (see Fig. 1) has been considered. The square element of size H is subjected to a combined lengthening and shearing process in the $\mathbf{e}_1$-$\mathbf{e}_2$ plane, such that the upper corners are moving along the ellipse with radii a and b.

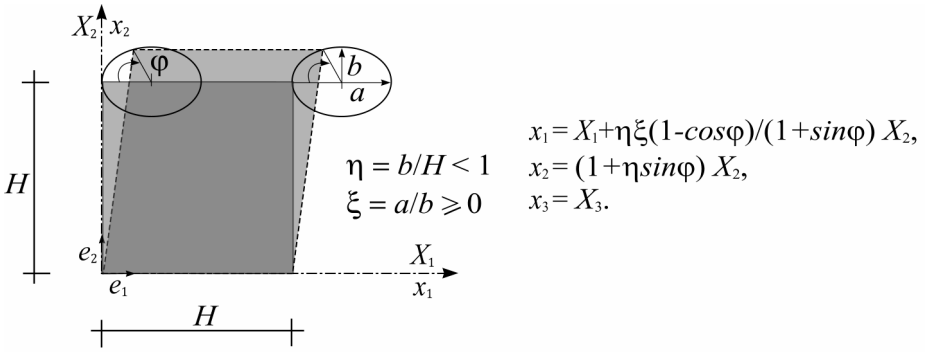

Fig. 1 Model and equations of deformation

The deformation is described by equations given in Fig. 1, where η and ξ are dimensionless parameters. The parameter $\eta = b/H$ ($0 < \eta < 1$) represents the measure of tension or compression, whereas $\xi = a/b$ is the measure of rotation to which the element is subjected. The parameter φ in the last relation is the single parameter that describes the deformation of the square plate. The material of the plate has been considered as initially isotropic and stress free. The adopted values for the Young's modulus and Poisson's ratio are E = 210 GPa and $\nu = 0.3$.

3.1. Large rotations

In this Section a stress response of the square element (presented in Fig. 1), subjected to the deformation consisting of the combined axial deformation and large rotation is examined. The extension in 2-2 direction will be in the range of 0 - 10%, whereas the shear deformation is predominant with relatively large values up to 50%, i.e. the parameters ξ and η are taking the values 5 and 0.1, respectively.

Development of the normal stresses τ_{11} and τ_{22} and the shear stress τ_{12} versus the deformation angle φ for all the considered rates have been presented in Fig. 2 and 3, respectively. In Fig. 2, for the given rates, the normal stresses in 1-1 direction are marked with the dashed lines and the normal stresses τ_{22} are presented by the solid lines.

The diagrams over a single cycle can generally be divided into three characteristic parts. The first one is that where $\varphi / 2\pi$ is in the range of 0 - 0.1. These are the values that are usually met as elastic deformations in metals, for example in civil engineering structures and during metal forming. It can be seen that in this part for all rates the plots are almost congruent.

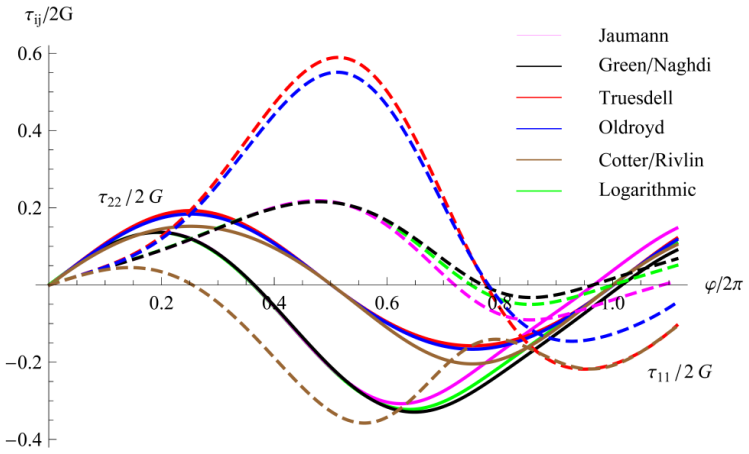

Fig. 2 Normal stress τ_{11} and τ_{22} single cycle development, $\xi = 5$, $\eta = 0.1$

For rubber-like and composite materials and shape memory alloys, which can be subjected to very large elastic deformations, the second and the third part of diagrams are of great importance. The second part, where $\varphi / 2\pi$ is in the range of 0.1 - 0.53, is characterised with an almost identical stress response for the corotational rates, whereas the stress responses considering the non-corotational rates are drifting apart. Concerning the normal stress τ_{11}, it is evident from Fig. 2 that the Oldroyd and Truesdell rates implementation in the hypo-elastic relation gives very high values of $\tau_{11,}$ while the reverse is observed for the Cotter-Rivlin rate that results in a rather low stress value. The third part of the diagrams is beyond the limit of 0.53 for $\varphi / 2\pi$, in which case the plots of shear and normal stresses even for the corotational rates are starting to drift apart.

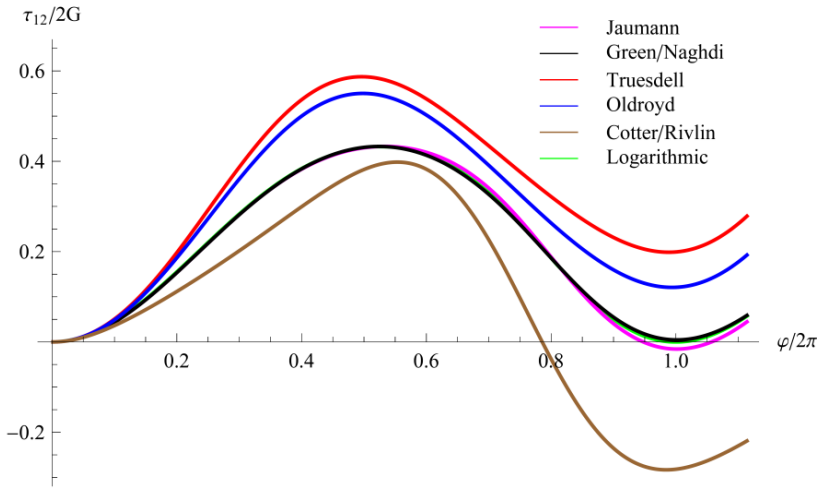

Fig. 3 Shear stress τ_{12} single cycle development, $\xi = 5$, $\eta = 0.1$

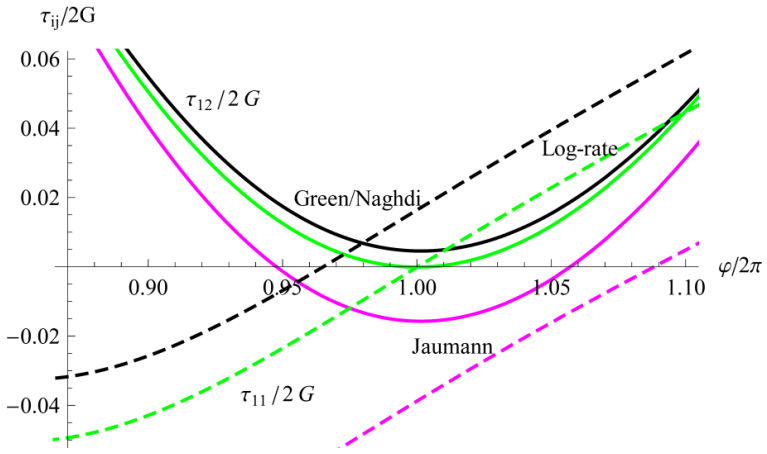

Fig. 4 Enlarged representation of τ_{11} and τ_{12} at the end of the first cycle, $\xi = 5$, $\eta = 0.1$

At the end of the first cycle some residual normal and shear stresses for the Green-Naghdi and Jaumann rates occur, whereas the non-corotational rates produce extremely high values of residuals. Only the Log-rate gives zero stress values at the end of the elastic deformation cycle (see Fig. 4). Here again, the normal stresses in 1-1 direction are marked with the dashed lines and the shear stresses are presented by the solid lines.

If the continuum square element is subjected to a deformation that repeats cyclically, the stress response error is accumulating for all the considered rates except for the Log-rate. The development of normal and shear stresses during 10 and 100 cycles for the logarithmic rate has been presented in the upper and down part of Fig. 5, respectively. It can be seen that

the development of all Kirchhoff stress components is regularly periodical with constant magnitudes and without any residuals at the end of each cycle.

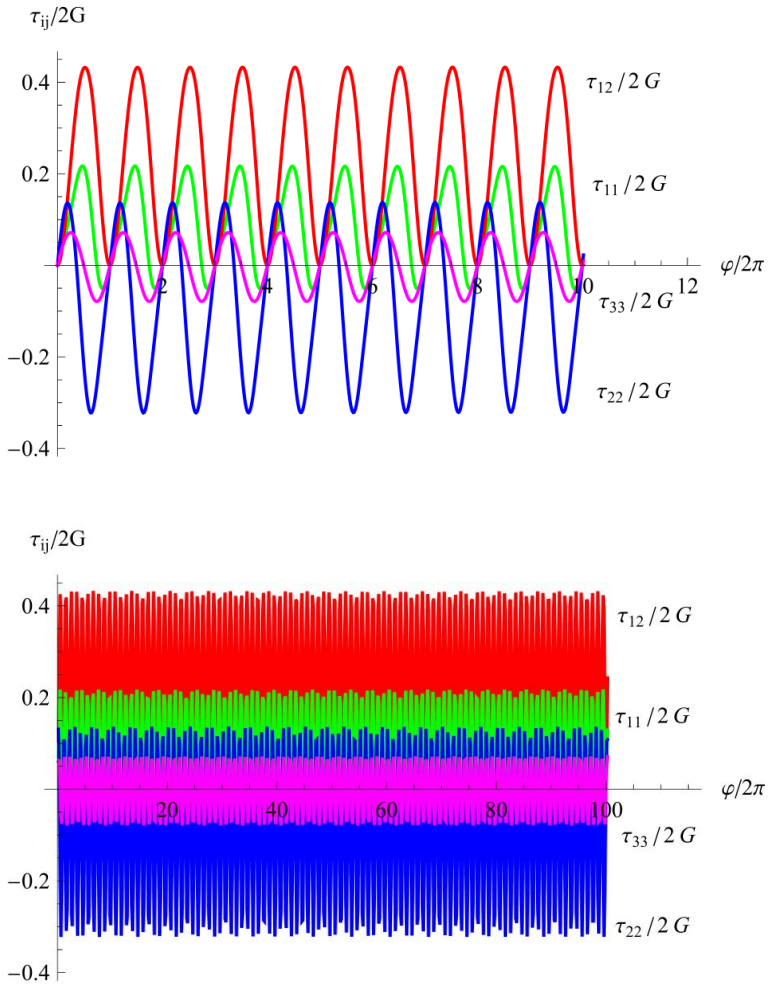

Fig. 5 Ten and hundred cycle stress development for the Logarithmic rate, $\xi = 5$, $\eta = 0.1$

The stress developments obtained using the Jaumann rate in the user-defined UMAT subroutine and ABAQUS built-in subroutine for hypo-elastic constitutive model have been presented in Fig. 6. From these plots it can be observed that the results for both models are completely congruent.

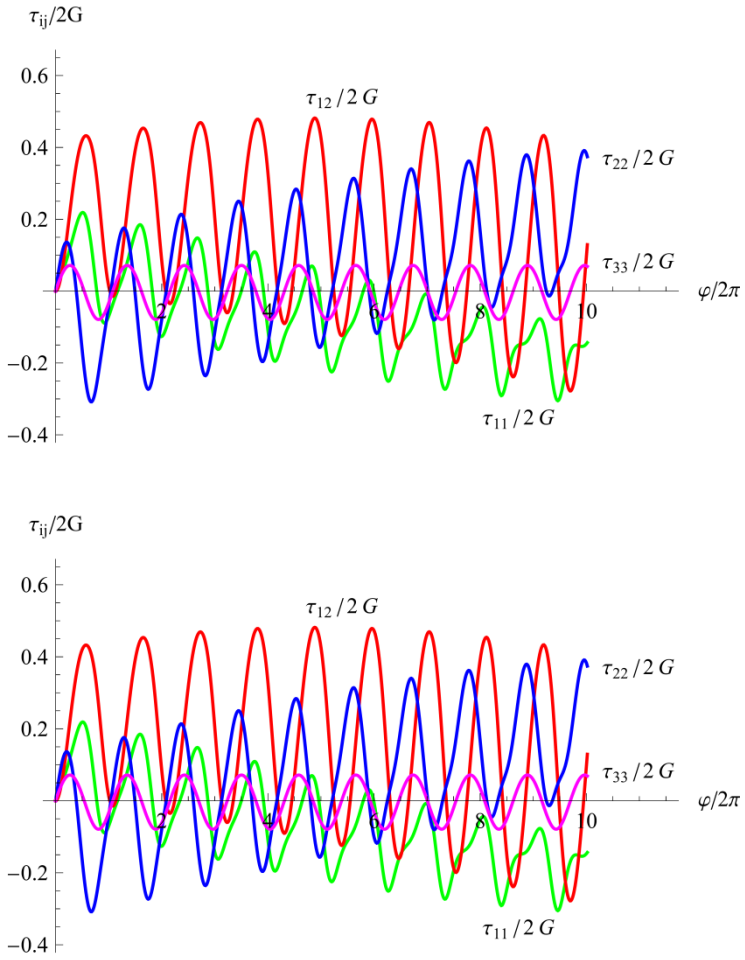

Fig. 6 Ten cycle stress development for the Jaumann rate using UMAT (up) and ABAQUS (down) model, $\xi = 5$, $\eta = 0.1$

The development of normal and shear stresses using the Jaumann rate for 100 cycles has been presented in Fig. 7. It is obvious that the Jaumann formulation provides an oscillatory stress response for all stress components except for τ_{33}, with variable magnitude of τ_{11} and τ_{12}. The residual stresses at the end of cycles are of non-negligible values and show an oscillating character as well (see Fig. 13). It can be concluded that the Jaumann rate gives results which are not in accordance with the physical behaviour of the materials. Therefore, this rate should not be implemented in the constitutive relations if large cyclic deformation occurs, ever for a low number of cycles (see Fig. 6).

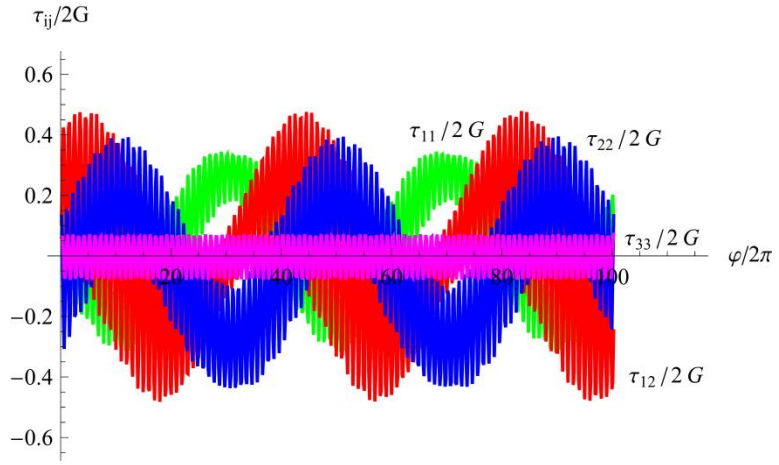

Fig. 7 Hundred cycle stress development for the Jaumann rate, $\xi = 5$, $\eta = 0.1$

In the case of moderate rotations, which are presented in detail in reference Trajković-Milenković, (2016), the Green-Naghdi rate was a more reliable choice than the Jaumann rate. Here, it can be seen that very high values of residuals occur even after a single cycle and their values are monotonically increasing as it is depicted in Figures 8 and 9.

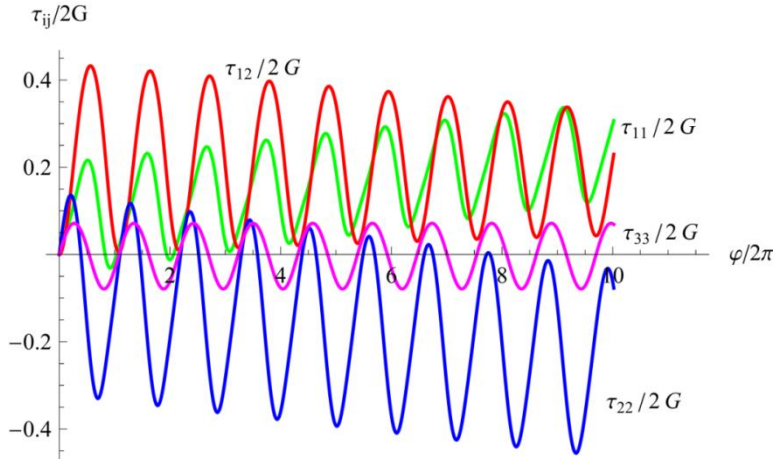

Fig. 8 Ten cycle stress development for the Green-Naghdi rate, $\xi = 5$, $\eta = 0.1$

As in the case of moderate rotations (see reference Trajković-Milenković et al., 2017), the stress responses of the Green-Naghdi rate formulation show the feature that the magnitude of the shear stress decreases as the number of cycles increases and after approximately 30 cycles its values are zero, which is a totally unrealistic result. After that,

the maximum shear stress is starting to increase monotonically. The plots for normal stresses τ_{11} and τ_{22} are drifting away and changing their magnitude with the number of cycles (see Fig. 9).

All the above stated remarks lead to the conclusion that for the case of cyclic elastic deformations with large rotations, the Green-Naghdi rate has to be excluded from the hypo-elastic formulations, except for only a few repeated cycles.

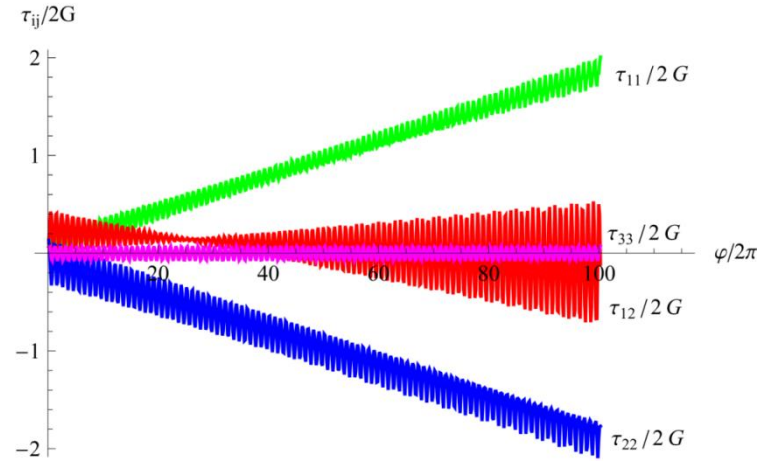

Fig. 9 Hundred cycle stress development for the Green-Naghdi rate, $\xi = 5$, $\eta = 0.1$

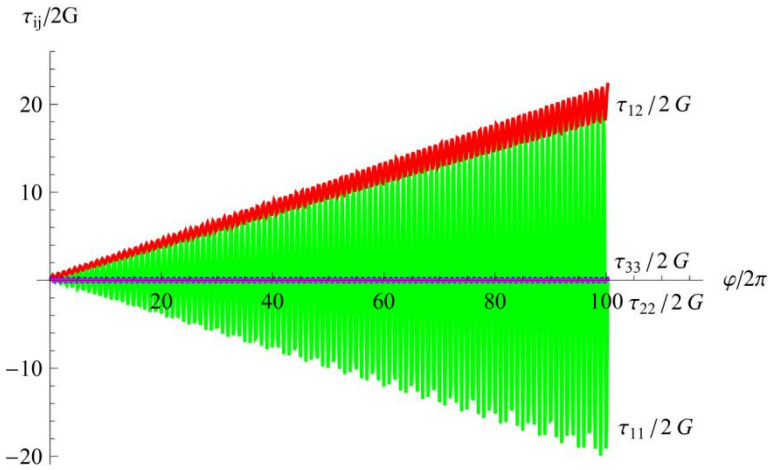

Fig. 10 Hundred cycle stress development for the Truesdell rate, $\xi = 5$, $\eta = 0.1$

The Truesdell and the Oldroyd rates give similar stress responses as it is illustrated in Figures 10 and 11, where the developments of the shear stress drift apart and increase the

magnitude to the unrealistic high values of 30 times for the Oldroyd rate and 40 times for the Truesdell rate compared with the shear modulus.

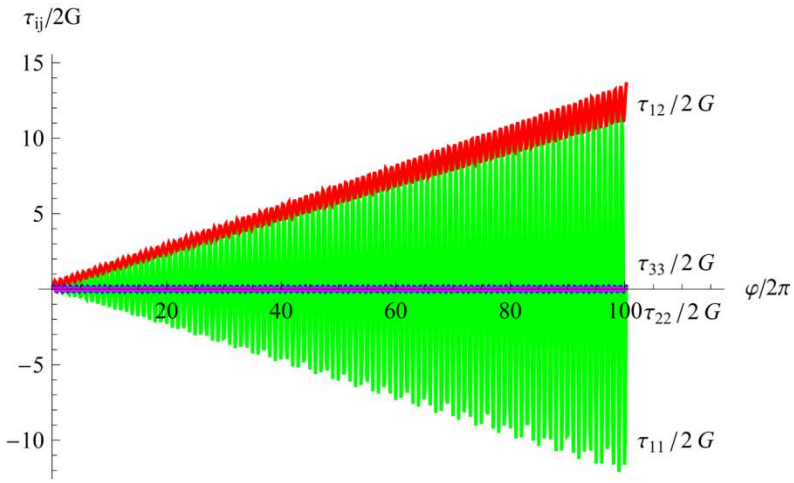

Fig. 11 Hundred cycle stress development for the Oldroyd rate, $\xi = 5$, $\eta = 0.1$

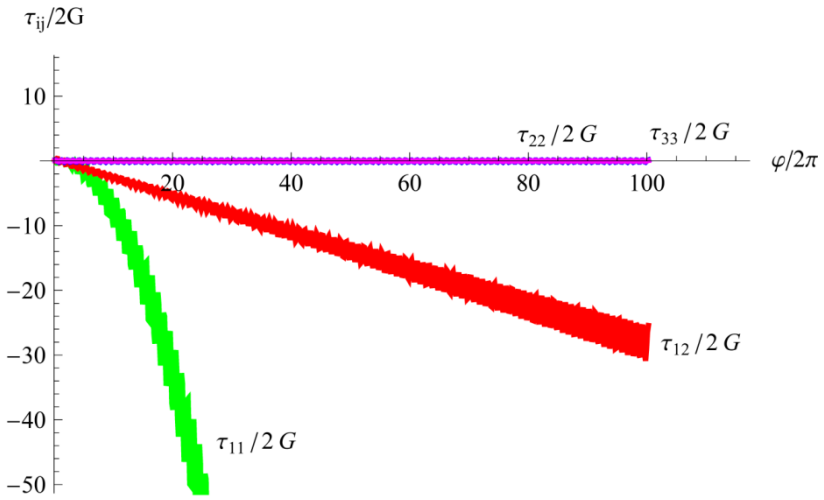

Fig. 12 Hundred cycle stress development for the Cotter-Rivlin rate, $\xi = 5$, $\eta = 0.1$

The results for the Cotter-Rivlin rate show great deviations from realistic values as well (see Fig. 12), and therefore, this rate must be excluded from the constitutive relation construction, too.

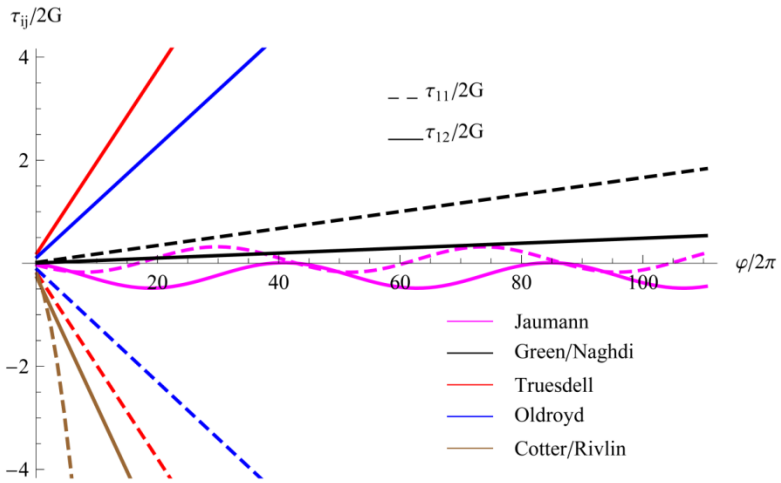

Fig. 13 Residual normal and shear stresses for various rates, $\xi = 5$, $\eta = 0.1$

In Table 1 the normalised residual stresses after 10 cycles are given for all the examined rates. The applied elastic deformation is with very large rotations, i.e. $\eta = 0.2$ and $\xi = 10$. It can be seen that except for the logarithmic rate the residual stresses considering the corotational rates are not negligible and for the non-corotational rates are of extremely high values.

Table 1 Residual stresses after 10 cycles for $\xi = 10$, $\eta = 0.2$

	Log-rate	Jaumann	Green/ Naghdi	Oldroyd	Truesdell	Cotter/Rivlin
$\tau_{11}/2G$	0.45732e-4	0.035174	2.8971	-43.925	-69.584	-721.76
$\tau_{12}/2G$	-0.43250e-4	-0.52436	3.1558	10.437	16.700	-24.353

4. Conclusion

In the case of finite deformations, prediction of the material behaviour is usually given in the rate form. In modelling of the elastic part of the deformation rates the hypo-elastic constitutive relation of grade zero is frequently used. Since the material time derivative in the Eulerian description is not an objective quantity the objective rate has to be incorporated in the constitutive relation.

The main objective of this work is the comparison of the recently-discovered logarithmic rate with actually mostly used objective rates for the case of pure elastic cyclic deformations. The range of validity is determined for the corotational objective rates, namely the Jaumann rate, the Green-Naghdi rate and the logarithmic rate, and the non-corotational objective rates, namely the Truesdell rate, the Oldroyd rate and the Cotter-Rivlin rate, in the case of finite cyclic deformation with large rotations.

For that purpose, aforestated rates have been implemented into the commercial software ABAQUS/Standard using the user-defined subroutine UMAT.

Through the numerical procedure it is shown that the occurrence of finite rotations in total deformation significantly influences stress responses. For cyclic deformations with large rotations all the examined rates except the logarithmic rate produce high values of residual stresses at the end of the cycle, especially if the deformation is repeated in large number of cycles, which is the usual case.

Taking all into account, the results of the presented study reveal the distinguishing feature of the logarithmic rate from remaining objective rates for the case of elastic deformations with large rotations. This rate is superior to others, since it is the only rate that gives reliable and physically admissible results for this kind of deformation, i.e. the only elasticity-consistent hypo-elastic constitutive relation would be the one based on the logarithmic rate. Consequently, the only correct choice among all objective rates regarding elastic deformations with large rotations would be the logarithmic rate.

Therefore, our recommendation would be the implementation of the logarithmic rate into the hypo-elastic constitutive relations in modelling the large pure elastic deformation or the elastic part of the finite elastoplastic deformations, since it is the only one among all the examined objective rates that meet the requirement of the Bernstein's integrability condition, i.e. for whom path-dependent and dissipative processes are not detected even for a very large number of cycles.

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NUMERIČKA ANALIZA KONAČNIH HIPOELASTIČNIH CIKLIČNIH DEFORMACIJA SA VELIKIM ROTACIJAMA

Marina Trajković-Milenković, Otto T. Bruhns

Konstitutivne relacije koje opisuju ponašanje materijala pri konačnim elastoplastičnim deformacijama su najčešće date u formi izvoda napona i deformacija. Jedan od mogućih pristupa u formulaciji ovih konstitutivnih relacija je aditivna dekompozicija ukupnog tenzora brzine deformacije na njegov elastični i plastični deo. Kako je doprinos elastične deformacije prisutan na svakom nivou ukupne elastoplastične deformacije, tačna i unapred dobro razmotrena formulacija elastičnog dela tenzora brzine deformacije je neophodna. Rešenje ovog problema je primena odgovarajućeg materijalnog zakona u kome glavnu ulogu imaju objektivni izvodi, koji u slučaju konačnih deformacija moraju zameniti materijalni izvod. Izbor odgovarajućeg objektivnog izvoda koji figuriše u konstitutivnoj relaciji ima ključnu ulogu i najvažniji je cilj ovog rada. Ovo može biti od posebne važnosti kada se razmatraju ciklične deformacije, čak i ukoliko su ukupne deformacije male.

U slučaju čiste elastične deformacije, implementacijom najčešće korišćenih korotacionih izvoda, t.j. Jaumanovog i Grin-Nagdijevog izvoda, u hipoelastičnim konstitutivnim relacijama pri malim i srednjim rotacijama dobijaju se tačni rezultati, dok je broj ponovljenih deformacionih ciklusa mali. Sa povećanjem broja ciklusa, međutim, implementacija ovih izvoda daje rezultate koji se medjusobno dosta razlikuju, a takođe često opisuju fizički nerealno ponašanje materijala. Ova nestabilnost u rezultatima je posebno uočljiva pri modeliranju cikličnih deformacija pri kojima se javljaju velike rotacije, što je glavni zadatak ovog rada. Suprotno predhodno pomenutim objektivnim izvodima, primena logaritamskog izvoda u hipoelastičnim konstitutivnim relacijama daje rezultate koji u slučaju čiste elastične deformacije opisuju fizički stabilan proces.

Ključne reči: *hipoelastičnost, objektivni izvodi, logaritamski izvod, konačne ciklične deformacije, ABAQUS, UMAT podprogram, velike rotacije*

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ONE METHOD FOR DEFINING AN ACCEPTABLE LEVEL OF RISKS IN TUNNELING

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005.334

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Abstract. *This article presents one method for defining an acceptable level of risks in tunneling. The analyses are based on a simple analytical method for definition of tunnel stability using appropriate software in order to define the stability of excavations with and without protection. These analyses helped to find an approach on how to link the Acceptable Level of Risks with values of the Safety Factor (SF) and the Probability of Failure (PF). The explained methodology is related mainly to tunnels constructed in soft rocks or fault zones, but with some adaptations, it can be applied to other tunneling problems and other engineering structures. The case history used to test the methodology is a diversion tunnel at Hydro System "Sveta Petka" near Skopje. Based on these analyses, one proposal to define an acceptable (tolerable) level of risks using the criteria of the probability of failure and potential economic costs is presented.*

Key words: *acceptable level of risk; the probability of failure, safety factor, stabilization, tunneling.*

1. INTRODUCTION

It is well known that tunneling is a very complex engineering discipline important for civil and mining engineering since constructing tunnel structures comes with a high level of different risks. Designing underground structures, including hydrotechnical tunnels, is a particularly complicated procedure, because of the need to know a large number of engineering and economic factors that in one way or another affect the risks involved in their implementation. The technology of construction should take into consideration several important factors as:

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- The stability of rock mass during excavation,
- Stability of individual large blocks,
- Stability problems due to swelling,
- Resistance to digging, mining, and drilling,
- Conditions for protection from groundwater,
- Conditions for protection against high temperatures and gases,
- Conditions for loading and transportation,
- The impact of working operations on the natural environment, etc.

When performing work, stability in hard rocks is treated in one, and in low-quality rocks in another way, therefore during the construction stage, a large number of specific cases are possible. To overcome this, it is necessary to apply different technical and economic analyses in order to reduce all risks to a tolerable level. The strategy for risk management should represent an optimal compromise between the level of investments necessary to construct safe structures and the acceptable level of risks during or after the construction. At the moment, in tunneling and also in geotechnics, the level of tolerable risks is still not clearly defined. Some recommendations for slopes and tunnels are given in [1], [2], [3], but still this is an open area for investigation. The general concept for the tolerability of risks is developed by the United Kingdom Health and Safety Executive in its regulation of the major hazardous industries, such as the nuclear, chemical, offshore oil and gas industries [4], [5].

Based on this concept, later, the so-called ALARP concept (from as Low as Reasonably Practical) is developed in order to define a tolerable level of risks, and it is explained in [6] and [7]. This is an interesting method which presents the possibility to connect some engineering problems with the tolerable risk level. Based on these approaches, in the frame of this article, we are presenting further possibilities, with an intention to show that it is possible to link the Safety Factor (SF) as a measure of the stability of a tunnel structure, Probability of Failure (PF) and Acceptable Level of Risk (ALR). This is presented through a case of the hydrotechnical tunnel "Sveta Petka" in the Republic of Macedonia, but with some modifications, it can be applicable for other engineering problems.

2. THE BASIC THEORETICAL BACKGROUND OF THE PROBLEM

The presented methodology is connected to the fact that construction of tunnels, slopes, and other underground structures involves a certain amount of uncertainty in input parameters as a result of the complex geological nature and different loading combinations, which affects the reliability of the analysis procedure. To cover uncertainties, in most cases Factor of Safety analysis (SF) is widely used in engineering analyses. Reliability analysis is another supporting method, expressed in probability density functions representing the range and degree of variability of the parameter. An important step is to analyze the Probability of Failure (PF) for rock masses in interaction with the primary and secondary lining (support) defined with an appropriate statistical distribution functions and relative frequency of SF.

The methods mentioned above, are more on the technical side of the problem, which in some way should be connected to the risk assessment methods. From the practice, it is evident that all risks cannot be completely eliminated, and therefore the concept of an acceptable level of risk has been introduced. The essence of the concept is to make a decision that determines the extent to which a certain risk can be accepted when analyzing

a number of factors. At the moment there are a number of concepts related to the topic, such as:

- ALARP (As Low as Reasonably Practicable)
- ALARA (As Low as Reasonably Achievable)
- BACT (Best Available Control Technology)
- RACT (Reasonably Achievable Control Technology)

In order to define the acceptable (tolerable) level of risk, we will illustrate the concept through the so-called ALARP method. The method is applied for problems in hydrotechnical engineering, slope stability, rock fall, and other engineering problems. The basics of the concept are presented in Figure 1.

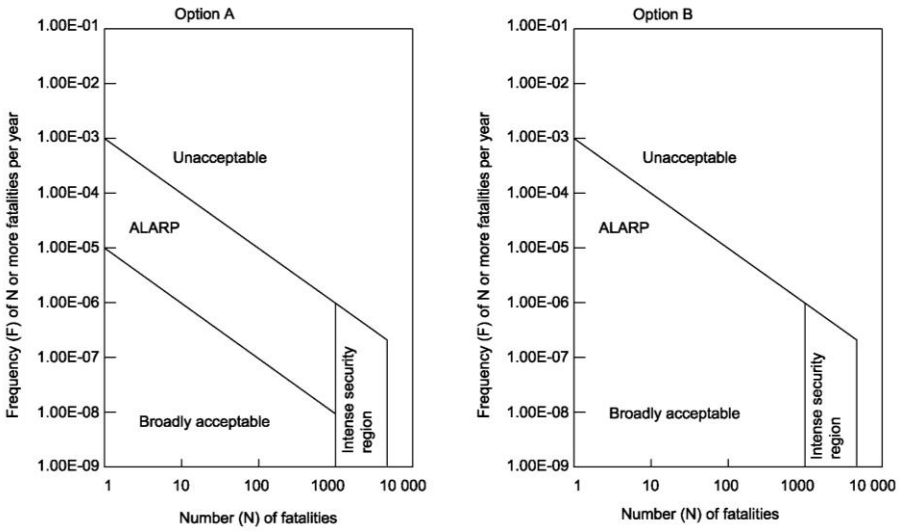

Fig. 1 Proposed societal risk criteria for landslides and boulder falls from natural terrain in Hong Kong [8]

If the risk falls into the unacceptable zone (Figure 1), it must be avoided or reduced, irrespective of the benefits, except in extraordinary circumstances. If the risk falls within the ALARP or tolerability region, then the cost may be taken into account when determining how far to pursue the goal of minimizing risk or achieving safety. Beyond a certain point investment in risk reduction may be an inefficient use of resources. Some analyses in this sense are presented in the frame of this article.

3. ANALYSES

The proposed methodology for connecting the Factor of Safety and the Probability of Failure, with the level of acceptable risks, is presented on the case for a diversion tunnel at "Sveta Petka" dam, near the capital of Skopje, The Republic of Macedonia."Sveta Petka" is a thin concrete arched dam, with a double curvature in the horizontal and vertical direction. The total height of the dam is 64.0 meters, not counting the fencing. Its body has

varying thickness and length- at an altitude of +364.00 m thickness -2.0 m, length- 10.0 m, and in the lower part at an altitude of +300 m - thickness 10.0 m, length 25.0 m. The length of the analyzed tunnel is 360 m., the diameter is 10 m, and the cross-section is circular. It was built in gray-white marbles, with an average compressive strength of 44 MPa, with variations from zone to zone. The main geological and geotechnical data are presented in Figure 2. According to these data, the tunnel is divided into 6 quasi-homogeneous zones with defined values for the deformation modulus (D), elasticity modulus (E), values of propagation velocity of longitudinal seismic waves (Vp), obtained from geophysical investigations, and parameters of rock mass quality based on Bieniawski Rock Mass Rating (RMR) and Barton Quality (Q) systems.

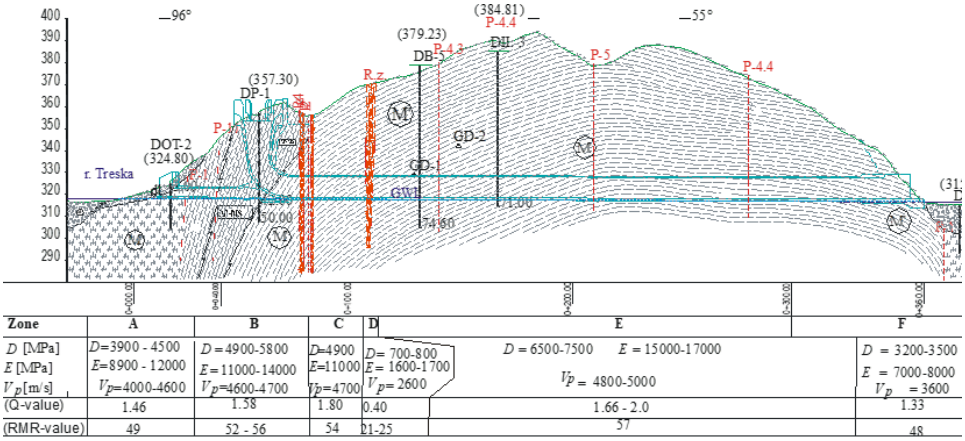

Fig. 2 Longitudinal geotechnical profile of „Sveta Petka“ hydrotechnical tunnel

In order to adequately illustrate the probabilistic analysis procedure, Zone D is used as a testing sequence. This zone is connected with a fault zone that intersects the tunnel. The rock mass in this zone has low quality, according to the RMR value of 21-25. Table 1 shows the input parameters for the zone D when analyzing an unsupported tunnel, using software RocSupport.

Table 1 Input parameters for zone D when analyzing an unsupported tunnel

Property	Distribution	Mean value	Standard Deviation	Rel. Min	Rel. Max
1 Tunnel Radius (m)	Normal	5	2	1	1
2 In-Situ Stress (MPa)	Normal	2.04	1	0.5	0.5
3 Poisson Ratio	None	0.3	0	0	0
4 Dilation Angle (degrees)	None	0	0	0	0
5 Compressive Strength of Intact Rock (MPa)	Normal	25	2	1	1
6 GSI (peak)	None	21	0	0	0
7 mi (peak)	None	10	0	0	0
8 Disturbance Factor (peak)	None	0.5	0	0	0

The following Figure 3 presents the results from the initial case of analyses of the unsupported tunnel opening.

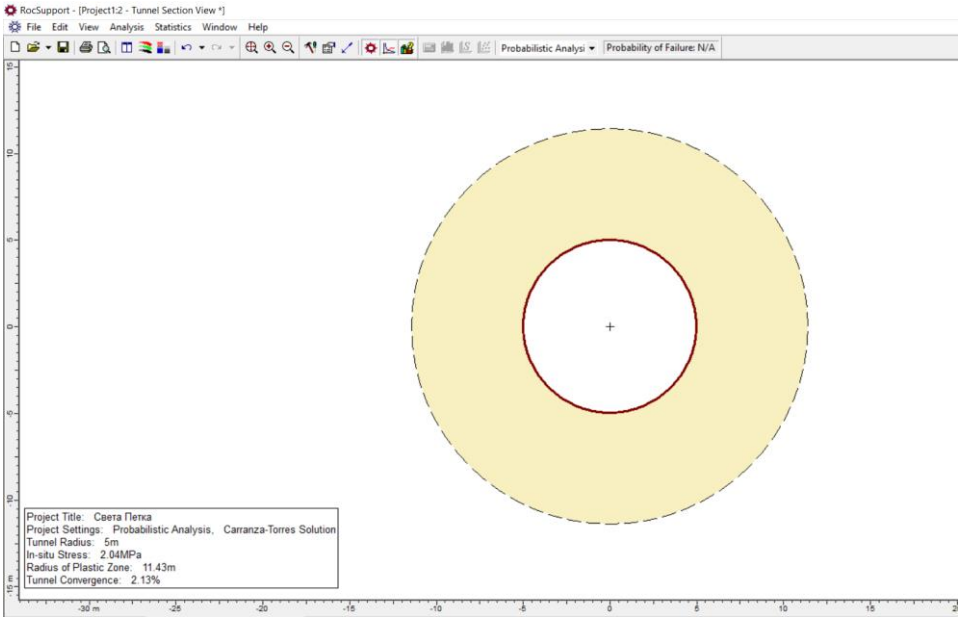

Fig. 3 Plastic zone radius for the unsupported tunnel for zone D

When analyzing the unsupported tunnel, it was concluded that the radius of the plasticization zone is 11.43 m. The excavation, in this case, is unstable and, it is necessary to immediately put primary lining support. Concrete support, with 5 cm thickness, 6 MPa compressive strength, reachable after 12 hours, was analyzed. Results show that the radius of the plastic zone, in this case, is 9.49 m, the safety factor (SF) is 0.45, and the probability of failure (PF) is 100%.

This means that measures need to be taken to increase the safety factor and reduce the probability of failure. Next, an analysis was made for the same concrete support and anchors with diameter Ø25, placed at 2m. After 12 hours, when the concrete reaches a compressive strength of 6 MPa, the safety factor (SF) was 0.75, and the probability of failure (PF) was 100%. After 3 days, with concrete compressive strength of 11 MPa, the safety factor (SF) was 1.02, and the probability of failure (PF) was 47.7%, and after 28 days, when the concrete reaches its maximum strength of 35 MPa, the safety factor (SF) was 2.28 and the probability of failure (PF) is 0%. The results for this case are presented in Figure 4.

It can be noted that the concrete support has a small effect on the radius of the plastic zone, but a significant effect on the safety factor, and the probability of failure decreases rapidly with the increase of concrete strength.

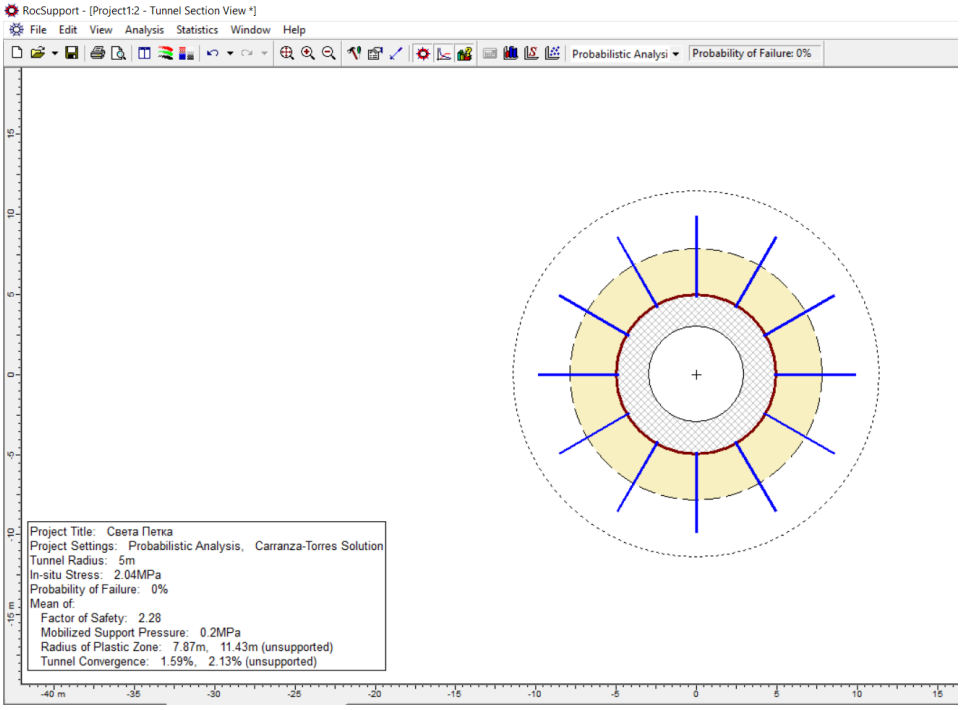

Fig. 4 Tunnel with concrete support 5 cm thick, after reaching a compressive strength of 35 MPa and Ø25 anchors

The logarithmic dependence of the probability of failure on concrete age is presented in Figure 5.

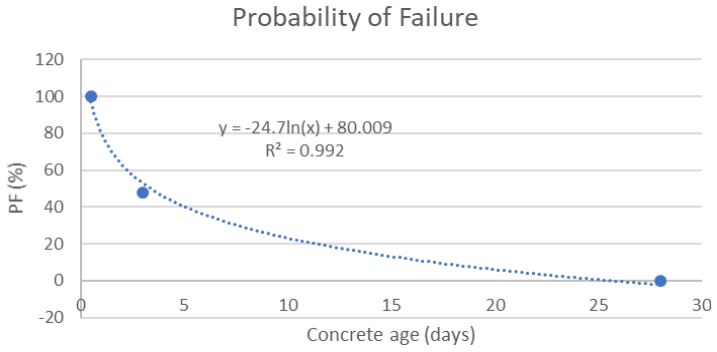

Fig. 5 The dependence of the probability of failure and the concrete age

From the obtained dependency, it can be calculated that the probability of failure will be zero, only after 25.5 days. It should be noted that after 25.5 days, the curve shows that the probability of failure will be less than zero, which does not have engineering logic.

This means, that after this period, the concrete gains the necessary strength and it can be assumed that there will be no failure. The dependence of the safety factor on concrete age is given in Figure 6.

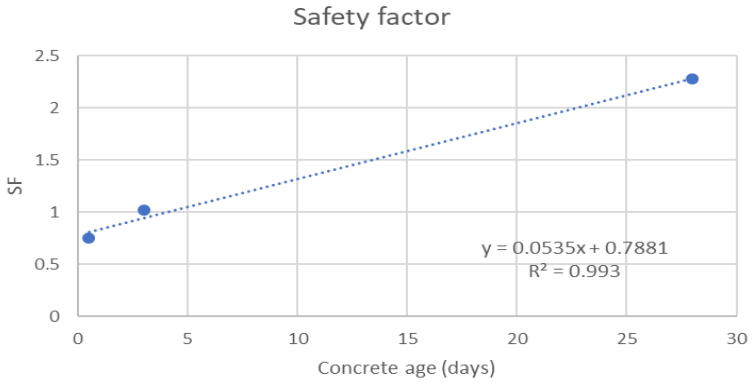

Fig. 6 The dependence of the safety factor on concrete age

Based on the analysis of the unsupported tunnel, it is obvious that some investments are necessary, in order to reduce the risk to an acceptable level, so in Figure 7, the relation between the costs for primary support, increasing of the safety factor and decreasing of the probability of failure for the analyzed section are presented.

Table 2 Input parameters for zone D when analyzing an unsupported tunnel

Support type	Cost for support (EUR/m')	PF (%)	SF
Shotcrete 5 cm	550	100	0.45
Shotcrete 5 cm +wire mesh Q221	770	47	1.02
Shotcrete 5 cm + anchors +wire mesh Q221	2695	0	2.28

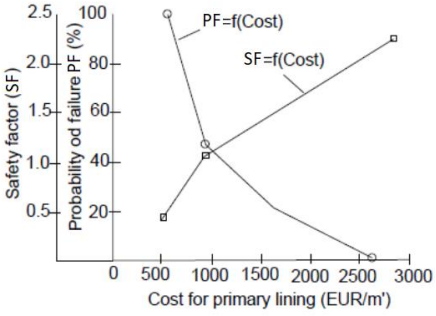

Fig. 7 Diagrams presenting the influence of investments on the SF and the PF based on data shown in table 2

4. PROPOSED METHOD

The presented analyses represent the base for the next step, which consists of proposing a method similar to the ALARP concept. In order to explain the concept further here, we present some charts in Figure 8. and Figure 9, which were given by [8].

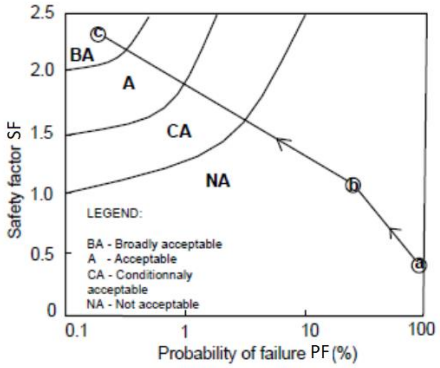

Fig. 8 Concepts of determining the acceptable level of risk with a combination of the safety factor and the probability of failure – a), b) and c) combinations from table 2

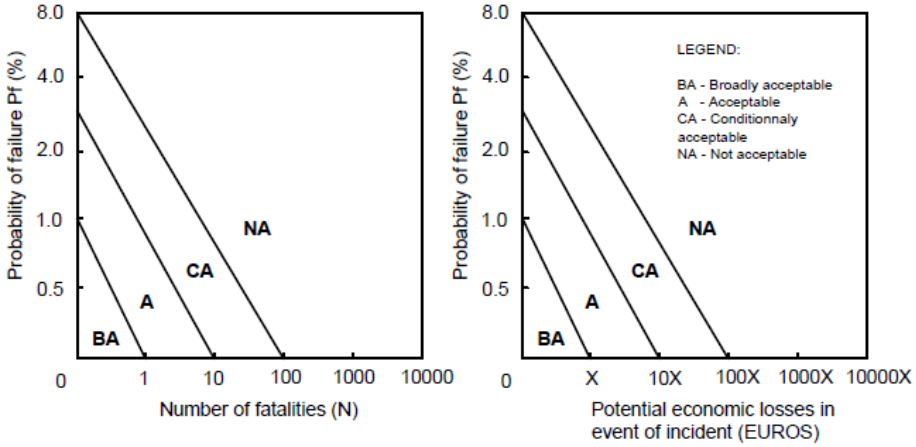

Fig. 9 Concepts of determining the acceptable level of risk a) Probability of failure - Number of deaths b) Probability of failure - Potential economic costs [8]

The value of X in Figure 9, is a variable related to estimated values that insurance companies shall pay for the possible loss of life, which as a problem is very difficult to determine with one simple value. Some recommendations for the "value of life" used by a number of countries are listed in Table 3.

Table 3 Typical "value of life" figures [9]

Country	Value of life (million £)
USA	1.67
New Zealand	0.75
Great Britain	3
France	4
Germany	2.1
Netherlands	0.3

The table shows that the "value of life" varies from country to country. This parameter is very difficult to determine. In Figure 10, we are presenting the possible cost of the loss of people in the above countries.

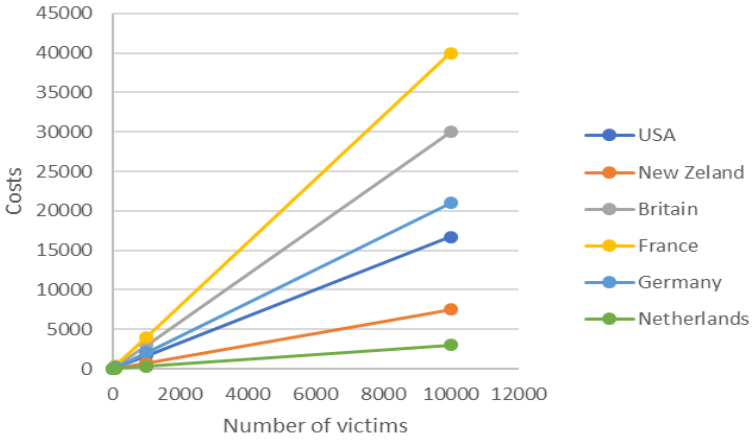

Fig. 10 The increase in costs for the loss of life for different countries according to Table 3

The value of X in Figure 9, can also be related to economic costs and loss in a case delays in the traffic because of accidents, remediations of the tunnel or other structures because of some unplanned event, etc., but this is a field for authors' further investigation.

Finally, in Table 4, we are presenting some ideas to define some acceptable risk levels according to [8], modified slightly by the authors of this article. The motivation for this modification was the fact that the existing recommendations take into consideration only temporary mine openings, but not the unsupported temporary excavations for other structures presented in Table 4. The author's recommendation for tunnels is added according to the ESR (Excavation Support Ratio) parameter. The ESR indicator is selected depending on the type of object. The Q-value is related to tunnel support requirement by defining the equivalent dimensions of the underground opening. This equivalent dimension, which is a function of the size and type of the excavation, is obtained by dividing the span, diameter or wall height of the excavation (Dt) by a quantity called the excavation support ratio (ESR), given as:

$$De = Dt/ESR \tag{3.1}$$

Table 4 Ratings of the excavation support ratio (ESR) (modified from [10]).

Type or use of underground openings	ESR	The acceptable level for Probability of failure PF (%)
Temporary mine openings	3.5	5-8
Temporary unsupported excavations in tunnels under pressure, pilot tunnels and excavations short time before installation of the primary lining	**3**	4-7
Vertical shafts, rectangular and circular	2-2.5	3-6
Water tunnels, permanent mine openings, adits, drifts	1.6	2-3
Storage caverns, road tunnels with little traffic, access tunnels, etc.	1.3	1.5- 2
Power stations, road and railway tunnels with heavy traffic, civil defense shelters, etc.	1	0.5-1.3
Nuclear power plants, railroad stations, sports arenas, etc.	0.8	0.1- 0.5

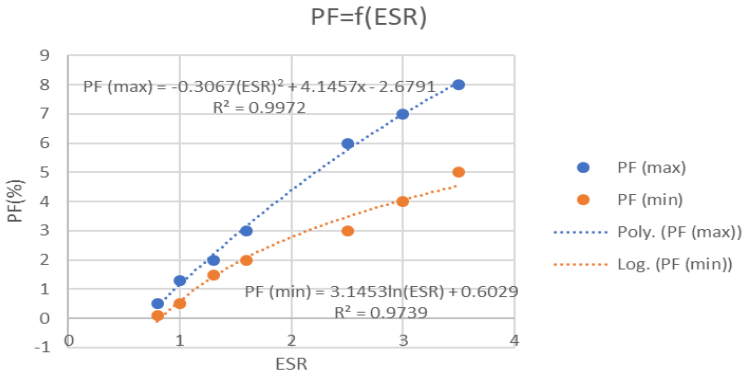

Fig. 11 Dependence of the acceptable probability of failure on the ESR value according to table 4

It should be noted that these charts should be considered as a first idea to determine an acceptable level of risk, and they should be additionally reviewed and improved. It is clear that all problems should be considered in terms of the specific set of circumstances, such as types of rock mass, design loads and the intended use of the future construction. Based on these concepts, in addition, we can underline some important steps that are necessary for the suggested method:

- Analyses of possible kinematic modes of failure along the tunnel section.
- Statistical analyses in order to define probability distribution functions for all input geotechnical parameters.
- Definition of Factor of safety (SF)
- Defining of the probability of failure, expressed with probability distributions of the Safety Factors SF.
- Analyses of costs and benefits from using some supporting measures for tunnels
- Definition of the acceptable level of risks.

These "simple" analyses give a clear view of the complexity of the problem. This is a subject for further occupation and development by the authors in the future.

5. CONCLUSION

Based on the presented analyses, it can be concluded that each design is unique and has to be considered in the terms of the particular set of circumstances, as rock types, design loads and the intended use of the future construction. The responsibility of the geotechnical and civil engineers is to find a safe and economical solution which is compatible with all the constraints that apply to the project. Solutions should be based on accurate analyses, and on engineering logic guided by practical and theoretical studies. The presented experiences are a good illustration, which shows that the knowledge of geological, tectonic and structural geological conditions is the basis for all analytical and numerical analyses and supporting measures design.

Based on the aforementioned, we can conclude that there are many possibilities for further researches in this area. The purpose is to improve and confirm methodologies suggested in this article and not only when it comes to tunneling but also for other types of structures.

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JEDAN METOD ZA DEFINISANJE PRIHVATLJIVOG NIVOA RIZIKA U GRADNJI TUNELA

U ovom radu je prikazan jedan pristup za definisanje dozvoljenog nivoa rizika u gradnji tunela. Prikazane analize su zasnovane na jednostavnim metodama i procedurama koje pomažu da se definiše stabilnost tunela sa ili bez podgradbe. Ove analize su od pomoći kako da se poveže nivo dozvoljenog rizika sa faktorom stabilnosti (SF) i verovatnoćom loma (PF). Prikazani postupak se odnosi uglavnom na tunele koji se grade u stenske mase slabog kvaliteta i u rasednim zonama, posebno za slučajeve za vreme nepodgradjenog iskopa i potrebnog vremena da se instalira privremena podgradba, ali sa određenim adaptacijama, moze da se iskoristi i za druge probleme u gradnji tunela i za druge inžinjerske probleme. Primjer na osnovu koji se prikazuje metodologije je razradjen za optocni tunel za branu Sveta Petka u R.Makedoniji. Na osnovi analiza, prikazani su mogući načini povezivanja rizika, dozvoljene verovatnoće loma i potrebna sredstva da se postigne dozvoljeni nivo rizika.

Ključne reči: *dozvoljeni nivo rizika, verojantost loma, faktor sigurnosti, stabilizacija, gradnja tunela*

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SPATIAL ORGANISATION CONCEPT OF TWO-ENTRANCE APARTMENT

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Abstract. *The location of the entrance and its relation to the main functional apartment groups in multi-storey, multi-family buildings, is to a great extent determined by the organizational concept of the apartment. The apartments with auxiliary entrances are less present in practice, majority of apartments fit the spatial frame of the building itself. The apartments can border with the next apartment on the same floor, be oriented towards one or more facades, but what is of key importance in determining the number of apartment entrances and their positioning is the size of contact zone between the apartment and common communication areas, as well as the configuration of the apartment. The aims of this paper include the analysis of the main positions of the entrance and the concepts of apartment organization that they determine, analysis of characteristic concepts of two-entrance apartments in multi-storey, multi-family buildings and re-examination of the relation between the introduction of the additional entrance and the necessity of having constant or occasional segregation of certain activities in them.*

Key words: *architecture, housing, concept, two-entrance apartment.*

1. INTRODUCTION

The entrance to multi-family buildings is most often achieved directly from the corridor zone, the lift, the stairway or some other communal space. Due to economic reasons of the construction, the inclination is to restrict the zone of common communication as much as possible, which often hampers or makes it impossible to achieve the auxiliary entrance to the apartment space. In apartments with small surface area, there is usually only one entrance, while bigger apartments often have two, and sometimes (but quite rarely) multiple entrances. Depending on the configuration of the flat, architectural solution of the building,

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as well as the needs of its users, the doors can lead directly or indirectly (via some of the "transitional" spaces)[1] from the living quarters towards the exterior space.

Numerous scientific research has been conducted so far, considering the organisation of the living space from different aspects and its influence on the following factors: usability value of the apartment, the quality of living, achievement of living comfort, compatibility of living functions, constructive systems, flexibility, etc., but there were just a few studies directed at theoretical consideration of the inter-relation of the functional apartment organisation and the position of the entrance. A significant contribution in this sense was made by Mate Bajlon, Grozdan Knežević, Milica Živković, Goran Jovanović and Mihailo Čanak.[2]

When considering the basic concept of living space organization, Mate Bajlon stated that, generally speaking, there were three common concepts of apartment organization and he refers to these in his papers as "X", "Y" and "Z" grouping concepts (Bajlon, 1979, 1975, 1972). (Fig. 1) By analysing the positions and inter-relation of the basic functional units in an apartment (common areas, individual areas and the household), Bajlon takes into consideration three characteristic positions of the apartment entrance (between the functional groups), without reference to the context and motives leading to application of just one, and not multiple entrances.

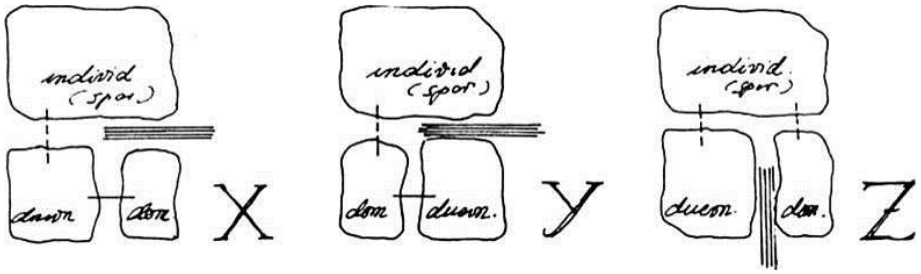


Fig. 1 Possibility of connecting functional groups within an apartment with relation to the direction of entry movement (Source: Bajlon, 1979:40)

Grozdan Knežević studied the position of the entrance and its relation to functional groups within the apartment, with a particular focus on the middle and corner position of the entrance. Knežević stresses that the middle position of the entrance is used more often in practice, but that the corner position can be incorporated successfully by using extended circulation area and irregular contour of the apartment (Knežević, 1989:39).

Milica Živković and Goran Jovanović analyse the importance of the central and peripheral position of the entrance from the aspect of space organisation and achieving the flexibility and they find the central position more optimal as it enables the shortest connection between all parts of the apartment (Živković, Jovanović, 2012:25).

[1] The term "transitional space" in architecture means the space whose main purpose is to connect two or more main rooms. In the functional sense, transitional space can have the purpose of transit (connective space), the purpose of preparation (transitional space) or the purpose of greeting guests. When looked at from the aspect of the position, they can be placed between the interior and the exterior, between the two interior or two exterior spaces (Kray, Fritze, Fechner, Schwering, Li, Anacta, 2013:17).

[2] Bajlon, 1979, 1975; Knežević, 1989; Živković, Jovanović, 2012; Čanak, 1976; et al.

In his study on the functional concept and usability value of the apartment Mihailo Čanak assesses the ways to achieve a certain connection in housing functions of the apartment (Čanak, 1976:306). According to this study, optimal relations are established by connecting the entrance with a) living room (in the form of extended or integral connection), b) dining (in the form of extended or integral connection), c) kitchen, d) toilet or e) bedroom (in the form of a dégagement).

After analysing a range of reference books dealing with the area of housing, it can be concluded that up to now, there has been no research into the concept of the apartment with two or more entrances, although multiple examples of such flats have been present in the architectural practice. The aims of this paper are:

1) Analysis of basic positions of the entrance and the concept of apartment organization stemming from them,
2) Analysis of characteristic concepts of two-entrance apartments in multi-storey, multi-family buildings and establishing the most frequent starting points that define their spatial and functional organisation, and
3) Examining the viewpoints that claim that the need for introduction of additional apartment entrance is characteristic in situations when, due to certain reasons, it is necessary to enable constant or occasional segregation of certain activities within the apartment.

2. Apartment Functional Organization and Entrance Position

Relying on theoretical stands expressed by Mate Majlon, referring to basic concepts of living space organization (Bajlon, 1979, 1975, 1972), it can be stressed that, along with three above stated concepts of apartment organization, that Bajlon named "X", "Y"and "Z" grouping method[3], in a wider sense we can also identify three more methods, resulting from the possibility of direct entrance into one of the living space functions. Thus, it is possible to determine twelve characteristic positions of an apartment entrance, as shown in the scheme below (Fig. 2).

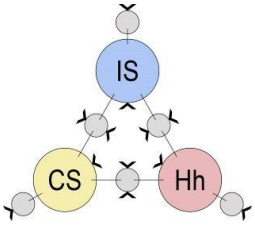


Fig. 2 Main positions of apartment entrance (IS – individual space, CS – common space, Hh - household) (Source: author's archive)

[3] Mate Bajlon does not state in his research which spaces he denotes as main groups of rooms in an apartment, but he identifies "common space" with the living room, "household" with the kitchen and "individual space" with sleeping and hygiene, in this way aspiring to abstract the concept of organization of the apartment into primary factor, as to make it easier to be understood and schematically presented. By analyzing numerous examples which illustrate his claims, it can be concluded that when using the term "common space" he means, along with the living room, free spaces (terrace, loggia), quite often even the dining room, if it was designed as the extension of the living room (the so-called "common table"); "household" stands for the kitchen and dining room, if it was an extension of the kitchen, then the pantry, sometimes the toilet; while the term "individual space" meant the bedroom or bedrooms, with bathroom, dégagement and sometimes the toilet.

If we were (during the course of extensive analysis) to eliminate from further consideration sub-versions of "external" and "internal" apartment entrance[4], in accordance with the shown scheme, we can get the following typology of apartment entrance (Fig. 3):

1) Indirect entrance between common space and the household
2) Indirect entrance between common and individual space
3) Indirect entrance between individual space and the household
4) Direct or indirect entrance through common space
5) Direct or indirect entrance through household space
6) Direct or indirect entrance through individual space

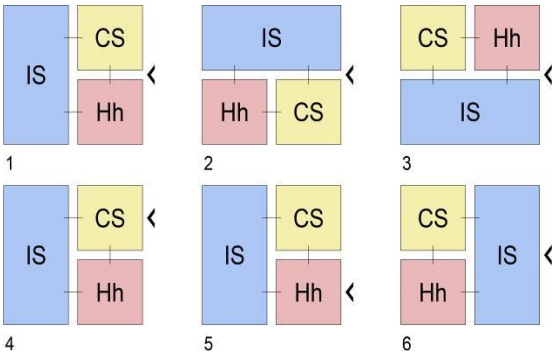


Fig. 3 Typology of the main concepts of apartment organisation with relation to the entrance position (IS – individual space, CS – common space, Hh - household) (Source: author's archive)

It is important to stress that not all presented entrance positions are of the same importance in terms of functional organisation of the apartment, nor can they provide equally good solutions. Depending on the position, importance, purpose or access, entrances can be divided according to:

- importance (or frequency) – into *primary* (main) entrance, used most often and *secondary* (auxiliary) entrance, used occasionally;
- position – into *external* entrance, through the external contour of the apartment (on the horizontal plane) and *internal* entrance, through the communication core in the centre – lift or staircase (on a vertical plane);
- type of access – into *direct* entrance, which directly leads into one of the main living space rooms and *indirect* entrance, through one of the "connecting" rooms (windbreak, dégagement, corridor, loggia, terrace, balcony, etc.);
- purpose – into economic, service, fire escape, staff entrance, etc.

[4] The term "external entrance" refers to the access through the external contour (as seen from the horizontal plane), while the "internal" entrance refers to an access through the center of the flat from the communication core (the staircase or the lift) and it is found mainly in large apartments with a core area.

2.1. Entrance between common areas and the household

In this type of apartment organisation the direction of entry movement divides the direct connection between common areas and the household. The position of the entrance enables quick access to the daily zone, through entry area and quick provisions required by household. Individual zone of the apartment is positioned away from the entrance, which, in certain situations, can impede the aim to achieve isolation and lead to reduction of the intimacy of occupants. Cutting off the direction of entry movement from the common space and household area can disturb the functioning of this quite frequent communication in the apartment (Čanak, 1976:203). This position of entry is mainly adequate for the main entrance to the apartment, although it can be used in some of the secondary entrances, such as economic, servants' entrance, business entrance in residential and business apartments, i.e. when the block of common rooms includes working space (office, library or cabinet room).

2.2. Entrance between common and individual areas

In this type of apartment organisation the direction of entry movement divides the direct connection between common and individual areas. The position of the entrance enables quick access to common and individual areas through entry area. The position of the entrance does not disturb the connection between common areas and household areas, while the distance of the household area from the entrance (and in some cases difficult provision for the household) can affect the activities carried out in the common areas. According to research by Boumová and Zdráhalová, this is one of the most preferred entrances by architects, as it enables a direct access to common areas, central position of the living room and achievement of the minimum of communication in the apartment (Boumová, Zdráhalová, 2016:37). This position of entry is mainly adequate for the main entrance to the apartment, although it can be used in some of the secondary entrances, such as business entrance in residential and business apartments, i.e. when the block of common rooms includes working space (office, library or cabinet room) or in cases when it is desirable to have auxiliary entrance for younger occupants or for the third generation of occupants.

2.3. Entrance between individual areas and the household area

In this type of apartment organisation the direction of entry movement divides the direct connection between the household area and individual areas. The position of the entrance does not disturb the connection between common areas and household areas and at the same time it enables quick access to household area, as well as provisions for the household through the entrance area. The proximity of individual areas enables undisturbed use of both the daily and the night zone, as well as achieving the required intimacy in the apartment. In some cases, the distance of common areas from the entrance zone can lead to cutting off the direction of visitors' movement and interrupted connection with the group of rooms reserved for personal life of all family members, and this has a negative effect on organisation of life within the apartment. (Bajlon, 1979:46). This position of entry is mainly adequate for the main entrance, although it can be used in some of the secondary entrances, such as economic, servants' entrance (as it is close to household areas), or in cases when it is desirable to have auxiliary entrance for younger occupants or for the third generation of occupants.

2.4. Entrance through common area

In this type of apartment organisation, the direction of entry movement penetrates directly or indirectly into the common area zone. Most often, it is thought that on entering the apartment it is necessary to provide adequate "preparation" area which enables the adequate level of preparation, for either the guest or the occupant, before they enter the intimate zone of the apartment, even in case of common areas. This "preparation" area can be in the form of the windbreak, staircase, corridor, lift or any other type of connecting area, depending on the structure of the apartment, i.e. the character that we want to achieve. Since the connection with individual areas and the household area is established through common areas, it is often necessary to introduce "circular connection" in order to achieve the required relation between functional groups (Alfirević, Simonović Alfirević, 2018). This position of apartment entrance is primarily fit for some of the auxiliary entrances (business entrance or the one for receiving guests), which are used less often and are expected to lead to some of the common areas (drawing room, cabinet room, library), areas not associated with the intimacy requirements. However, if the entrance leads to common rooms used primarily by the family (living room, dining room, TV room, etc.), and the preparation prerequisites were not met, i.e. there is no intimacy at the moment of entering the room, this could create functional conflicts.

2.5. Entrance through household area

In this type of apartment organisation, the direction of entry movement penetrates directly or indirectly into the household area. As the household can, in a way, be considered an unrepresentative zone of the apartment, not meant to be seen by visitors, due to different rhythms and ways of maintenance, the entrance through household zone cannot be deemed as an adequate solution for the main entrance. In apartments with smaller surface areas, where the aim is to form the daily zone by maximally using the lit part of the apartment. This places the kitchen, out of necessity, at the far end of the daily zone, close to the entrance. On the other hand, the existence of auxiliary entrance thorough the household area, especially in larger apartments or apartments with servants, can contribute to usability value of the apartment, as the activities such as receiving guests or supplying the household can be conducted simultaneously and undisturbedly.

2.6. Entrance through individual space

In this type of apartment organisation, the direction of entry movement penetrates directly or indirectly into the individual space. As individual space requires the highest level of intimacy in the apartment, in most cases this position of entrance is not suitable for the main apartment entrance. A specific case of apartment organization which can, in certain versions and in an acceptable way, use this position of entrance is the concept of the apartment with a corner entrance, which requires a direct connection of one of the functional groups with the entrance (most often individual group of rooms), with the use of an extended communication area or a circular connection (Knežević, 1989:39). This entrance position is most suitable for some of the auxiliary entrances, particularly when we want to achieve a higher level of autonomy of the room for guests, younger occupants or the third generation of occupants. Grozdan Knežević is of the opinion that the intimate zone of the apartment should under no circumstances be "exposed" to the entry area, regardless of the size of the apartment (Knežević, 1989:44).

3. CHARACTERISTIC CONCEPTS OF TWO-ENTRANCE APARTMENTS

Previously discussed typology examined possible positions of the entrance in the living courters in a multi-storey, multi-family building and its impact on the layout of the main functional groups, whether it is the main or auxiliary apartment entrance. We also stressed which type of entrance was the most suitable for certain apartment organisation. In order to establish what motives could initiate the choice of having the secondary entrance along with the main entrance, it is necessary to analyse characteristic concepts of two-entrance apartments.

3.1. The apartment with auxiliary entrance through the kitchen

Auxiliary entrance through the kitchen is most frequently used in situations when it is necessary to visually isolate the household area as a unit separate from the rest of the apartment, which enables easier supply and functioning of the household. In this type of apartment organization the dining area is most often separated from the kitchen area and is an independent space (or part of the living room, in the open-plan type of space), while the area for receiving guests and other social activities of representative character are distanced from the potentially unrepresentative space. (Fig. 4) The need to separate the kitchen and have an auxiliary entrance is also present when the kitchen is used intensively, as well as in apartments with more occupants or three-generation families. Due to different lifestyle rhythms and specific individual needs, it is necessary to achieve a certain level of autonomy of the kitchen space. The entrance through the kitchen can be achieved indirectly or directly, while the secondary spaces, whose purpose is subordinate to the functioning of the household (pantry, service room, terrace, loggia, etc.)

Fig. 4 Characteristic apartments with auxiliary entrance through the kitchen: 1) Kanchanjunga tower, Mumbai (Charles Correa Associates, 1983), 2) Ninetree Village, Hangzhou (David Chipperfield Architects, 2008), 3) Rue Franklin Apartments, Paris (Auguste Perret, 1904) (Source: author's archive)

3.2. The apartment with auxiliary servants' entrance

Unlike examples with auxiliary entrance through kitchen used mainly by family members, in apartments with auxiliary service entrance, it is used for the staff maintaining the apartment or helping in different activities. This approach is characteristic of larger

living spaces, with areas too large to be maintained by a family, but in adequate social and economic conditions when a family can afford to engage help outside the family to run the household and carry out service tasks (Brkanić, Stober, Mihić, 2018:27). These apartment concepts are characterised by having a separate block for accommodation of one or more servants, and the block is directly connected with the household area. (Fig. 5). Servants' block can be an integral part of individual areas or can be completely separate, but in such a position which is close to common apartment areas (Kubet, 2015:182; Cunha, Trigueiro, 2005:39). In the past, this apartment concept was much more used, as hiring servants was much more affordable (Gürel, 2012:115; Ducat, 2007:10; Alfirević, Simonović Alfirević, 2017:7). Nowadays the concept of having servants is mainly found in capitalistic societies and in well-off families that can afford it.

Fig. 5 Characteristic apartments with auxiliary servants' entrance: 1) Apartment building at Carrer del Mestre Nicolau, Barcelona (Francesc Mitjans, 1960), 2) Seida building, Barcelona (Francesc Mitjans, 1962), 3) Banco Urquijo, Barcelona (José Antonio Coderch, 1967) (Source: author's archive)

3.3. The apartment with auxiliary entrance through individual space

Although we mentioned previously that the main entrance into individual spaces can be functional in rare cases, in apartments with this type of entrance serving as auxiliary entrance, its existence can contribute to better functioning. It enables the option of separation from the individual block and autonomous functioning of certain activities carried out in it. According to Bajlon, the contribution to good apartment organisation is also proven by the fact that in such an apartment children and their friends can engage in activities separated from the activities of parents and their visitors (Bajlon, 1979:45). In apartments with multi-generation structure of occupants it is desirable to achieve a higher level of intimacy in spatial units, which justifies the existence of the auxiliary entrance that can be used on special occasions, when family members require to be separated from others in order to perform their own activities (social activities of younger occupants, arriving back home later in the evening, etc.), particularly if the individual spaces include secondary space for family gatherings (Ghadir, 2016:52). (Fig. 6)

Fig. 6 Characteristic apartments with auxiliary entrance through individual space: 1) Cité Descartes, Marne-la-Vallée (Yves Lion, 1995); 2) Housing in J. S. Bach street, Barcelona (José Antonio Coderch, 1957); 3) Holland Green, London (OMA & Allies & Morrison, 2016) (Source: author's archive)

3.4. The apartment with auxiliary entrance through working space

The concept of the apartment with joined residential and business activities, the use of auxiliary entrance through the working space can be of multiple importance. Depending on the type and intensity of business activities carried out in the apartment, auxiliary entrance can lead into: a) working room (cabinet), connected to the common space of the apartment, b) working block (office with kitchenette and sanitary block), reserved for business activities and reception of clients and c) indirectly to linked functional unit with developed space structure (business area with kitchen, sanitary block, pantry, bedroom, etc.). In rare cases, when the scope of business is intensive and includes receiving frequent clients, it is possible to use the main entrance, for representative purposes, to receive clients, while the auxiliary entrance can be used by family members. (Fig. 7)

Fig. 7 Characteristic apartments with auxiliary entrance through working space: 1) Casa N, Murcia (Ad-Hoc, 2015); 2) Residential building in Senjak, Osijek (Andrija Mutnjaković, Stanka Polić, Ivan Tomičić, 1968); 3) Photographer's Loft, New York (Desai Chia Architecture, 2014) (Source: author's archive)

3.5. The apartment with the option of unit division

In cases of multi-generation family units, the concept of apartment organisation with division options enables the independence of grown-up children or younger couples, as well as the elderly, who can be close to their family members if they need care, but also live independently (*In-law suite*) (Borsi, 2018:1116). Functional units can be of the same size and structure or in subordinate positions, but both must have all the essential spaces, that two separate apartments would have. Most often, they are linked through the entrance zone connection, which achieves unity of space, as in the concept of dual-key apartment. Depending on the organisation concept, the units can share certain contents, such as common space or household areas, which in some cases can disturb intimacy within these units. If one unit is subordinate to the other, i.e. when it has a more minimalist space structure, the minimum required is the existence of the room and the bathroom, sometimes even the kitchen. According to Bajlon, the solution of two connected flats on the same floor, which can be enlarged, or reduced by adding or reducing space of one of the units is considered one of the most optimal solutions in cases when the number of family members is increased or reduced (Bajlon, 1979:51). (Fig. 8) In shared apartments, such as apartments which are rented, apartments for students or the elderly, there could be separate entrances to separate rooms with bathrooms, while the common spaces include the kitchen, living room or working space.

Fig. 8 Characteristic apartments with the option of unit division: 1) Siemensstadt, Berlin (Hans Scharoun, 1958) (Source: Borsi, 2018:1116); 2) Apartment "plus-minus" (concept) (Source: Mate Bajlon, 1979:51); 3) Residential building at 14 Pariska street, Belgrade (Mirko Jovanović, 1956) (Source: author's archive)

3.6. The apartment with auxiliary entrance on the second level

Secondary entrances are quite often found in duplex apartments or maisonette apartments, spreading on two or more levels, as their use shortens the way from the entrance to distant rooms. In most cases their functions are divided, on two levels, into daily or night functions, with main entrance leading to common rooms, while auxiliary entrance leads to individual space or sometimes, to service zone. The importance of separating the entrance in this kind of apartment organisation concept is reflected in light differentiation of zones and achieving a higher level of intimacy in the apartment. (Fig. 9)

Fig. 9 Characteristic examples of apartments with auxiliary entrance on the second level: 1) Corringham building, London (Kenneth Frampton, 1960); 2) 50 West, New York (Helmut Jahn, 2018) (Source: author's archive)

3.7. The apartment with auxiliary fire escape

In apartments in higher buildings, along with the main entrance, reached through common communication areas or directly from the lift leading inside the living quarters, there is often an additional entrance/exit in the form of fire escape, which is not used except in rare situations, for evacuation purposes. Although the role of this type of entrance is mostly peripheral for everyday activities, as it is primarily an emergency exit, it can be used more frequently in order to reduce or neutralize the zone of internal communications within the apartment (corridor, dégagement, and hall). (Fig. 10)

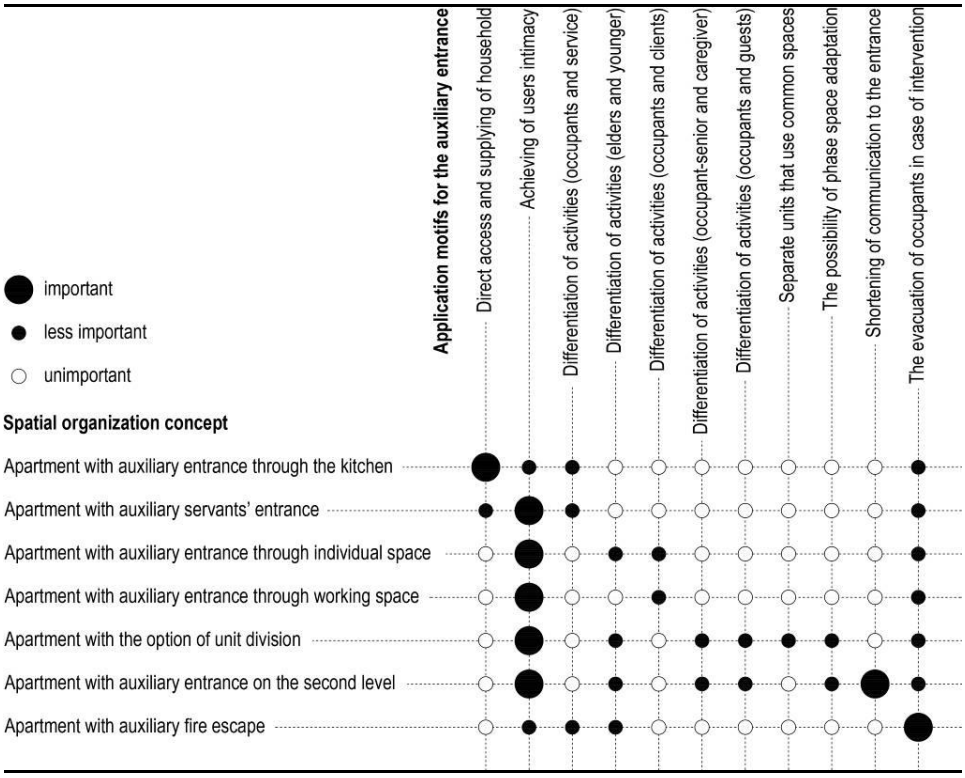
Fig. 10 Characteristic apartments with auxiliary fire escape: 1) Zellwegerpark Apartment Building, Uster (Herzog & de Meuron, 2015); 2) Tides IV, Charleston (LS3P, 2015) (Source: author's archive)

4. Discussion

Summarising the results of the analyses of characteristic concepts of two-entrance apartments and the motives that might initiate their use, it can be concluded that the concepts of apartments with second-level entrance and the apartment that can be divided

into two units, achieve the greatest number of motives. (Tab. 1) This conclusion can be explained by the fact that in the above mentioned concepts, two-space units can be clearly identified in the internal structure (in the horizontal and vertical sense), with the highest level of autonomy, which makes it possible for them to function as separate apartments, while at the same time being part of the same apartment.

Table 1 Presentation of the most significant motives and concepts of apartment organisations with auxiliary entrances (Source: author's archive)



On the other hand, when considering the presence and significance of certain motives in two-entrance apartment constitution, it can be noticed that the aim to achieve intimacy for different categories of users is of paramount significance when making the decision which of the analysed concepts to apply. What is of minor importance is the possibility that each of the secondary entrances can serve the purpose of evacuating the occupants in emergency situations, which can be taken as particularly important in apartments with large surface area, which, due to the larger number of rooms can be complex, and some parts can be quite far from the main entrance. Of equal importance is the option of direct access and household provision activity, which, as historically proven, contributed to the segregation of the activities performed by occupants and servants. Although it seems that the group of motives encouraging differentiation of activities of occupants is the most influential (as it is the most numerous group), the primary motive initiating all forms of differentiation or

segregation is the aspiration towards achievement of intimacy required by the occupants. However, the presented table showing the relation between the apartment concepts and the motives is still not an accurate indicator of real-life conditions, i.e. the frequency of certain concepts. It only indicates potential cause-and-effect connections, which could be further explored in research of a wider scope.

If we consider grouping apartments with two or more entrances into the same dwelling cluster, we can conclude that there is a large number of combinations that could be achieved. As in most cases these are large surface space apartments (100 - 250m2), the most frequently used approach is to combine two apartments per floor, and in rare situations a single apartment spreading over the whole surface area of the floor. Grouping three or more apartments within one dwelling cluster is the least frequently used approach and is found most often when combining two residing units with two entrances and one single-entrance apartment or in duplex apartments, when the entrance to the apartment can be accessed from interior corridor or the gallery, from different levels.

5. CONCLUSION

Our paper explored cause-and-effect relations between the entrance and the concepts of spatial organisation of apartments in multi-storey, multi-family buildings. Generally, the paper focused on possible positions of apartment entrances, whether they were main or auxiliary entrances, their influence on the distribution of basic functional groups in a living space. On the other hand, the paper also analysed characteristic concepts of two-entrance apartments in multi-storey, multi-family buildings, aiming to establish the most frequent starting points which determine the characteristics of their spatial and functional organisation.

The starting hypothesis, claiming that the introduction of additional entrance to the apartment emerges when it is necessary to enable constant or temporary segregation of certain activities, was proven as true, with additional note that the primary motive (leading to numerous other motives) is the aspiration to achieve an adequate level of intimacy of the apartment users.

The research included primarily the concepts of two-entrance apartments, which constitute the most numerous group, while indicating possible further research, focusing on apartments with three or more entrances. The relevance of this paper lies mainly in promoting the possibilities stemming from concepts of two-entrance apartments and which are reflected in achieving better functional connections in the living space and increasing its usability value.

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KONCEPT PROSTORNE ORGANIZACIJE STANA SA DVA ULAZA

Položaj ulaza i njegov odnos prema osnovnim funkcionalnim grupama u stanu u višespratnim višeporodičnim objektima, u velikoj meri određuje koncept organizacije stana. Stanovi sa pomoćnim ulazima su manje prisutni u praksi, jer je većina stanova „upakovana" u prostorni okvir zgrade. Stanovi se mogu graničiti sa susednim stanovima na istom spratu, mogu biti orijentisani prema jednoj ili više fasada, ali za određivanje broja ulaza u stan i njihovo pozicioniranje, od presudnog značaja su veličina kontaktne zone između stana i zajedničkih komunikacija, i konfiguracija stana. Ciljevi ovog istraživanja obuhvataju analizu osnovnih pozicija ulaza i koncepata organizacije stanova koje oni određuju, zatim, analizu karakterističnih koncepcija stanova sa dva ulaza u višespratnim višeporodičnim objektima, kao i preispitivanje relacije između uvođenja dodatnog ulaza u stan i neophodnosti stalne ili povremene segregacije pojedinih aktivnosti u njemu.

Ključne reči: *arhitektura, stanovanje, koncept, stan sa dva ulaza.*

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