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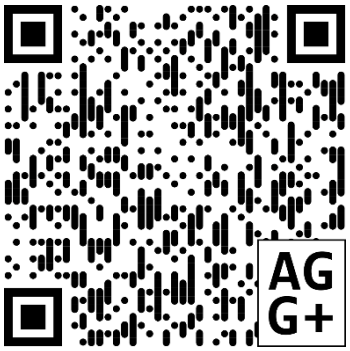
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Introduction 10(1)

Jubilee volume 10 stands for ten years of AGG+ journal existence. The journal publisher, Faculty of Architecture, Civil Engineering and Geodesy, celebrates this year the twenty-five years of the Architecture study program, fifteen years of the Geodesy study program, and the long-awaited completion of the new faculty building. In this context, we could say that the number 10 marks the end of one cycle and the beginning of a new one in the life of the journal and the school.

Volume 10 brings seven scientific articles. The 15th biannual International Conference on Contemporary Theory and Practice in Construction (STEPGRAD), organised by the Faculty of Architecture, Civil Engineering and Geodesy, took place this year. The editors selected three papers from the conference and had them specially prepared for the journal format. We would like to single out *environmental responsibility* as the dominant theme tackled in all the articles in different ways. Approaches to architectural design, architectural education, built heritage, and traffic network planning were discussed in light of climate change and the relationship of spatial disciplines to the natural and human environment.

The editors hope that the readership will find the articles constructive, engaging, scientifically profound, and enjoyable to read. We welcome contributions from all over the world and invite researchers, academics, professionals, educators, and students to submit their research and insights for volume 11.

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Editors-In-Chief

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Vanja Spasenović
University of Belgrade, Faculty of Architecture, Serbia, v.spasenovic@arh.bg.ac.rs

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Vanja Spasenović *
University of Belgrade, Faculty of Architecture, Serbia, v.spasenovic@arh.bg.ac.rs

PERCEPTION OF HERITAGE VALUES: EXPERIENTIAL QUALITATIVE MODEL FOR ASSESSING THE URBAN POTENTIAL

ABSTRACT

Modern-day is defined as a period of globalization, a complex construct that can pose a threat to maintaining the uniqueness of a place and creating a distinctive city identity. The hypothesis of this paper is that, while the phenomenon of globalization is researched within different disciplines, a common interdisciplinary theme stands out - the experience and perception of urban space that further builds a unique impression of the observed scene. The assumption will be investigated through the formation of a qualitative model for examining the urban potential with the aim of affirming the visual quality of the place as an important factor in the construction of local identity. The established model is examined through case studies of the 20th-century heritage. This period was chosen because it represents the subject of a contemporary global discussion about the conservation, activation and use of heritage in urban structures. The premise is that the qualitative model can be adequately applied to architecture from this period and contribute to its visibility and understanding, as well as to the examination of its role in the creation of contemporary local identity. The research is significant because it enables an interdisciplinary consideration of heritage as a key factor in building the modern city identity based on its visual impression.

Keywords: *visual impression, identity, globalization, heritage, spatial cognition*

1. INTRODUCTION

The 21st century has been established as a period of globalization. This complex phenomenon, in addition to numerous qualities, represents a risk to the preservation of the unique cultural heritage, striving for general economic, social and cultural globalization. Cultural heritage represents the legacy of the physical space and social and community values that makes the society distinctive. These physical and intangible values create a sense of belonging and place identity.

The contemporary city image is undergoing a constant transformation as a result of rapid urban development. The development of urban areas further conditions the adaptation of functional, ambient, social and cultural city parameters to current development tendencies. Rapid changes in the urban landscape can also lead to conflict between new and existing buildings and their contextual and visual connection. It is necessary to introduce continuity within the colorful network of contemporary and historical urban entities, which highlights the need for defining a new methodology of environmental analysis of heritage.

Cultural heritage is interpreted as significant within various disciplines: as a resource of economic and cultural capital or a sociologically significant factor for place recognition and the creation of belonging and identification with the observed. The common denominator of all recognized interpretations of heritage is the experience of space - the unique urban impression that allows the user to form a viewpoint through the perception of space and interpret it as unique. Contemporary heritage research and its preservation methodologies predominantly focus on tangible conservation aspects, such as adaptive reuse and building reconstruction. A disproportionately small amount of research focuses on the *values* embedded in heritage sights, the specific meaning they communicate to people and its role in the formation of individual and collective identity. It can be argued that the preservation of the unique values that stakeholders bring to heritage buildings is not preserved as equally as the material aspects of the buildings themselves. The analysis of the value that heritage carries is complex due to its shifting character - new stakeholders, fickle social conditions and time deviation can greatly affect the way we perceive heritage, as well as the value we assign to it based on personal conclusions. Due to the observed neglect of heritage values in relation to its material components, the research within this paper focuses on the formation of a qualitative model for examining the relationship between an observer and heritage through the visual perception of urban space. The research is based in the field of architecture, in view of the fact that it focuses on the perception of the built structure and the conditionality that the context and the building carry in understanding the experiential potential. The research outcome within this paper is the formation of a model for the valorization of the visual impression of urban structures that are rich in heritage which, with its application, enables (1) the formation of an objective overview of urban space, with a special focus on intangible values it carries to the observer, (2) recommendations for improving the location and (3) the highlighting of perceptually significant zones within observed context.

The qualitative model will be examined through a case study of 20th-century heritage. A significant discussion is taking place about the way in which these contemporary artefacts are treated and conserved, as well as their recognition and presentation on a global level. I believe that the qualitative model especially contributes to the understanding and valorization of 20th-century heritage from an architectural perspective by illustrating the building-observer relationship and the values embedded in this exchange.

2. HERITAGE AND IDENTITY: GLOBAL PERSPECTIVE

Place identity is a key concept in the discussion of contemporary cities and local heritage. When interpreting the future development and "behavior" of European cities, Manuel Castells points out that cities are increasingly turning to local heritage, concluding that the weakening of national identity makes people insecure and distrustful of the environment, politics and social relations [1]. This claim inspired much future research and the overall impression that modern-day cities are now perceived as active factors when tackling contemporary societal challenges, ranging from social cohesion to local peculiarities [2]. Cultural heritage can be seen as an effective tool that conditions the identity of a place and our perception of urban space in several ways. A unique urban landscape creates a sense of community and belonging to a certain social entity. Cultural heritage contributes to the economic development of cities as tourist places and business centers. In this way, a sense of social solidarity based on local and global development perspectives is created [3: 232].

Cultural heritage is one of the building elements of the unique identity of the observed place. The influence of identity on the observer's attitude towards space can be positive or negative. Gregory Ashworth points out that a positive attitude represents a universal benefit to local development just because of its existence, calling this phenomenon the *identity dividend* [4: 10]. Identity profit, whether economic, social or psychological, characterizes a territory as rich in experiences, culture and history and affirms an initially positive view towards the inhabitants and users of said space. The instrumentalization of heritage is not the only way to create an approving attitude towards space, but it represents a direct and recognizable pattern for establishing a memorable place identity.

During the process of economic globalization, many of the world's cities become connected by intangible characteristics of the environment that are outside their territories, creating a unified network of urban structures - global culture [5: 32]. The built structure, events or notable people from the past represent elements of identity that are interpreted and adapted to contemporary demand. The unique value of heritage includes not only the observed cultural heritage but also its meaning in the historical, cultural, social and psychological context of the perceived territory, independent of the market or financial value it possesses. Heritage is defined as a part of cultural capital, i.e. an integral part of the territory's wealth [6: 438]. Upon contact with the heritage space, this specific heritage value is recognized by the observer. Therefore, it can be concluded that this value depends on the quality and intensity of the exchange of various information between the observer and the built environment.

2.1. VALUE VS MATERIALITY: SCALE 1:1

The value of cultural heritage does not derive from the profits and businesses it encourages but rather from the values inherent in the wealth of heritage. Local peculiarities, history and culture become part of the spatial development strategy. The link between heritage and identity is undeniable. However, the existing built structure in many cities creates a unique urban landscape that is universally recognizable and standardized and is therefore considered insufficient in the struggle to establish an authentic and noticeable impression of space. Contemporary research examines the impact of innovative architectural feats and large projects in the age of economic and cultural globalization on the "branding" of the city [7]. Striking architectural projects create a unique contemporary image of the place. New

elements of urban morphology become recognizable and contribute to the creation of contemporary identity and the desired image of space.

Modern methodologies for the implementation of heritage in everyday city life engage predominantly in research of the tangible building aspects – the technical and technological adaptation to the modern needs and use, the building repurposing in accordance with current necessities or the use of new materials and innovative technologies. A significantly smaller quantity of research deals with the values that heritage carries and the importance it has in shaping the image of the place and the local community. Researching the value of heritage is complex due to its impermanent character. Different stakeholders/groups of observers can interpret a certain spatial zone in a completely different way, depending on age, gender, social conditions or cultural differences. The value can also be affected by the passage of time - the development of the city over time transforms the way we perceive the area of interest in relation to the wider context. It is commonly accepted that the values attributed to heritage places are not an immutable constant, but rather that they evolve in respect to both time and space [8: 58]. The observed transformable character of heritage value mapping thus must be taken into account in the process of forming any future research methodology.

Considering the presented views, the research within this paper is focused on the topics of identity and spatial (inter)relationships. The recognition of defined research areas as significant stems from the potential for establishing a quality connection with research from the domain of architecture. The topics of identity and space largely depend on the determinants of the physical, functional, historical and ambient context and characteristics of the place, making them adequate fields of analysis for defining the contemporary image of the city.

2.2. SPATIAL IDENTITY: AN ARCHITECTURAL PERSPECTIVE

The construction of meaning through the interplay of place-making, architecture and collective memory has always given shape and embodied spatial identity within the built environment. The physicality of place has provided a sense of continuity, and with that, architecture has constructed a tangible spatial identity through the manipulation of space, employment of materials and technology, and the resultant appearance and associated experiences [9: 14]. In the formation of the contemporary image of the city, heritage is a significant factor affecting the definition of the immediate representation and personal experience of the environment. The influence of cultural heritage on the contemporary social context is illustrated through the degree of connection of an individual or community with space, that is, the desire for further participation in its construction. Defining the collective place identity rests in culture as the bearer of social heritage, patterns of behavior, thoughts, feelings and actions. The urban environment can be interpreted as a unique expression of culture in a local context; therefore, when interacting with the elements of the built structure, the user of space participates in the construction of collective identity. Recognizing the building elements of identity in the architectural discourse opens the possibility for interdisciplinary cooperation and exchange of methodologies between architecture and related disciplines. The expected outcome of the research involves examining the potential of contextual analysis of heritage through the hypothesis that this type of research is inseparable from the spatial, social, historical and environmental context in which it is located.

Architectural research on the topic of identity predominantly focuses on the experience of space and the unique relationship between the user and the environment. Architect Aldo Rossi points out that the research of collective identity is inseparable from the territory, considering that this relationship is crucial for understanding the architecture of the city. The continuity of urban development, which is observed through the transformation of the physical and functional structure, is of essential importance for the understanding and interpretation of the city's identity. In his exploration of the urban context identity, Rossi classifies the elements of the built environment into (1) propelling and (2) pathological spatial artifacts [10: 373]. He recognizes the driving elements in historical monuments that permanently contribute to the city's vitality due to the permanent economic or social role of monuments within the city structure. The pathological characteristics of the urban environment include historical artifacts that have lost their functional value and deviated from the dynamic development of the territory over time. Although they do not participate in urban transformation, they can be significant from the aspect of establishing a connection with the past. It can be concluded that the driving elements are significant because they form a collective identity through continuous experience, while the pathological elements attach to a history with which the user has no direct connection. The interpretation of identity viewed in this way highlights the problem of the dominance of pathological spatial elements where the historical context is illustrated as distant and foreign.

3. CONCEPTION OF A MODEL FOR DEFINING THE EXPERIENTIAL URBAN POTENTIAL

Observing the identity theme within the framework of architectural theory requires the introduction of scale into spatial analysis. Defining the subject of investigation as a city, settlement or person greatly affects the issue of identity and its perception. The exploration of the experience of space in this paper predominantly focuses on the scale 1:1 - the immediate view of the user on the urban environment. Central to the understanding of the identity of space – viewed through heritage – is the experience of space, which represents the basis for further interpretation of heritage in different disciplines. The location memorability defines how the space will be further interpreted from a sociological, psychological, economic or geographical point of view. The observer is a reference point for all mentioned spatial qualities, such as perception, memory, affection and evaluation [11: 71].

Identity can be seen as a form of non-verbal communication of the physical environment. Polish architect Amos Rapoport is considered one of the pioneers of environmental-behavioral research in the field of architecture. A special review within the research of spatial identity as a form of non-verbal communication is defined by observing the influence of scale on the way we perceive space. Elements of the urban structure and the spatial (inter)relationships they build are divided by Rapoport into (1) fixed elements of the environment, (2) partially fixed and (3) variable elements of the environment [12]. Fixed elements of the environment refer to features of the built structure that change rarely or very slowly, such as infrastructure and facilities. The way in which these elements are placed in the space relating dimension, location and composition communicates meaning to traditional culture, but it also represents a favorable place for observing the (inter)relationship with other elements of the environment [13]. Partially fixed characteristics of the environment include urban elements that can be changed quite

quickly and easily, such as furniture and other attributes of interior decoration, clothing, urban furniture, advertisements, etc. These elements are of particular importance for identity analysis because they provide more information about the observed place compared to fixed elements of the environment. Variable elements are space users; their dynamic positions, formed relationships with other users and spatial elements define different forms of verbal and non-verbal behavior and experience of space.

When forming a model for the valorization of the perceptual quality of heritage, this paper will focus on the period of the 20th century. Recognition of heritage from the recent past is not sufficiently expressed on a global level. Defining a model for recognizing the perceptual quality of architecture can contribute to the improvement of recognition of this sensitive heritage group. A large number of architectural works of the 20th century with high historical value are still unprotected and pose a risk of inadequate maintenance and conservation. Furthermore, researchers conclude that the sharp decline in various resources calls for a wider reflection on heritage preservation, which should converge not only on the restoration of iconic monuments from the past but also on built heritage in the broad sense – most of which is from the 20th century – as a resource that is spread all across the territory [14: 42]. The interest in the twentieth-century heritage has developed in recent decades into an independent research practice through various initiatives for the preservation and conversion of modernist period buildings, such as Docomomo International, ICOMOS and the Association for Preservation Technology. In recent years research has been focused on methodology advancements, such as the formation of new tools for assessing the twentieth-century thematic framework [15].

Space provokes the observer's curiosity and becomes a place of infinite construction of experiences by evoking successive memories and relations within the moment of perception. In this way, an open space is left for upgrading the experience with the help of new knowledge and through the generalization of the visible and cognitive [16]. The preservation of 20th-century heritage is now one of the most challenging debates taking place in the field of architectural conservation [14]. The heritage of the 20th century does not have established forms of conservation and global recognition, although it often, to a large extent, participates in creating the identity and uniqueness of a place. The formation of a qualitative model enables the verification and valorization of the authenticity of heritage and its role in building global recognition. Memorability is based on the experience of space, specifically on the visual perception of the observed. The quality of perception is an objectively important factor of analysis because it can be studied equally in diametrically opposite contexts. The subjects of qualitative model analysis are fixed elements of space [12] – architecture, built structure and space. It is important to consider the subject of analysis as an integral part of the immediate environment while valorizing the continuity of viewing the built structure. The goal of the analysis is to determine how identifiable the building is at the perceptual level, which conditions the possibility of creating a globally affirmed identity.

3.1. WHAT DO WE SEE? DEFINING RELEVANT CHARACTERISTICS OF EXPERIENCE

When we talk about the perception of space, an important factor is the perceptual intensity that the observer achieves in direct contact with the environment. The object of observation is the border of perception, which in most cases is the street front - the silhouette of the built structure. In the process of perception, four types of variables are recognized: (1) observer, (2) mode of observation, (3) environment and (4) attributes of the

environment [17]. In the framework of this research, the observer and his mode of observation refer to a person watching the location in direct contact with a built structure through pedestrian movement. The subject of research - environment refers to the mandatory observation of heritage buildings as part of the context in which they are located. The attributes of the environment are defined through a qualitative model that will be presented below (Table 1).

In the process of perceiving the environment, the eye recognizes patterns of materiality that are open to further interpretation. Throughout visual contact with the built environment, the observer notices spatial (inter)relationships of tangible spatial elements, which can then be further cognitively interpreted. During the visual process, the observed characteristics are distinguished: the space of grouping (uniform character of the space) and the space of contrast (dynamic/heterogeneous character). In order to attract attention and interest, the composition of the built structure must be diverse, original, complex and ambivalent [17]. Order, organization, repetition and symmetry keep the viewer's interest within satisfactory limits, creating a moderate perceptual intensity. The environment should be continuous, varied and full of patterns in order for the perceptual process to be sufficiently interesting for the observer. In this way, a high-quality perceptive experience is formed with zones of greater intensity that make the built structure recognizable.

Table 1. *Review of environment attributes relevant to the experiential qualitative model*

PERCEPTUAL INTENSITY	ENVIRONMENT ATTRIBUTES	URBAN POTENTIAL	LIMITATIONS
moderate perceptual intensity	Predictability Organization Repetition Symmetry Uniformity Recognizability	The basic process is grouping - the observer notices zones of perceptually similar characteristics and further interprets them in cognitive processes as uniform groups	Visual perception of constant uniformity can be too boring and uneventful, which further causes the unrecognizability of the observed
high perceptual intensity	Diversity Originality Complexity Ambivalence Contrast Continuity Pattern recognition Characteristic	The high intensity of perception abounds in contrasts that suddenly attract the observer's attention. A person perceives (inter)relationships between built elements, which create a memorable image of the place	Constant high intensity of perception can lead to perceptual fatigue due to an excessive amount of stimuli from the environment

4. CASE STUDY: EMERGING HERITAGE

The problem of recognizing the importance of the 20th-century heritage lies in the short temporal distance from the present. A growing interest in recent heritage artifacts has been greatly intertwined with different markers of city identity from the architectural, epistemological or ideological point of view. Great changes are also taking place in the way we interpret heritage from different periods - the principles of preservation are not only related to the traditional protection of a building, historically significant place or archaeological site; the whole process becomes more dynamic in order to respond to the economic, spatial and social needs of modern society. This *living heritage* requires complex preservation modes in order to be protected but also integrated into everyday life. Ignoring the process of globalization and its impact on heritage and identity can pose a great risk to local identity safeguarding – with it being ultimately forgotten or marginalized.

Modernism marked the architectural theory of the 20th century through new paradigms and the transformation of architectural form. The use of mass production and prefabrication in construction represented a sign of a new social order and architecture that followed modern society's infrastructure and standard of living. New Belgrade is a municipality of Belgrade, planned and built in the second half of the 20th century. It is founded on the principles of modern urbanism and the modernist movement. New Belgrade was constructed as a modern, post-war city that illustrates the specific discourse of its time. Central zones of New Belgrade now hold the status of cultural heritage, which is one of the rare examples of mass housing being recognized as historically valuable and necessary for conservation. New Belgrade was recognized as an adequate scope for assessing the established qualitative model on the example of *living heritage*. The selection of cultural property of New Belgrade (Table 2) is taken from the database of the *Institute for the Protection of Cultural Monuments of Belgrade*, which primarily deals with the protection of cultural monuments, spatial cultural and historical zones, archaeological sites and notable places in the city of Belgrade.

Table 2. *Immovable cultural property on the territory of the municipality "NOVI BEOGRAD" [18]*

Cultural monuments	Museum of Contemporary Art Staro Sajmište – Gestapo Camp Church of St. Georgia in Bežanija Palace of the Federal Executive Council in New Belgrade Hangar of the Old Airport in New Belgrade The building of the Old Primary School in Bežanija
Notable places	Jewish cemetery in Ledine Memorial cemetery Friendship Park in New Belgrade
Facilities	"Sava Center" and "Intercontinental" Hotel (Crowne Plaza) "Fontana" Local community center "Genex" Residential and business center
Zones with historical or architectural value	Central zone of New Belgrade (blocks 21, 22, 23, 24, 25, 26, 28, 29, 30) Blocks 1 and 2 in New Belgrade Coastal zone of New Belgrade

One representative from categories (a) Cultural monuments, (b) Facilities and (c) Zones with historical or architectural value was chosen for further research through a case study with the experiential model for assessing the urban potential. The selection was made through these categories with the aim of evaluating the model behavior in different spatial intervals – from single building assessment to multiple block exploration. The assumption is that comprehensive testing of the qualitative model in different scopes enables a critical evaluation of its success and potential further use in heritage research. Selected tangible cultural property includes (1) the Museum of Contemporary Art, (2) *Genex* Residential and business center, and (3) Blocks 1 and 2 in New Belgrade.

4.1. MUSEUM OF CONTEMPORARY ART

The Museum of Contemporary Art in Belgrade is located opposite the Kalemegdan fortress and represents a notable architectural work by architects Ivan Antić and Ivanka Raspopović. The project was the winning entry in the 1960 competition for a contemporary museum building and represented a masterpiece of 20th-century Belgrade architecture. This institution has a high design quality, as well as functional support allowing it to continue to be the main location for the presentation of contemporary art in the capital after its reconstruction in 2017.

Figure 1. *Museum of Contemporary Art. Image source:* https://msub.org.rs/

The example of the Museum of Contemporary Art in Belgrade illustrates the favorable positioning of the built structure in the context of perception. The museum is located within a landscaped green area as the only built structure, so all attention is focused on it. Regarding the analysis of visual intensity using the set model, the museum is positioned as high-quality because it creates an optimal balance. Visual intensity is dominantly moderated through the perception of landscaped greenery, which achieves visual continuity and predictability. At the same time, the museum building represents a clear contrast in relation to the environment and thus attracts the attention of passers-by with its high intensity of

perception. A major contribution in terms of visual quality is the recognizable silhouette of the museum, which participates in creating the building's recognition and a local identity. Also, the prominence of the building as the only one in the immediate environment suggests to the observer that it is a building of notable purpose. A pedestrian unfamiliar with the building's contents can guess which typology it belongs to, which additionally affirms the visual impression as an important topic in terms of local recognition (Figure 1).

4.2. *GENEX* RESIDENTIAL AND BUSINESS CENTER

The *Genex* high-rise building in New Belgrade was designed by architect Mihajlo Mitrović in the second half of the 20th century. The building consists of two units, commercial and residential, with a restaurant at the very top. In 2021, the tower was included in the list of cultural assets and was under the protection of the *Institute for the Protection of Cultural Monuments*. It represents one of the most significant architectural works of its time and depicts the development of the capital.

The block in which the *Genex* tower is located is predominantly residential, with a built structure of uniform quality and appearance (Figure 2). This perceptual uniformity of the context allows the tower to stand out visually as a dominant benchmark and a zone of high perceptual intensity that contrasts with the rest of the block. In this way, the observer, without any prior knowledge of the location he is visiting, gets the impression that it is an important visually dominant building. This balance of moderate and high-intensity zones represents a quality relationship because it creates a perceptual experience for pedestrians that is dominantly moderate, full of patterns that repeat and create continuity, with a contrasting structure that visually appears complex, challenging and recognizable to the observer. This intensity ratio can be considered very favorable for the presentation of heritage within the immediate environment because, without any additional intervention, it calls for attention and creates a striking impression of the place.

Figure 2. *Genex Tower. Image source: https://nationalgeographic.rs/ekologija/a39194/Novi-beograd-ostaje-bez-zelenila.html*

4.3. BLOCKS 1 AND 2

Blocks 1 and 2 in New Belgrade are of great importance in the architectural activity of multi-family housing in the 20th century. The first blocks were realized in the big campaign of building apartments in New Belgrade in the 1960s, and for that reason, they are often called *experimental blocks* [19]. The authors of the project are architects Branko Petričić, Tihomir Ivanović and Dušan Milenković. The built structure was designed in accordance with the original block plans made of free-standing buildings, paying special attention to the amount of open public areas and greenery. Further development of the blocks led to the formation of informal built structures that do not follow the given geometry of the original block.

The analysis of the perceptual qualities of blocks 1 and 2 in New Belgrade using a qualitative model positions this zone dominantly as a zone of moderate perceptual intensity. The visual characteristics that stand out are continuity, uniformity and predictability. Even though the two blocks are separated by high-traffic roads, the similarities that the locality bears in the visual experience interpret these zones as one visual entity. Observing the two blocks clearly shows the sensory unity of the context and architecture, which connects this whole into a unique atmospheric group.

Figure 3. *Block 1 and Fontana local community center. Image source: https://www.gradnja.rs/novi-beograd-simbol-socijalizma-simbol-kapitalizma/*

The category of contrast is not observed in the expected tangible categories, such as residential towers of larger volume, because their repetition introduces them to the general continuity of the locality. The identified zones of higher intensity can be classified architecturally into (1) planned and (2) non-planned structures. The planned building of the “Fontana” local community center occupies a corner position within Block 1. It is a planned

building defined as a local commercial center for residents of multi-family buildings in its hinterland (Figure 3). Plan-defined visual contrast represents a perceptually important element, which diminishes the potentially too uniform or bland visual impression of residential architecture. It is successful if it has no experiential competition, that is, it clearly stands out as visually important. Adding an unplanned built structure poses a risk for the visual detection of a valuable building pattern. Contemporary single-story buildings built on the perimeters of blocks 1 and 2 represent unplanned buildings that greatly disturb the clearly defined concept of blocks and, in the perceptual analysis, represent zones that attract attention due to their deviation from the recognized building pattern.

It can be concluded that the analyzed zone represents one sensory unity within the layered city structure. In the analysis and valorization of heritage, this zone is not independently visually recognized as very significant. Still, it participates in the wider construction of the local identity of New Belgrade, which is globally recognized, carrying architectural values that are visually detectable. Using the experiential qualitative model for assessing the urban potential allows us to identify zones of higher interest for further exploration, which in this case refers to non-planned structures that potentially limit the value and recognition of the analyzed heritage.

5. CONCLUDING REMARKS: *LIVING HERITAGE*

It is certain that the preservation of cultural heritage affirms the ecological, social, cultural and economic sustainability of the city. Adequate treatment of cultural heritage contributes to the quality of life of the social community by mitigating the impact of cultural globalization and encouraging sustainable economic city development. By interpreting the role of heritage in creating a unique identity of a place, we see the advantages and potential problems of its use within development strategies. The global character of modern information technology leads to a simple and direct acquaintance with different cultures and a selective, concise and simplified observation of the territory. It can be concluded that cultural heritage has different economic, social and cultural dimensions that can represent a significant role in the local development of the analyzed place. Cultural heritage can be viewed as a flexible and recognizable resource that is instrumentalized for the purpose of more effective local development. Future research trajectories must also interpret contemporary heritage through modern-day tools of experiencing and visualizing – rapid digitalization and everyday use of social media. Our sense of place can also be greatly influenced through digital networks that create borderless space, which can ultimately support engagement with different territories and expand our understanding on local identity.

This paper analyzes heritage as an initiator of the process of conceptualizing places. This phenomenological approach emphasizes heritage as a marker of urban space experience and forms a methodological apparatus that examines space from the perspective of observers. Personal contact at a scale 1:1 opens the possibility of viewing places from different perspectives - physical, functional, ambiental, historical or social. The analysis is in the domain of architectural spatial research, since the recognized research polygon is comprised of tangible built context components. The research result is a qualitative model for examining the experiential potential that, through the analysis of spatial (inter)relationships, illustrates the existing position of the analyzed heritage building in the immediate context and allows us to understand better its current role in the exchange

between the observer and the building. The attempt to objectify complex spatial relations represents a step towards a wider application of the set model in different contexts.

The established qualitative model measures the strength of the visual intensity of the observed building in the immediate context, thus emphasizing the urban place potential. The model represents a starting point for further development of the heritage area in the local context with the purpose of achieving global recognition. The limitations of the set model are recognized in its generality and objectivity - as much as these qualities can be considered favorable for the wider applicability of the model in different contexts, there is a danger of making too general conclusions that ignore the place peculiarities. Having this in mind, the application area of the qualitative model should be an introductory segment of a complex heritage analysis - a base and an overview of locational conditions that enable further qualitative analysis. Case studies in the area of New Belgrade enabled the verification of the model in real space and in different scopes, which can additionally affirm the use of the presented model for assessing heritage. The period of the 20th century is especially singled out because I believe that the qualitative model can make a special contribution to the examination of *living heritage*. Living heritage is an active part of the surrounding context; it is important to understand its position in the environment before making additional interventions. By assessing the current state and the visual impression that the artifacts of the recent past left in the current, it is possible to valorize its position in the immediate environment.

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AUTHOR'S BIOGRAPHIES

Vanja Spasenović

Vanja Spasenović was born in 1994 in Belgrade. She graduated from the Faculty of Architecture – University of Belgrade in 2018, where she enrolled in doctoral studies in the same year. She was enlisted as a Teaching Assistant for the scientific field of Architectural Design at the University of Belgrade in 2020. As an author, she displays works at national and international exhibitions in the field of art, architecture and urbanism and has won awards and honors at international competitions within various author teams, namely Stattwerk - Balkan Eco Center on Zeleni venac (2017), Viewpoint of the Fjords (2018), River block and walk Zenica (2019) and Interio (2020). She actively presents her scientific research at international scientific gatherings in the field of architecture and art.

ОПАЖАЊЕ ВРЕДНОСТИ НАСЛЕЂА: ИСКУСТВЕНИ КВАЛИТАТИВНИ МОДЕЛ ПРОЦЕНЕ УРБАНОГ ПОТЕНЦИЈАЛА

Сажетак: Савремени тренутак дефинисан је као период глобализације, сложен конструкт који може представљати опасност по неговање јединствености места и изградњу препозантљивог идентитета града. Хипотеза овог рада је да се, упркос истраживању феномена глобализације у различитим дисциплинама, издваја заједничка интердисциплинарна тема – искуство и доживљај простора који даље гради јединствен утисак о посматраном месту. Претпоставка ће бити истражена кроз формирање квалитативног модела за испитивање урбаног потенцијала са циљем афирмисања визуелног квалитета места као значајног фактора у изградњи локалног идентитета. Постављени модел испитује се кроз студије случаја наслеђа 20. века. Овај период је изабран јер представља предмет опште дискусије на глобалном нивоу о начину конзервације, активирања и коришћења наслеђа у урбаним структурама. Претпоставка је да се квалитативни модел може адекватно применити на артефакте из овог периода и допринети њиховој видљивости и разумевању, као и испитивању њихове улоге у креирању савременог локалног идентитета. Истраживање је важно јер омогућава интердисциплинарно разматрање наслеђа као важног фактора изградње савременог идентитета места утемељеног на визуелном утиску простора.

Кључне ријечи: *визуелни утисак, идентитет, глобализација, наслеђе, просторна когниција*

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Ana Kisjan
University of Belgrade, Faculty of Architecture, Serbia,
2021_41008@edu.arh.bg.ac.rs

Dubravko Aleksić
University of Banja Luka, Faculty of Architecture, Civil Engineering and Geodesy,
Bosnia and Herzegovina, dubravko.aleksic@aggf.unibl.org

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* corresponding author

Ana Kisjan *
University of Belgrade, Faculty of Architecture, Serbia, 2021_41008@edu.arh.bg.ac.rs

Dubravko Aleksić
University of Banja Luka, Faculty of Architecture, Civil Engineering and Geodesy, Bosnia and Herzegovina, dubravko.aleksic@aggf.unibl.org

THERMAL LANDSCAPES: RAHM'S METEOROLOGICAL ARCHITECTURE

ABSTRACT

In this paper, we will consider the issue of climate discourse, which is consistently connected with the emergence of the meteorological approach in the theory and practice of contemporary architecture and urban design. Thermal modernity appears as a contemporary space of critical debate that expands the possibilities of architectural thinking, positioning it in a transdisciplinary knowledge framework. The concept of meteorology is the result of research on biological and ecological causes and processes, thermal factors, actions, and interactions to establish a sensory connection of users with space. Therefore, invisible spatial qualities, atmospheres, are recognised as ontologically important elements of spatial experience. The new paradigm opposes visual dominance, formalism, and semiological interpretations, establishing a new way of social and environmental responsibility.

Keywords: *meteorology, thermal places, atmospheres, post-critical, space experience*

1. INTRODUCTION

The atmosphere of the zeitgeist imposes a change in the paradigm of built spaces through the possibility of transitioning the architectural form from primarily physical to physiological/atmospheric. Architecture is not only visual; it is experienced by people both physically through the senses and extrasensory; it generates a spatial feeling and represents the main bearer of the mood in the building, the city and the space in general. It also implies something indefinite, undefined, something beyond rational explanation. The primacy of the "ocular" must be reduced in favour of a balance not only towards the other senses but also extrasensory and experience.

The research shows one type of transition from a primarily metrical composition to an atmospheric-experiential composition in architecture and urban design. An analysis of the alternative path taken by this transition is shown through Philip Rahm's experiments, which are found in a new paradigm called "atmospheric architecture". The reason for choosing this case study is mainly because the design parameters of atmospheric architecture and its limitations, which shape the architectural space, are set equally according to the macro scale (such as the location of the building in the city and the invisible-soft dimensions of the space) and the micro scale (such as is the sensory and physiological relationship between the tenant and the building). Each chapter revolves around research questions that relate to the bigger picture of environmentalism. Also, the intimate methodological connection between atmospheric architecture and the post-critical phenomenon is shown.

2. POST-CRITICAL THEORY IN ARCHITECTURE

In contemporary terms, criticism is hardly an action. Critical theory does not want to accept general reality as it is, but it is constantly debating and re-questioning. [1]. It allows researching from a wide range of points and different perspectives. Critical theory points to advance self-reflexive investigations of the encounters we have and the ways in which we make sense of ourselves, our societies and our surroundings. Nevertheless, the theory itself is not one or the other, a homogeneous discipline nor a bound-together process [2].

Even though, in recent times, critical theory has ended up solidly set up in numerous arts, humanities and social science disciplines as a question of study in its own right [2], criticism is nowadays seen as outdated, insignificant, and an inhibitor of creativity in design [3]. Critical design is a big obstacle and a block in the creative process. It prevents the free development of an idea and narrows the potential of the multitude of solutions, directs the solution in only one design and creates non-resilient finished spaces that are often doomed to failure due to their inability to adapt to new circumstances. A critical approach in design interrupts and stops the architect in the creative process and puts him in a position to constantly make decisions or make judgments in situations that do not only concern him and often only concern others.

Walter Gropius and Ludwig Mies van de Rohe, the pioneers of the Bauhaus school, justified their departure from the romantic utopianism of expressionist architecture by emphasising the pragmatic need to accept new circumstances and environmental conditions: new technologies, materials and conditions of life and housing [4,5]. Mies van de Rohe claimed that it is necessary to accept the conditions that are in front of us and that are current regardless of everything because the new conditions have their own trends and values. He

explained that the designer must accept current conditions and values and adapt and extract value from them [5]. A critical approach, on the other hand, establishes universal values that the architects draw from theories they identify with or define themselves. Based on theories, through a criticism-based design process, they design a determined and finished space that forces its users to adapt to it. Due to the social nature of humans and the need to communicate with others, they are forced to adapt to the determinism of urban forms if they want to communicate with others in the city.

Contemporary architecture is in a post-critical phase. It is the phase in which ideological criticism and resistance give way to successful implementation, pragmatic efficiency and creative freedom. Progressive contemporary architecture should be inspired by the so-called design intelligence that can arrange and manipulate everyday and unexpected events and conditions interwoven in a network of different information, all with the aim of a pragmatic search for greater efficiency in realisation, i.e. a greater final effect [6]. The post-critical approach is a process in which criticism is not determined by resistance, novelty or fashion but by the need to solve growing global problems of a large scale, and that is why it is increasingly present in the space of contemporary architecture [7]. The diminishing importance of traditional critical methodologies gives preference to a generic or systemic approach to problem-solving that is more flexible and resistant to change. Traditional methodologies are based on values that they impose themselves regardless of the circumstances in which they operate, that is, they provide a very little compromise.

Rem Koolhaas pointed out the problematic relationship between critical theory and the creative act. Post-critical retrospective history highlights his apparent defection as prominent. The common basis of the 'post-critics' lies in the dissatisfaction with the 'negation' of the critical theory of the Vitruvian imperative towards the construction of architecture that aims to create a better world. The question is how long critical architecture can delay the inevitable moment when its hermetically sealed framework of opinion will open under the influence of increasing social disparity, wars of choice and the unfolding environmental cataclysm [8].

3. CLIMATE DISCOURSE IN ARCHITECTURE

At the beginning of the twentieth century, the combination of different interpretations of the climate phenomenon brought an expanded representation of the term, but also the implication of a new climate discourse [9]. The appearance of a large number of studies in this area can be interpreted from two angles. On the one hand, a transdisciplinary field of climatology was constituted in the intersection with a whole series of other disciplines; on the other hand, significant technological progress resulted in innovative thermal control strategies that established new means of expression. As the climate change debate rapidly evolves, different actors are setting new priorities and key questions to create a common understanding of the challenges we face [10].

In an attempt to explain the spread of the climate discourse, Vladimir Janković refers to European naturalists from the eighteenth century, who, in their works, developed new doctrines about the causal relationship of climate with human health. Furthermore, several experiments have been conducted to confirm the hypothesis that sunlight, fresh air, and a comfortable temperature play a central role in increasing the quality of life [11]. As examples of many types of research for that thesis, there are outdoor school projects, the

heliotherapy method, and the British Peckham experiment [12]. Historian Thomas Richards explained that climate from the perspective of European colonialism was positioned in the context of health and global empire, and architecture was an important medium for achieving those goals [13]. Later, in the nineteenth century, Fernández-Galiano pointed out that the first buildings designed as thermal machines were agricultural greenhouses. This means that the term artificial climate appeared as an attempt to reproduce and optimise outdoor climate conditions in the interior, primarily for growing plants. Nevertheless, this led to the use of so-called "residential greenhouses" or even for public purposes, such as the Mechanical Aquatic House (Claudius Loudon, 1817) or the Crystal Palace (Joseph Paxton, 1851) [14]. Even in these early examples, like the greenhouses of Victorian England, we can see the first evidence that human societies were explicitly concerned with controlling the atmospheric nature of their environment. The new possibility of manipulating atmospheres in indoor spaces was an enticing idea that preceded patents such as air conditioners or the "appareil pour laver l'air" (air washing machine) devised by the physiologist Charles Richet. The introduction of air conditioning systems in cinemas, theatres, and public and private facilities, initiated a series of changes that greatly affected the cultural life in cities, both for users and designers [12].

The semantic shift from controlling the air to establishing indoor climate diversity reflects the contemporary belief that artificially created atmospheres could overcome the limitations of nature [15]. Sciences that combined knowledge about the creation of synthetic atmospheres and, consequently, their relations with users' physiological and psychological states appear today as a relevant entry point for the study of thermal perceptions in modern practice. Concepts such as temperature gradations, insolation, and humidity are again recognised as key elements for creating a multi-sensory environment that promotes social, cognitive, and emotional human development.

4. ARCHITECTURE AS METEOROLOGY

While outdoor weather conditions have long been the domain of climatologists, consideration of indoor climate control has gained momentum with the rise of modern architecture, especially since the mid-twentieth century [16]. As discussed in the above chapter, the desire for architecture to be independent of weather conditions has become a kind of obsession in the modern age [17]. As Blagojević and Ćorović claim, the search for new forms and approaches is an essential problem in the relationship between people and the environment and changes in those relationships [18]. An insight into the new, complex trends and forms of modern architecture is given by the architectural historian and theoretician Charles Jencks. In his book "New Paradigms in Architecture", he announces another paradigm shift, introducing the term "architecture of complexity". According to Jencks, contemporary architecture is dedicated to pluralism, heterogeneity, and global culture and acknowledges the diversity of users' tastes, media, and visual codes. It describes an environmentally conscious architecture supported by technology, which creates a "new manufacturing facility" [19].

We may have experienced different concepts that aim to become a new, contemporary practice with ideas more radical than the previous ones. However, what they have in common is the movement of architecture towards a more progressive direction that can respond to emerging challenges. Authorities in these fields stand out, not because of optimistic ideas resulting from technological innovations but because practice is based on

research on causes and processes, climate factors, energy sources, human reactions, and interactions [20]. The German philosopher Sloterdijk claims that the growing awareness of the "atmospheric conditions" we live in, their fragility and changeability, has led us to understand that our atmosphere, now explicit to us, acts as our life support system. He summarises: "The topic of civilisation at the transition from the twentieth to the twenty-first century makes the topic of air and climate explicit", which gives the climate phenomenon an ontological significance [21]. Precisely within these frameworks of transdisciplinary knowledge, and a new dimension of social responsibility, there is a meteorological architectural practice that sets the possibility of an adaptable space generated by the climatic qualities of natural landscapes.

The application of meteorological principles in practice includes the logic of space division and the generation of forms from the perspective of energy exchange in nature. By considering the physical elements of pressure, temperature, and humidity as realistic shaping tools, the space becomes a controlled atmospheric environment with abundant diversity. The idea that started this concept is based on the sensory connection of the user with the space in which gradations of climatic elements, as connected series of microclimates, create physical and biological comfort [20]. This is a clear example of contemporary considerations of sensory and dynamic architecture that comprehensively create the second dimension of spatial experience, thereby questioning the traditional boundaries of architectural practice.

5. THE WAY OF PHILIPPE RAHM

At the Venice Biennale of Architecture in 2008, the "Digestible Gulf stream" by the Swiss architect Philippe Rahm stands out as a particularly indicative work, both an art installation and an experiment. Curator Aaron Betsky emphasizes the possibility of architecture to express light, taste, smell, touch and temperature [22]. The new paradigm of contemporary architecture opposes visual dominance and semiological interpretation in the postmodern era. It is no longer enough to just see architecture; it is necessary to experience it [23]. In his theoretical works, Rahm describes the metrological practice as a phenomenon in which it is not about "images of buildings and their functions, but about climates and interpretations; about air and its movement, about the phenomenon of conductors, evaporation, convection as transitory, fluctuating meteorological conditions...shifting the composition from metric to thermal, from thinking about construction to climatic thinking and from narrative to meteorological thinking". Rahm's meteorological work is freed from formalism and meaning beyond architecture itself, based on the dichotomy of physiological and meteorological [20]. The thermodynamic imbalance in the project "Digestible Gulf stream" created by two sources, two horizontal metal planes, where one heats and the other cools the space, creates a complex atmosphere between temperature polarities, but also subjects between them [24]. After decades dedicated to visible space saturated with symbols, narrative meanings, and individual interests, we are witnessing a "slippage" towards invisible spatial qualities, i.e. its atmospheres [25]. These intangible spatial qualities are recognized as important elements in the experience of architecture, as they connect the inner sensibility with outer space. Outside of all contextual frameworks, thermal perception is primarily associated with atmosphere and sensation [26]. The use of the concept of the atmosphere is mentioned in the works of Hermann Schmitz, whom Böhme believed to be the first to systematically introduce the term into philosophy. As architecture is not visual

but a spatial art that is experienced through bodily sensibility and not only a rational apparatus, these prominent philosophers explain the atmosphere as a spatial feeling or "spatial carrier of mood" [27]. On the other hand, Sloterdijk claims that the climatic qualities are not read as an aesthetic metaphor but as experiments of "air shaping" [21]. One often gets the impression that the atmosphere implies something vague, undefined, almost like Adorno's "more", which evocatively points to something beyond rational explanation. [25].

In the experimental project called "Domestic Astronomy", a prototype of an apartment is presented, in which Rahm primarily deals with atmospheric phenomena. The user occupies atmospheres instead of surfaces, the horizontal way of life is replaced by a vertical one, cold air sinks, and hot air rises. The physical division of space has been replaced by temperature air flows, which, according to their temperature characteristics, have a specific purpose that the user creates at his discretion [28]. Here, we can refer to Gaston Bachelard when he claims that space should be a "polyphony of the senses" because it is made for living and not for viewing. It is perceived by the body and mind in a comprehensive articulated process [29].

Different in scale, another example of the meteorological practice is the "Jade Eco Park", the result of a collaboration between Philippe Rahm and Catherine Mosbach for the city of Taichung in Taiwan. The thermal approach to the design of open spaces goes beyond conventional ideas of beauty and appears as an intriguing model for creating hybrid green spaces [30]. Discussions about an artificially controlled climate are shaped by the processes of accelerated globalisation, climate change, and less and less accessible greenery in cities [31]. Camillo Sitte established the key terminology for green urban infrastructure planning. Among other things, he introduced the notion of "sanitary green", which, unlike decorative green, is characterised by freedom from geometrisation to create variations of shaded, sunny, warm, and cold zones [32]. Using the techniques of artificially controlled climate environments, which are opposed to any visual representation, and closer to Sitte's notion of "sanitary green", the experience of being in an interior space is translated to the exterior and vice versa. Therefore, the Jade Eco Park project demonstrates the treatment of climate as a "building material" where architects use all the advantages of the site to embody the aesthetic dimensions of the thermal experience. Data, such as prevailing cold and warm wind directions, distance from roads, humidity and pollution, were carefully analysed and recognised as starting points for design. The result of these analyses is the creation of three climatic gradations, "Coolia, Dryia, Clearia", in which each one corresponds to a certain thermal parameter [30], allowing the visitor to walk through the diversity of microclimates. In times when microclimates were not yet observed from a scientific perspective, they were described through poetry and painting, where thermal experiences are mentioned as part of synesthetic sensations that foster pleasantness and pleasure. In the 1979 essay "Thermal Delight in Architecture", Lisa Heschong defined the term "thermal delight" as the multi-sensory experience provided by certain "thermal places" such as gardens and parks. She emphasises that pleasure results from a conscious combination of architecture, vegetation, water, and topography that together create a series of microclimatic experiences [33]. We can connect this interpretation of pleasure creation with a park in Taiwan, where the authors, instead of vegetation, topography, and water, use a conscious combination of different thermal parameters to create a modern type of thermal pleasure that is a reflection of the new, more complex needs of the city.

6. CONCLUSION

In the past, the issue of air and atmosphere was viewed from the technological side, while the potential of applying ambient parameters in architectural design remained neglected for a long time. Contemporary efforts to approach architecture from the meteorological side establish new means of expression through research into climatic phenomena and their connection with human beings' physiological and psychological functions. As a result, thermal modernity appears as a contemporary space of critical debate that expands the possibilities of architectural thinking to the fields of politics, medicine, ecology as well as immaterial spatial qualities. The traditional field of architecture is expanding to new atmospheric proportions, breaking down the barriers between interior and exterior, body and space. Thermal environments become the lens through which modern concepts of living and staying indoors are observed and, at the same time, the medium through which they are constructed.

Invisible and "soft" spatial characters are carefully researched, framed, and displayed elements that generate an alternative framework for living in Philip Rahm's practice. This "new aesthetic" relies on the construction of atmospheres, examining the limits of how much a sensory event in space can induce a change in mood and opinion because, according to Rahm, what we can feel is subject to consideration through the deliberation process. The metrical composition becomes a thermal composition that can only be grasped from within, through personal and collective experience, which makes it resistant to the modalities of classical representation and symbolism. It is important to emphasise that the space as the overall result of the architectural process must be read equally visually and ephemerally.

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AUTHOR'S BIOGRAPHIES

Ana Kisjan

Born in Banja Luka, where she finished elementary school and then high school, majoring in sociolinguistics. She graduated from the Faculty of Architecture, Civil Engineering and Geodesy in Banja Luka (2016) with a degree in architectural engineering. In 2019, she enrolled in master's studies - Interior Architecture at the Faculty of Architecture in Belgrade. She got her master's degree in 2021 in the class of prof. Milan Maksimović, PhD, on the topic of "Utopian visions of space", which was singled out and displayed at the "Royal Institute of British Architects" (RIBA). In 2021, she enrolled in doctoral academic studies at the University of Architecture in Belgrade under the mentorship of prof. Lidija Đokić, PhD. The main framework of her theoretical research is in the field of contemporary housing concepts, architectural philosophy, and sustainable development.

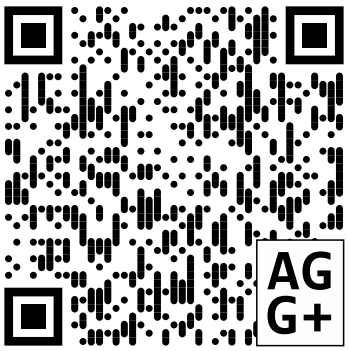
Dubravko Aleksić

Born in Brčko, where he finished primary and secondary school. He graduated from the Faculty of Architecture, Civil Engineering and Geodesy of the University of Banja Luka. He earned his PhD from the Faculty of Architecture, University of Belgrade. His scientific research deals with public spaces, quantum architecture, augmented reality and relations between body, space and architecture.

ТЕРМАЛНИ ПЕЈЗАЖИ: РАМОВА МЕТЕОРОЛОШКА АРХИТЕКТУРА

Сажетак: У овом раду размотрићемо питање климатског дискурса који је консеквентно повезан са настајањем метеоролошког приступа у теорији и пракси савремене архитектуре и урбаног дизајна. Термална модерност појављује се као савремени простор критичке дебате који проширује могућности архитектонског мишљења, позиционирајући га у трансдициплинарни оквир знања. Концепт метерологије, резултат је истраживања о биолошким и еколошким узроцима и процесима, термалним факторима, акцијама и интеракцијама у циљу успостављања сензорне конекције корисника са простором. Стога су невидљиви просторни квалитети, атмосфере, препознати као онтолошки важни елементи просторног доживљаја. Нова парадигма супротставља се визуелној доминацији, формализму и семиолошким интерпретацијама, успостављајући нови одос социјалне и еколошке одговорности.

Кључне речи: *метеорологија, термална мјеста, атмосфере, посткритички, просторни доживљај*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Ana Nikezić
University of Belgrade, Faculty of Architecture, Serbia, ana.nikezic@arh.bg.ac.rs, https://orcid.org/0000-0003-0158-731X

RESPONSIBLE EDUCATION OF ARCHITECTS – EXPERIENCE FROM INTERNATIONAL RESEARCH PROJECTS AT THE UNIVERSITY OF BELGRADE – FACULTY OF ARCHITECTURE

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Ana Nikezić *

University of Belgrade, Faculty of Architecture, Serbia, ana.nikezic@arh.bg.ac.rs, https://orcid.org/0000-0003-0158-731X

RESPONSIBLE EDUCATION OF ARCHITECTS – EXPERIENCE FROM INTERNATIONAL RESEARCH PROJECTS AT THE UNIVERSITY OF BELGRADE – FACULTY OF ARCHITECTURE

ABSTRACT

EAAE Charter on Architectural Research states that architecture is facing challenges of globalization, rapid urbanization, ecological disturbance and social transformation that necessitate permanent development in the field of education [1]. Educators, in particular, faculties and universities, need to understand and explain those changes and find a way to broaden the competencies of future generations to accept and deepen a responsible attitude towards the environment. Apart from permanent curricula improvements and innovative ways of intertwining research and teaching into a unique educational agenda, one of the essential components is also internationalization, both on the level of the study program and the level of student and staff mobility. The University of Belgrade – Faculty of Architecture is determined to strategically enhance the educational process through internationalization under the umbrella of Sustainable Development Goals (SDGs), Green Deal and New European Bauhaus. In that way, research and education expand horizons mutually, with international experience and expertise widening our knowledge and learning to accept differences and responsibilities as educators and architects.

Keywords: *architectural education, internationalisation, research in architecture, innovative study program*

1. BACKGROUND: RELATING ARCHITECTURAL EDUCATION AND RESEARCH

"Architectural education should have two basic purposes: to produce competent, creative, critically minded and ethical professional designers/builders; and to produce good world citizens who are intellectually mature, ecologically sensitive and socially responsible." [2]

Today, in the age of the Anthropocene, engaging with different socio-economic, cultural and environmental conditions which influence the everyday quality of life, architecture is facing challenges of climate change, globalization, urbanization and social transformation [3]. These challenges need vital research and permanent development in the fields of practice and education [4]. Consequently, there has been a trend among architects, urban designers and planners to introduce a new paradigm of responsible thinking as a new approach to the design of the built environment with an emphasis on the concept of sustainability.

The architectural education sphere accordingly faces contemporary challenges, including a lack of concern for sustainability, the growth of faceless urban sprawl and deregulation, the deterioration of historic fabric, and the loss of local traditions and identities. Therefore, architectural education is committed to supporting this responsibility agenda and reconfiguring its curricula, involving art, science, design, conservation, planning, management, construction and representation, with the aim of addressing issues of ethics, aesthetics, culture and society [5]. Therefore, the horizons of architectural education are changing and nowadays are expanding rapidly, mainly through the collaboration of architectural research and education with the development of new technologies and media, with globalization and the frame of internationalization through European and Worldwide funds [5]. In this context, schools of architecture are faced with a new set of challenges emerging from the contemporary debate on architectural research, professional engagement, the broader cultural framework, as well as the national and international institutional environment [3].

Guided by the challenging context in which schools of architecture are developing, this paper aims to illustrate one of the models for strengthening the institution's capacity and developing new study programs in line with contemporary educational strategies. The specific goal of the research is to provide an introduction to the current projects being implemented at the University of Belgrade – Faculty of Architecture and thereby provide an insight into the ways in which sustainability, and particularly a responsible attitude towards the environment, can be included in architectural education.

In the first part of the paper, a general framework on responsible education, the starting points for the subject research are explained, as well as the three key domains of action (cultural difference, mobility and flexibility, and widening knowledge base). The core shows the strategic initiative of the faculty through accreditation on one side and international Erasmus research projects on the other. The last part discusses the overall benefits of internationalization.

1.1. RESPONSIBLE EDUCATION FRAMEWORK

A considerable amount of attention has been focused recently on the responsible attitude toward the education of architects [2]. It is necessary to anticipate and act in respect to socio-political, environmental and cultural issues facing architecture so as to provide an

educational environment that is socially and environmentally responsible and acts in respect to sustainable goals.

In an open letter to the Architectural community, more than 2500 students and educators (https://www.architectureeducationdeclares.com/), namely academics, signed for a substantial curriculum change. It starts with the ecological crisis and goes into the unprecedented social, political and ecological challenges our generation is faced with. A wider scope of responsibility to meet an uncertain future with a socially and environmentally informed education is evident; therefore, a nuanced understanding and engagement are needed. The manifesto focuses on ecological understanding and interconnection between the social and ecological dimensions of the environment. However, it also proclaims that reevaluation of an existing and the development of a new deep competency, together with diversifying international cooperation and forming alliances, is an essential ingredient of a future responsible education. This way, the urgency of establishing a connection between education and sustainability as an overall approach is demonstrated. In this sense, environmental awareness is listed here as just one example that is the reason for a large petition that further indicates how many topics of education in the field of sustainability are not part of the formal curriculum.

Educators, in particular, faculties and universities, need to understand and explain those changes and to find a way to broaden the competencies of future generations to accept and deepen a responsible attitude towards the environment. Therefore, apart from permanent curricula improvements and innovative ways of intertwining research and teaching into a unique educational agenda, one of the essential components is also internationalization, both on the study program level and on the level of student and staff mobility.

1.2. INTERNATIONAL ARENA FOR EDUCATION

While debating on the link between education and internationalization, the current research framework on designing an innovative pedagogy for sustainable development in higher education is directed toward developing (1) an internationally recognized and accepted regional leader and (2) creating supportive strategies for improving the knowledge base and networking of researchers, students and institutions. The international arena is also essential for the development and improvement of teaching competencies. Therefore, there is a clear indication of the need for further enhancement of international research projects on one side and international recognition on the other, as tools that can contribute to creating responsible education for a sustainable environment at different scales. In this regard, one of the leading challenges for faculties and schools is the need to develop research that interrelates the leading sustainability agenda with internationalization and accreditation.

1.3. CHARTER, STRATEGY AND AGENDA FRAMEWORK

“There is no doubt that the architect’s capacity to solve problems, can greatly contribute to tasks such as community development, self-help program, educational facilities, etc., and thus make a significant contribution to the improvement of the quality of life of those who are not accepted as citizens in their full right and who cannot be counted among the architect’s usual clients...Beyond all aesthetic, technical and financial aspects of the professional responsibilities, the major concerns, expressed by the Charter, are the social commitment of the profession, i.e. the awareness of the role and responsibility of the

architect in his or her respective society, as well as the improvement of the quality of life through sustainable human settlements." [2]

As the standard for architectural education within the international community, UIA Charter is an important medium for advocating social responsibility in architectural education around the world. The Charter sets forth a number of 'General Considerations' and 'Objectives of Architectural Education', which take a similarly strong stance on the role of social responsibility in the architectural profession. Points 0, 2, and 7 in General consideration and points 4, 5 B2, and 5 B3 in Objectives of Architectural education are those most relevant to this discussion of social responsibility in architectural education [2].

Among others, three issues prevail when the responsibility of architectural education is taken into consideration [7]. The first one implies acknowledging cultural differences. The second one focuses on expanding and reevaluating disciplines knowledge base focusing on sustainability Goals through awareness and responsibility towards the environment. And finally, the third covers mobility and flexibility of education, enhancing interdisciplinarity and diversity.

1.3.1. Acknowledge Cultural Difference

Cultural diversity contradicts the ideas and concepts of globalization. While globalization has the potential to homogenize the world, a cultural difference diversifies subcultural values. Global perspectives and technologies flatten cultural variety and erase differences. Acknowledging cultural differences thrives to integrate architectural research and curricula considering global as well as local perspectives in terms of cultural, social, economic, environmental, and technical aspects of planning, designing and building [8] as to achieve the right balance between them and improve the way in which architecture as a discipline is perceived on both regional and global level. It values flexible education capable of conforming to different and diverse surroundings, learning to manage cultural differences as a means for all students to become more global in their outlook and behavior, as well as more flexible and effective in their own local environment.

In the era of the development of New European Bauhaus (NEB) as an initiative of hope and perspectives, we are experiencing a new cultural and creative dimension to the European Green Deal to enhance sustainable innovation, technology and economy [9]. NEB recognizes social practices, cultural activities and education programs as a beacon of the initiative and inspires new ideas. This recognition is confirmed within the NEB co-design phase, highlighting the crucial role of education and culture in the paradigm shift towards a new behavior and values.

Architectural education needs to position these concerns at the core of its program and a means of learning about them [10]. When cultural differences are understood as a resource, then all benefit. Instead of proclaiming the impossible global perspective, we should opt for cultural openness and sophistication. Employing a wide range of cross-cultural perspectives, the focus is on the flexibility of the global to fit the regional through an international framework.

1.3.2. Expand Knowledge Base: Research-based Framework for Education

"Tell me and I forget, teach me and I may remember, involve me and I learn." [11]

Bringing innovation into education implies permanent improvement of the curricula on the one hand and designing ways in which students can take an active role in the development of the syllabus. Therefore, the efficiency of pedagogy is under question [10]. A permanent change in curricula due to uncertain future needs is an essential ingredient of every study program. Teaching should grasp a critical momentum by generating a new approach to dealing with discords within and beyond the built environment [12]. Imbedding constant development and flexibility is one of the focal points of today's education agenda. Instead of redefining the core of education, we should consider adapting to current critical realities by rethinking and redesigning the relationship between teaching and learning [13].

The research-based framework for education is stimulated through the EAAE Charter on Architectural Research which highlights Architecture both as a Discipline and as a Field of Knowledge. It derives the following notions: (1) Architectural Research as a generator of knowledge base, mode, scope, tactics and strategies, (2) Research by Design as a pathway through which new insights, knowledge, practices or products come into being, and (3) Connection to Other Disciplines as a fertile for trans- and inter-disciplinary endeavors [14].

Architectural education needs to seek new relations between education and research, focusing curricula toward urgent topics and through a problem-based methodology. Employing a wide range of cross-cultural perspectives and multiple set of skill development models drawing on place-based and case-based study approach results in an inter-cultural and trans-cultural exchange of knowledge and experience.

1.3.3. Enhance Flexibility and Mobility on the International Level

"Practice is the raw data on which architectural knowledge is founded" [6]

Curricula that embrace this notion have better chances to increase student motivation in learning, and they foster student engagement [15]. The four pillars of this specific pedagogical approach are: 1) to push students to think outside of their comfort zone and inside their personal capabilities, 2) to create collaborative and beyond-disciplinary experiences, 3) to blur the academic and industry boundaries by engaging student's projects into the industry opportunities from the beginning of the process, and 4) to reinforce experimentation towards a positive environmental and social impact [16]. Also, architecture incorporates knowledge of other disciplines. It is comprised of practice-based and place-based education, inter- and trans-disciplinarity and global connectivity. On the other side, opportunities offered by digital technologies and global connectivity through internet platforms and social media put pressure on education to reimagine the learning framework and introduce flexible and adaptable knowledge delivery. Architectural education needs to understand and accept mobility as a means to support and widen the base upon which architecture as a discipline is conceived.

All three measures of responsible education capitalize on each partner's diversity of perspectives and practices being offered in hopes of providing innovative solutions and culturally different perspectives. Educators have to be sensitive and advocate for multicultural competency to facilitate international research and education. Through awareness of one's own disciplinary culture and sensitivity to others, international research may provide creative solutions for future education. By embracing cultural differences, a research-based framework for education as well as enhancing mobility and flexibility of the teaching and learning agenda, various aspects of education practices blend together, enriching architectural education to better suit a sustainable future.

2. CASE STUDY: UNIVERSITY OF BELGRADE – FACULTY OF ARCHITECTURE

The University of Belgrade - Faculty of Architecture is the oldest school of architecture in the region, with over 170 years of experience in educating architects and engineers. It is aimed at the development, promotion and dissemination of knowledge in the field of architecture and urbanism. The specificity of the study program is based on an integrative approach to teaching and learning architecture in which fields of Urbanism, Architectural Design, History and Theory, Technologies and Construction intertwine, providing a unique experience where technical and technological sciences, arts and humanities, and social sciences overlap and engage with current social, political, spatial and environmental issues.

During the Bologna process and through permanent accreditation processes since 2008, and particularly since 2012, the Faculty has been building a flexible and adaptable program structure that corresponds to the European educational arena, with the idea to expand institutional networks and borders as easily as possible, ensuring compatibility. In this way, the knowledge exchange, mobility and institutional networking are facilitated and simplified. While undergraduate studies are a place to gather basic knowledge and tools in all areas of the discipline, master's studies are focused on one of the offered modules (Architecture, Urbanism, Technologies and Structural Engineering) or the master's studies of Interior Architecture or Integral Urbanism and enable more profound research in focused areas of expertise for both teachers and students. In order to further emphasize the international perspective, the Faculty has been accredited by the RIBA validation system since 2014, and again in 2021, which gives the Diploma worldwide legitimacy. The RIBA accreditation process particularly emphasizes the importance of connecting all theoretical, experimental and applied knowledge and techniques through a Design studio as a focal point of an architect's education, and enables the almost palpable connection between research, education and practice through a single learning framework. Finally, starting from the second year, students have the possibility to slowly individualize their studies according to their interests. The selection rate increases with the year of study, where by the fifth year, only 20 per cent of credits are obligatory, which gives students additional self-confidence, enabling them to study abroad, and additionally provides the opportunity for teachers to connect with their colleagues from other institutions through various programs in order to form joint programs, study units and courses.

Belgrade, on the other hand, with its rich history and culture, represents a fertile ground and a platform for learning and acquiring knowledge through different scales and in different fields of education. As such, it is also attractive on an international level, as it intertwines diverse political and cultural-historical influences providing a fertile ground and a complex built environment full of educationally interesting and challenging topics. Thus, having that in mind, the Faculty of Architecture in Belgrade provides a vibrant field for the development of an international framework for the development of the connection between research and learning. In this sense, the Center for Research was launched in 2018 as a strategic platform for developing learning and research, promoting student and teacher results, encouraging extracurricular activities, exhibitions and alike.

Today, the Faculty is strategically following the sustainability agenda, reaching the goal of responsible education through three distinctive tracks. The first one considers international accreditation. The second one follows urgent global discipline problems on the international level through relating research and education. The third focuses on the development of

existing and new study programs that offer flexibility and mobility, as well as on regional visibility and leadership.

Future perspectives are reflected in the development of partnerships with international partners with the aim of developing: a) international joint study programs, international summer schools, b) a research platform for the development of key topics dealing with environmental problems, c) collaboration with the aim of tailoring and disseminating different public policies and strategies on the national level, and d) mobility support for teachers and students through various funds. One of the next steps is building a platform for cooperation between faculties in the region, which would aim at networking for mutual support in the application and implementation of projects, as well as for the exchange of teachers and students.

2.1. INTERNATIONAL ACCREDITATION

International accreditation systems vary substantially. According to various research [17, 18] on individual accreditation criteria in the world's leading education countries, it is evident that social responsibility is being, almost universally, acknowledged and embraced [2]. Although responsible accounting has always been a part of all strategic documents, it has not found an adequate way to become an integral part of the study program, and it is not widely applicable. The need to form a measurable system of review and evaluation of aspects covering environmental and social responsibility in the design process has not yet been established.

Figure 1. RIBA Exhibition. 1 October 2021. Source: https://exhibition.arh.bg.ac.rs/

International accreditation is a voluntary procedure applied by faculties in order to carry out internal control and self-evaluation and define the degree of modernity of the school on the one hand, as well as to align the faculty program and strategy with international standards and strategies aimed towards sustainable development recommendations on the

other hand. NAAB and RIBA international accreditations are the most common in the field of architecture [19,20]. Both go in line with the UIA general consideration focusing the assessment on a strong connection between study contents and learning outcomes through Student Performance Criteria.

It is a valuable bottom-up approach in which a structural variety of the local study program is being kept with a flexibility to focus on the global outlines through the structure and learning outcomes of the whole study program. The study program is not a fixed matrix but a flexible and open project in which learning outcomes outline the whole structure, leaving the specificities of the content on the regional level. In that way, the creativity of the curricula is preserved, as well as the diversity and particularity of the school, with particular topics given according to the global aims and perspectives of the future profession and practice.

Given the growing relevance of accreditation and recognition, the first step for UB AF was acquiring RIBA validation so as to be ranked and perceived [21]. For the Faculty of Architecture in Belgrade, the process of RIBA accreditation was beneficial for two main reasons, being (a) internal reevaluation and (b) external recognition. Therefore, the Faculty outlines the RIBA accreditation as a tool of continuous assessment for the architectural program to foster competitiveness in both academia and professional practice. It validates equivalency for professional practice worldwide and compatibility of the outcomes on a global scale. On the school level, it promotes equality, grade levelling among peer students and educators, content transparency, focusing on introspection and balancing between teaching agendas through curriculum development and learning outcomes through student results.

2.2. INTERNATIONAL COOPERATION

An increase in international cooperation is necessary to encourage knowledge exchange and help architecture schools to develop in a more systematic, scientifically aware and internationally recognized way [21]. Funding helps to establish a mutually valued framework as to develop synergies and strategies to transfer knowledge and locally engage, and to globally deepen the teaching and learning capacity building.

In academia, architectural education is supported by research, both directly through research projects and indirectly by providing for permanent knowledge exchange and development [14]. The goal of architecture students' education is to master design and research tools, with the idea of developing analytical, critical and reflective knowledge. As future architects, they must recognize the problem, determine its position in relation to society and proctor, that is, conduct a critical analysis and dynamic research, and independently propose a spatial synthesis.

Given the growing relevance of establishing the relation between research and education, the first step for UB AF was the assessment of ERASMUS + projects. It is important for the Faculty of Architecture in Belgrade for two reasons, being (a) knowledge exchange on the international level and (b) recognition of the variety of research specializations on a national and regional level.

Therefore, the Faculty outlines the ERASMUS project HERSUS (https://hersus.org/), which proposes enhancing and testing innovative teaching practices in the field of sustainability of the built heritage. The project strives to enhance the competence and motivation of

educators and researchers to include curricula elements that will have tangible results, preparing students and educators to become real actors of the environmental change. The practice and education in the field of architectural and urban design related to raising awareness about the sustainability of the built environment and heritage face numerous challenges, such as social transformation, climate change, globalization, urbanization and housing issues. HERSUS target groups (teachers/trainers/tutors, and students) need specific training and teaching activities within the frame of sustainability of the urban and architectural heritage: (1) a new profile of an architect/urban designer, a professional that is trained in the broad architectural domain, who owns technical, technological, socio-humanistic and artistic skills and, therefore, is equipped to contribute to the socio-environmental challenges, and (2) a new profile of architectural educator capable of assuming responsibility for the improvement of education and training of future architects to enable them to meet the expectations of 21st-century societies worldwide for sustainable human settlements in every cultural heritage. (https://hersus.org/ - The material used to describe the HERSUS project was taken from the project application and intellectual outputs).

Figure 2. HERSUS Intellectual Outputs. Source: hersus.org

The main project objective is to create and pilot new innovative courses/groups of courses/extracurricular activities within existing study programs of the participating HEI, which can contribute to bridging the gap between sustainability and heritage. HERSUS aims (1) to enhance existing study programs at the MSc level, and (2) to achieve a stable and sustainable education framework complementary to the globally established goals in the field of architectural and urban studies education.

The results of the HERSUS project and the longer-term impact lie in five output perspectives:

- The development of new and innovative courses/groups of courses/extracurricular activities and teaching methods for urban and architectural design schools in Europe.
- The first phase of the project creates state of the art in the field of urban and architectural design education in line with the concepts of sustainability and

heritage through a review of good practices, a critical questionnaire report and Statements for Teaching through design for Sustainability of the Built Environment and Heritage Awareness.

- The second phase is focused on strengthening the research and practical relationships between sustainability and heritage frameworks.
- In the sense of the transnational strategic partnership established between urban and architectural design schools in Europe, processes and synthesis of project results will be disseminated at the national and European level through the Sharing Platform open publicly. The participating organizations share common interests and ambition to enhance cross-culture connectedness and to enhance a sustainability-based approach in the learning-teaching design process
- The improvement of the quality of teaching and curricula provides innovative methods developed through teacher seminars and student workshops that will allow to increase and update the educational offer in sustainability and heritage thematic framework within urban and architectural study programs.

Therefore, the project has introduced and enhanced all three perspectives of internationalization . The experience gained so far from this project shows the importance of looking at specific topics at the international level, where all phases of the study program development, from the understanding of basic concepts to the scope of learning methodologies within the discipline of architecture and urban design, are checked, harmonized and developed uniquely.

2.3. STUDY PROGRAM

Blending different educational environments opens various horizons. It opens and expands school abilities and enables sharing of competencies among partners. It points towards understanding different legislation frameworks, increasing mobility, levelling up the faculty competency and enabling the study program development within which the competencies of several different schools and frameworks intertwine. It also harmonizes the legislative framework at the international level, ensures the development of studies in English, and the development of current global topics at the local level. Finally, it provides a change in the local perspective in terms of targeting a particular group of countries or a particular topic or specialization.

Given the growing interest in the topic of responsibility and awareness of Modernist heritage, the faculty outlines the Master program RMB – REUSE OF MODERNIST BUILDINGS (follow-up of the ERASMUS+ program: REUSE OF MODERNIST BUILDINGS. DESIGN TOOLS FOR SUSTAINABLE TRANSFORMATION. The material used to describe the RMB project was taken from the project application and intellectual outputs.

RMB is an educational platform on a European level based on existing research, educational practices and reference projects in the RMB partner countries with the aim of developing a unique strategy for learning about the reuse of modernist buildings. The adaptive reuse of buildings has been the subject of considerable attention by the end of the 20th century. RMB collects existing national and international results from different European regions to develop them as new transnational teaching material. In this relevant professional area and research field, a European approach to reuse can integrate different European contexts in

respect to the varied urban fabric, cultural and socio-political heritage, as well as climate and morphology specificities on one side and regulatory framework on the other side.

The RMB study program is based on togetherness and interdisciplinary work, a holistic vision where collaboration leads to excellence and new visions in a cross-fertilizing process. Innovation in RMB lies mainly in the way it addresses a specific topic (reuse) on a specific segment (modern movement) and does this by enclosing national and regional knowledge, combining it and making it accessible to an international global audience.

All RMB partners strive for a broadening of their international activities. The increased interaction between national and international activities necessarily implies a qualitative boost. The national and regional position of the HEIs increases significantly with the following perspectives:

- Education can be used more effectively; educational offerings can be developed and deployed in different places, thus achieving more with less.
- The exchange of ideas, knowledge and research activities will, by definition, lead to an increase in the quality of the HEIs and, thus, of the European educational system.
- The smaller HEIs benefit from the experience and the wider educational offer of larger partners. The larger HEIs benefit from the flexibility of the smaller ones.
- The interaction with academics, professionals and institutional partners will offer a solid network for future employment opportunities and applied research.
- The dissemination of scientific and design results (conferences, magazines and websites) will positively impact the RMB partners' position in local and international contexts.

In general, RMB contributes to the realization of the EU strategies for increasing the attractiveness of the European Higher Education Area. Modernism and modern movement architecture are completely intertwined with European history and identity. RMB works with this heritage, promotes it, and questions the positive and negative aspects of this heritage, making it a part of being in Europe. RMB establishes a network of European universities with a legal status and awards a European joint degree. It establishes automatic mutual recognition of learning periods across the member states. To conclude: RMB actively aligns skills with the needs of the labor market.

Given the growing need for framing the mutual international platform for joint degree, the faculty outlines the ECOBUILT project (The material used to describe the ECOBUILT project was taken from the project application and intellectual outputs). The reason for undertaking ECOBUILT Consortium is based on the recognition that the framework of research, practice and education in the field of architectural and urban design faces numerous eco-oriented challenges and thematic issues such as climate change, environmentally sensitive development, green economy, sustainable cities and human settlements, and preservation of biodiversity and ecosystems. The above-mentioned challenges require the improvement of curricular and extracurricular activities in higher education, which should be transnationally carried out; to equip the future graduates of the program with the knowledge, skills, and competencies which will help them to set the trends in a dynamically changed environment; to embrace new concepts of teaching and learning in a subject field;

to effectively work in different locations and cultures, and to bridge Europe's skills and competencies gap in an Eco-friendly Built Environment.

The concept of the project is to develop an integrated Master program in an Eco-friendly Built Environment aimed at training highly qualified professionals who will be able to design and restore buildings and landscapes in urban and rural settings with a minimal impact on human health and the environment. The concept of the ECOBUILT is to design a multidisciplinary program with regard to the-state-of-the-art trends in architectural and urban design education, and the philosophy of the green architecture. The program will bring together several scientific fields: architectural design, civil engineering, circular economy, and horticulture.

Whatever the track, it will be based on three topical approaches: sustainability, diversity, and practicality. The methodology behind the ECOBUILT will take into account region-specific features in terms of culture, climate conditions, and natural resources to cover diverse settings presented by the project partnership: historic and classic Italian environment; medieval and modern Latvian urbanism; hills and rivers in Serbia, and steppe and rivers in Southern Russia. Besides, all the territories involved in the project are within different climate zones: subtropical - Serbia, Mediterranean Italy, moderate sea zone in Latvia, and moderate continental in southern Russia, which will provide an opportunity to develop design solutions for diverse settings.

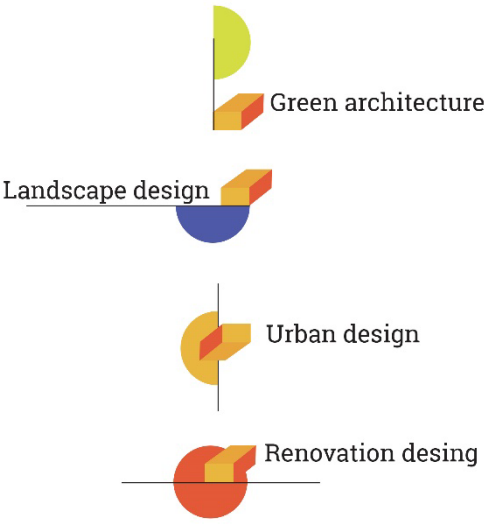

Figure 3. ECOBUILT Track. Source: UB ECOBUILT Team

Therefore, both ECOBUILT and RMB help each partner faculty expertise to permeate each other, building a program that meets the needs of modern society in accordance with international strategies of sustainability.

3. CONCLUSION: TOWARDS RESPONSIBLE EDUCATION

The UNESCO/UIA Charter gives us an inspiring vision of the role of architectural education and the architectural profession in addressing society's challenges and needs. It provides a

suitably ambitious set of criteria to serve as a benchmark for national and international architectural education accreditation criteria, and will hopefully serve to guide the profession toward a future in which all architectural education program produces graduates who are inspired and empowered to take an active and effective role in helping society to meet the challenges ahead [22].

UB-FA benefits from the project by expanding the network through both the international visibility on the account of RIBA accreditation, and enhancing the dynamic development of the study program through research projects. Firstly, the awareness of the way to include sustainability and the attitude towards sustainable education becomes more developed. The faculty also has the opportunity to cooperate with experts from the wider national framework and enable students to access new professional paths. Furthermore, students and programs taught at UB-FA through an international perspective can become recognized and verified for those areas in which they still do not have developed human resources. Research projects provide funds for the study program development and motivate teachers to constantly develop expertise in the areas in which they work. They provide a platform for testing new teaching techniques and models. Lastly, the overall international agenda provides students with work in a specific learning environment, especially when it comes to multiple learning models (from one-to-one to one-to-many) through extracurricular workshops, seminars and alike.

The architectural schools, as a whole, are places for international research practice par excellence that should be transferred to educational practices. Valid architectural research, which goes in line with internationally validated and responsible education, produces outputs (1) meaningful and relevant for the discipline and society; it explores regional limits and internationally expands them, (2) important for better spatial understanding. It also broadens knowledge (3) through intellectual work characteristic of architecture and design practice; (4) through varied methods, contexts, processes and results communicated and submitted to regular internal and external peer review. In the end, internationally enhanced responsible education creates and exploits trans-disciplinary connections. A clarification of this position is necessary, stimulating stronger links between different cultures, between theoretical and practice-based research and between academic and professional arenas.

In that way, research and education expand horizons, mutually developing educational strategies and methodologies, and updating curricula, with international experience and expertise broadening our knowledge and learning to accept differences and responsibilities as educators and architects.

In the light of responsible education that supports the agenda of sustainability, it is necessary to reconsider the role that education plays in building the profile of an architect. It is clear that a paradigm shift is inevitable, with an emphasis on connecting research, learning and practice. It can be said that one of the basic challenges facing education is the conflict between the rigorous rules imposed by the study program structure and creative research that requires a sustainable and responsible approach. In this sense, curriculum development must simultaneously ensure the integration of these fields and provide a dynamic and adaptable transfer of knowledge that lies in the essence of a responsible and sustainable relationship to space and, therefore, also to the disciplines of architecture, tourism and urbanism.

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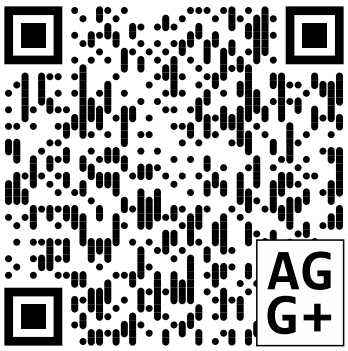
AUTHOR'S BIOGRAPHIES

Ana Nikezić lives and works in Belgrade. She holds a PhD in Architecture (2006) with more than 20 years of teaching experience in the area of Architectural and Urban Design and over 14 years of experience in research projects. Since 2010 she has been a member and mentor for the elaborations of doctoral thesis. In 2015 she was named Vice Dean for post-graduate studies, and in 2018 Vice Dean for Education and Research. Nikezić is fluent in English and has solid knowledge of French. She has published more than 30 papers in monographs, magazines, journals and conference proceedings of international importance. Nikezić is the author of the book "Formats for Urban Living – Family House in a Contemporary City" and editor and one of the authors of the scientific monograph "Playing Landscape – Košutnjak: Principle of Architecture Design in the Context of Climate Change", published by the Faculty of Architecture. Her research and architectural design are regularly exhibited at the Salon of Architecture and at the Salon of Landscape Architecture. She was also a member of the organizing and science committee for a number of national and international conferences. She has also participated in a significant amount of international and national workshops. She is particularly interested in connecting the theoretical and practical dimensions of designing and architecture in general. A direct contact with students represents a special pleasure and an opportunity to acquire new experiences and strengthen her knowledge. Particular academic attention has been brought to the subject of relations between architecture and nature, architecture and urban culture, sustainability and heritage, as well as to the subject of socially responsible architectural education based on an interdisciplinary approach.

ОДГОВОРНО ОБРАЗОВАЊЕ АРХИТЕКАТА ЗАСНОВАНО НА ИСКУСТВУ ИНТЕРНАЦИОНАЛНИХ ПРОЈЕКАТА

Сажетак: Архитектура се суочава са изазовима глобализације и урбанизације, еколошких поремећаја и друштвених трансформација које захтевају стални развој у области образовања. Уколико желимо да разумемо, објаснимо, предвидимо и утичемо на последице ових промена, да припремимо и развијемо компетенције за будућу генерацију архитеката, интернационализација образовне арене је од суштинског значаја. Универзитет у Београду – Архитектонски факултет опредељен је да интернационализацијом унапреди образовни процес. На тај начин, истраживање и образовање проширују хоризонте и са међународним искуством и експертизом обједињују и унапређују наше знање и учење да прихватимо разлике и одговорности као едукатори и архитекте.

Кључне ријечи: *архитектонско образовање, интернационализација, истраживање у области архитектуре*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Miloš Jočković
University of Belgrade, Faculty of Civil Engineering, Serbia,
mjockovic@grf.bg.ac.rs, https://orcid.org/0000-0002-2409-9450

Marija Nefovska-Danilović
University of Belgrade, Faculty of Civil Engineering, Serbia, marija@grf.bg.ac.rs,
https://orcid.org/0000-0002-2613-1952

Aleksandar Borković
Graz University of Technology, Institute for Applied Mechanics, Austria,
aborkovic@tugraz.at, https://orcid.org/0000-0002-4091-3379

LINEAR DYNAMIC ANALYSIS OF A SPATIALLY CURVED BERNOULLI-EULER BEAM SUBJECTED TO MOVING LOAD

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* corresponding author

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Miloš Jočković *

University of Belgrade, Faculty of Civil Engineering, Serbia, mjockovic@grf.bg.ac.rs, https://orcid.org/0000-0002-2409-9450

Marija Nefovska-Danilović

University of Belgrade, Faculty of Civil Engineering, Serbia, marija@grf.bg.ac.rs, https://orcid.org/0000-0002-2613-1952

Aleksandar Borković

Graz University of Technology, Institute for Applied Mechanics, Austria, aborkovic@tugraz.at, https://orcid.org/0000-0002-4091-3379

LINEAR DYNAMIC ANALYSIS OF A SPATIALLY CURVED BERNOULLI-EULER BEAM SUBJECTED TO A MOVING LOAD

ABSTRACT

This paper considers the dynamic analysis of a spatially curved Bernoulli-Euler beam subjected to a moving load. The isogeometric approach is used for the spatial discretization of the weak form of the equation of motion. Both the reference geometry and the solution space are represented using the same NURBS basis functions that guarantee an accurate description of the beam centerline. The time integration is done by the explicit technique. The presented formulation is validated by the comparison with the existing results from the literature for the curved beam subjected to a constant load moving with a constant velocity. In addition, the influence of the moving load velocity on the dynamic response of a spatially curved beam has been investigated.

Keywords: *isogeometric approach, Bernoulli-Euler curved beam, moving load*

1. INTRODUCTION

Beam-like structures are often subjected to dynamic loads during their lifetime. Consequently, numerical methods are essential for more accurate and reliable prediction of their dynamic behavior. The standard dynamic load case for cranes and bridges is a mass that moves along the structure. The moving mass is usually modeled as a moving force with constant magnitude and direction. Such an approach is referred to as a "moving load" model, where the inertial term of the moving mass is neglected. The majority of the research in this field is related to the analysis of a mass moving along a straight beam. One of the earliest investigations was carried out by Stokes in 1849 [1], where the influence of the moving mass on the plane straight Bernoulli-Euler beam was considered analytically using the moving load model.

Due to the aesthetic and functional requirements in the design process, curved spatial beam elements are common in structural engineering. The geometrical model of the curved spatial beam requires the spatial curve, which is usually defined using computer-aided design (CAD) software packages. To accurately describe the free-form curves and the curves of conic sections such as a circle, ellipse, parabola and hyperbola, CAD packages utilize the NURBS (Non-Uniform Rational B-Spline) basis functions. Furthermore, the computation of the dynamic response of complex spatially curved beams in practical applications is performed using the Finite element method (FEM), which is implemented in many software packages for structural analysis. A direct relation between the CAD and FEM has not yet been established [2], leading to a costly and time-consuming iterative design process. The isogeometric approach establishes a direct relationship between the geometry and the unknown fields of the structure [2]. This is enabled by using the NURBS functions as basis functions for both reference geometry and solution spaces of a numerical model. Therefore, the same basis functions are applied for the geometry and kinematics, which eliminates the errors due to the geometric approximation in a spatially discretized model. In order to improve the mesh, three types of mesh refinement are used in the isogeometric approach, denoted as H-, P-, and K-methods [2].

A dynamic analysis of an arbitrarily curved spatial beam subjected to a moving load is studied in this paper. A short review on the NURBS basis functions is given in Section 2 and followed by a representation of the beam geometry. The governing equation of motion of the Bernoulli-Euler isogeometric beam element is briefly given in Section 4, while more details can be found in the authors' previous paper [3]. The moving load model is presented in Section 5, followed by the numerical example of a spatially curved beam subjected to the moving load presented in Section 6. At the end, the main conclusions have been drawn.

2. BASICS OF NURBS

The exact shape of an arbitrary curve $\mathbf{C}(\xi)$ in Euclidean 3D space can be represented as:

$$\mathbf{C}(\xi) = \sum_{i=1}^{n} R_{i,p}(\xi)\mathbf{C}_i \tag{1}$$

where $R_{i,p}(\xi)$ is the i-th NURBS basis function, p is the function degree, $\mathbf{C}_i$ is the position of the control point i, while n is the number of basis functions and control points. NURBS functions are derived from the B-spline functions:

$$R_{i,p}(\xi)=\sum_{i=1}^{n}\frac{N_{i,p}(\xi)\cdot w_i}{\sum_{j=1}^{n}N_{j,p}(\xi)\cdot w_i} \tag{2}$$

where w_i is the i-th function weight. In order to define B-spline functions, the Cox de Boor algorithm is often applied [4].

For the case of a zero degree (p = 0), the B-spline functions are defined as:

$$N_{i,0}(\xi)=\begin{cases}1, & \text{if } \xi\in[\xi_i,\xi_{i+1}[\\ 0, & \text{otherwise}\end{cases} \tag{3}$$

while for the polynomial degree greater than zero (p > 0):

$$N_{i,p}(\xi)=\begin{cases}\dfrac{\xi-\xi_i}{\xi_{i+p}-\xi_i}N_{i,p-1}(\xi)+\dfrac{\xi_{i+p-1}-\xi}{\xi_{i+p+1}-\xi_{i+1}}N_{i+1,p-1}(\xi), & \text{if } \xi\in[\xi_i,\xi_{i+p+1}[\\ 0, & \text{otherwise}\end{cases} \tag{4}$$

The B-spline functions are polynomial functions defined in a parametric domain (ξ) using the knot vector. This vector represents a set of non-decreasing real numbers, the knots.

Important properties of the B-spline function, as well as the NURBS functions, used in the following derivations, are the non-negativity and the partition of unity over the parametric domain. More about the B-spline and NURBS basis functions can be found in [4].

As mentioned in the previous section, there are several important features of the NURBS-based parameterization. For example, it is possible to exactly describe the initial smooth geometries, which promises more accurate simulations. Furthermore, besides standard H- and P- refinement strategies, the isogeometric approach allows the definition of an interelement continuity up to C^{p-1}, known as K-refinement. The high smoothness of the kinematic field often returns improved convergence rates [5,6].

3. BEAM GEOMETRY

Due to the assumptions of beam theories, all kinematic and stress quantities of a beam can be given as a function of the beam centerline. In general, the beam centerline has an arbitrary shape in the Euclidean three-dimensional space, forming a curved line. The formulation of a curved beam is conducted using the curvilinear coordinate system attached to the beam centerline.

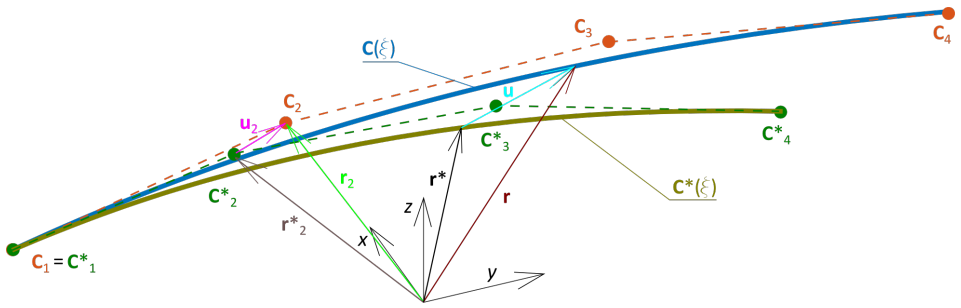

Figure 1. Centerline of a curved beam with corresponding control points

Using the NURBS parameterization, the position vector of a curved line is defined as:

$$\mathbf{r}(\xi)=\sum_{i=1}^{n}R_{i,p}(\xi)\mathbf{r}_i \tag{5}$$

where $\mathbf{r}_i$ is the position of the *i*-th control point, Figure 1. To fully define the beam continuum, a unique triad must be attached to each point of a curve. Here, this triad is aligned with the Frenet-Serret frame. The basis vectors are defined using the well-known relations of differential geometry [7] and the relations between the arc-length and NURBS parameterizations:

$$\mathbf{g}_1=\mathbf{r}_{,1}=\frac{d\mathbf{r}}{d\xi}=\frac{d\mathbf{r}}{ds}\frac{ds}{d\xi}=\mathbf{t}\frac{ds}{d\xi}=\mathbf{t}\sqrt{g_{11}}$$

$$\mathbf{g}_2=\mathbf{n}=\frac{1}{K}\frac{d\xi}{ds}\frac{d}{d\xi}\left(\frac{\mathbf{g}_1}{|\mathbf{g}_1|}\right) \tag{6}$$

$$\mathbf{g}_3=\mathbf{b}=\frac{\mathbf{g}_1\times\mathbf{n}}{|\mathbf{g}_1\times\mathbf{n}|}$$

where **t**, **n** and **b** are orthonormal basis vectors of the beam centerline obtained using arc-length parameterization (Frenet-Serret frame of reference), while $\mathbf{g}_1$, $\mathbf{g}_2$ and $\mathbf{g}_3$ form orthogonal vector basis with respect to the parametric coordinate. The vector $\mathbf{g}_1$ is collinear with the tangent **t**, while the vectors $\mathbf{g}_2$ and $\mathbf{g}_3$ are in the beam cross-section plane. In the previous relations, *K* is the modulus of curvature, while g_{11} is the component of the metric tensor of the beam centerline:

$$g_{ij}=\begin{bmatrix}g_{11}&0&0\\0&1&0\\0&0&1\end{bmatrix},\ \det\left(g_{ij}\right)=g_{11}=g \tag{7}$$

By using the well-known Frenet-Serret relations and Eq. (6), the derivatives of the basis vectors with respect to the parametric coordinate are:

$$\begin{bmatrix} \mathbf{g}_{1,1} \\ \mathbf{g}_{2,1} \\ \mathbf{g}_{3,1} \end{bmatrix} = \begin{bmatrix} \Gamma^1_{11} & gK & 0 \\ -gK & 0 & \sqrt{g}\tau \\ 0 & -\sqrt{g}\tau & 0 \end{bmatrix} \begin{bmatrix} \mathbf{g}_1 \\ \mathbf{g}_2 \\ \mathbf{g}_3 \end{bmatrix} \tag{8}$$

where $()_{,1}$ represents the derivative with respect to the parameter ξ, Γ^1_{11} is the Christoffel symbol of the second kind, and τ is the torsion of the beam centerline.

In this paper, the beam cross-section principal axes coincide with the basis vectors $\mathbf{g}_2$ and $\mathbf{g}_3$. If this condition is not satisfied, the basis vectors $\mathbf{g}_2$ and $\mathbf{g}_3$ need to be rotated around the basis vector $\mathbf{g}_1$ to align them with the principal axes, forming a new moving frame of reference [8].

Using the introduced basis vectors, the position vector of an arbitrary point of the beam can be defined as:

$$\hat{\mathbf{r}} = \mathbf{r} + \eta\mathbf{g}_2 + \zeta\mathbf{g}_3 \tag{9}$$

where η and ζ are the coordinates along the principal axes of the cross-section. Consequently, the first basis vector of an arbitrary point is defined as:

$$\hat{\mathbf{g}}_1 = \frac{d\hat{\mathbf{r}}}{d\xi} = \mathbf{g}_{1,1} + \eta\mathbf{g}_{2,1} + \zeta\mathbf{g}_{3,1} = g_0\mathbf{g}_1 + \eta K_1\mathbf{g}_2 + \zeta K_1\mathbf{g}_3 \tag{10}$$

Due to the assumption of the rigid cross-section, the vectors $\mathbf{g}_2$ and $\mathbf{g}_3$ are translated from the beam centerline to an arbitrary point. From the last equation, it is evident that the basis vector $\hat{\mathbf{g}}_1$ is not perpendicular to the vectors $\mathbf{g}_2$ and $\mathbf{g}_3$. However, in the frame of linear analysis, it is possible to orthogonalize these vectors by introducing a new coordinate system [8,9].

4. ISOGEOMETRIC BERNOULLI-EULER BEAM FORMULATION

Due to the external impact, the beam centerline has a new position defined with the current position vector:

$$\mathbf{r}^* = \mathbf{r} + \mathbf{u} \tag{11}$$

where $\mathbf{u}$ represents the displacement vector of the beam centerline. Using the isogeometric approach, the displacement vector can be represented as:

$$\mathbf{u}(\xi) = \sum_{i=1}^{n} R_{i,p}(\xi)\mathbf{u}_i = \sum_{i=1}^{n} R_{i,p}(\xi)u_i^m\mathbf{i}_m \tag{12}$$

where $\mathbf{u}_i$ is the displacement vector of the i-th control point. Note that the displacement vector and the reference geometry of the beam centerline are represented using the same basis functions, which is the fundamental property of the isogeometric approach.

Formulation of the spatial Bernoulli-Euler isogeometric beam is conducted by applying the convective coordinate system, and the position vector of an arbitrary point of a deformed beam is:

$$\hat{\mathbf{r}}^{*} = \hat{\mathbf{r}} + \eta \mathbf{g}_2^{*} + \zeta \mathbf{g}_3^{*} \tag{13}$$

The basis vectors of the deformed configuration can be expressed as:

$$\mathbf{g}_m^{*} = \mathbf{g}_m + \mathbf{u}_m \tag{14}$$

where $\mathbf{u}_m$ is the gradient of displacement along the m^{th} axis of the (ξ,η,ζ) coordinate system.

Using Eqs. (9), (13) and (14), the displacement vector of an arbitrary point of a beam is defined as:

$$\hat{\mathbf{u}} = \mathbf{u} + \eta \mathbf{u}_2 + \zeta \mathbf{u}_3 \tag{15}$$

Using Eq. (15), the acceleration vector of an arbitrary point is obtained as the second material time derivative:

$$\hat{\mathbf{a}} = \left(\ddot{\hat{\mathbf{u}}}\right) = \ddot{\mathbf{u}} + \eta \ddot{\mathbf{u}}_2 + \zeta \ddot{\mathbf{u}}_3 \tag{16}$$

In addition, the variation of displacement of an arbitrary point is obtained from Eq. (15) as:

$$\delta\hat{\mathbf{u}} = \delta\mathbf{u} + \eta \delta\mathbf{u}_2 + \zeta \delta\mathbf{u}_3 \tag{17}$$

The components of the Green-Lagrange strain tensor are:

$$\hat{\varepsilon}_{ij} = \frac{1}{2}\left(\hat{\mathbf{g}}_i^{*} \cdot \hat{\mathbf{g}}_j^{*} - \hat{\mathbf{g}}_i \cdot \hat{\mathbf{g}}_j\right) = \frac{1}{2}\left(\hat{g}_{ij}^{*} - \hat{g}_{ij}\right) \tag{18}$$

The assumption of rigid cross-cross section returns only three non-zero components of the strain tensor:

$$\hat{\varepsilon}_{11} = \frac{1}{2}\left(\hat{g}_{11}^{*} - \hat{g}_{11}\right)$$

$$\hat{\varepsilon}_{12} = \frac{1}{2}\left(\hat{g}_{12}^{*} - \hat{g}_{12}\right) \tag{19}$$

$$\hat{\varepsilon}_{13} = \frac{1}{2}\left(\hat{g}_{13}^{*} - \hat{g}_{13}\right)$$

By substituting the second Bernoulli-Euler assumption of orthogonality between cross-section and centerline into the previous equations, the required kinematic relations are obtained. Degrees of freedom of the isogeometric Bernoulli-Euler beam are the displacements of the beam centerline and the torsional rotation of the beam cross-section. The detail derivations of the kinematic relations can be found in [3].

Assuming the linear elastic material behavior, the constitutive relations can be written as:

$$\hat{S}_i^j = 2\mu\hat{\varepsilon}_i^j + \lambda\delta_i^j\hat{\varepsilon}_m^m \tag{20}$$

where $\hat{S}_j^i$ are the mixed components of the second Piola-Kirchoff stress tensor, while μ and λ are Lame's constants.

In order to obtain the discrete equations of motion, the principle of virtual work is used:

$$\int_{V_0}\rho\hat{\mathbf{a}}\cdot\delta\hat{\mathbf{u}}dV_0 + \int_{V_0}\mathbf{S}:\delta\boldsymbol{\varepsilon}dV_0 = \int_{V_0}\hat{\mathbf{f}}\delta\hat{\mathbf{u}}dV_0 \tag{21}$$

where ρ is the mass density, while $\hat{\mathbf{f}}$ is the external load. By substituting Eqs. (16), (17), (19), and (20) into Eq. (21), the governing equation of the motion of the Bernoulli-Euler isogeometric curved beam subjected to the moving load is obtained:

$$\mathbf{M}\ddot{\mathbf{q}} + \mathbf{K}\mathbf{q} = \mathbf{Q} \tag{22}$$

where **M** is the mass matrix, **K** is the stiffness matrix, **Q** is the vector of equivalent control forces, while **q** is the displacement vector of the control points. The solution of this equation requires the application of a time integration procedure. The explicit step-by-step integration has been applied using the finite differences method [10]. The reduced integration has been applied in Eq. (21) [11], and implemented into the original MATLAB code [12].

5. MOVING LOAD

A mass moving along the structure generates a dynamic response. This load can be modeled as a single load with constant magnitude and direction, $\mathbf{f}_0$, that moves along a beam with the constant velocity:

$$\mathbf{f}(t) = \mathbf{f}_0\cdot\delta\left(\xi - V_\xi t\right)$$

$$V_\xi = \frac{d\xi}{dt} = \frac{ds}{dt}\frac{d\xi}{ds} = \frac{V}{\sqrt{g}} \tag{23}$$

where V_ξ and V are the magnitudes of velocity with respect to the parametric and arc-length coordinates, respectively.

The vector of equivalent forces of the i-th control point in the case of a point load is:

$$\mathbf{Q}_i = \int_{d\xi}\mathbf{f}\cdot R_{i,p}(\xi)\sqrt{g}d\xi = \mathbf{f}\cdot R_{i,p}(\xi_m)\sqrt{g} \tag{24}$$

where ξ_m is the position of the moving load on a beam.

6. NUMERICAL EXAMPLES

6.1. VALIDATION AND CONVERGENCE STUDY

The validation study of the proposed formulation is given in this section. A horizontally curved arch in the x-y plane with the length L = 24 m and the subtended angle α = 30° is subjected to the out-of-plane and in-plane moving load with constant speed V = 40 m/s. The displacements and the torsional rotations at both ends of the beam are restrained. The beam geometry has been modeled with the cubic NURBS, as given in Figure 2.

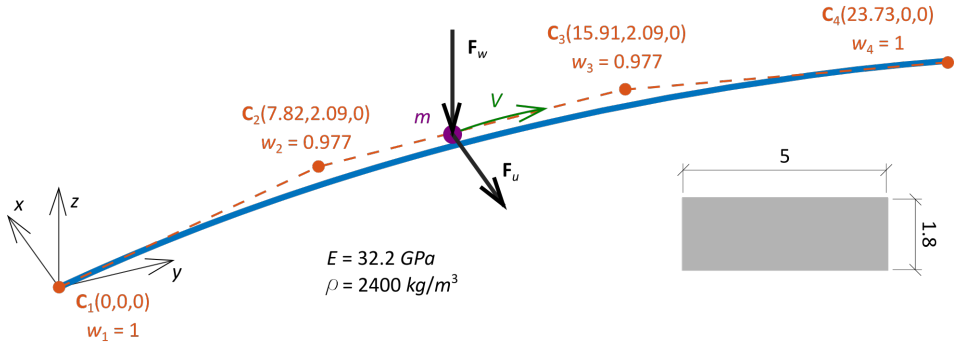

Figure 2. The arch subjected to the moving load

The material is homogeneous and defined using the Young's modulus E = 32.2 GPa, the Poisson's ratio ν = 0.2 and the mass density ρ = 2400 kg/m^3, while the cross-section is rectangular with the dimensions b/h = 5/1.8 m. The beam is subjected to the out-of-plane load $\mathbf{F}_w$ = -293.32 kN and the in-plane load $\mathbf{F}_u$ = 1043.71 kN directed towards the arch center. The displacements of the beam midpoint obtained using the isogeometric approach have been compared with the semi-analytical results from the literature, applicable only for simply supported arches [13]. It is important to point out that the beam model presented in [13] is based on the Timoshenko beam theory. In this example, the validation study, as well as the convergence study, are conducted using the P-refinement procedure.

The in-plane (u) and the out-of-plane (w) displacement components of the midpoint obtained using the P-refinement procedure are presented respectively in Figure 3 and Figure 4.

In addition, the same example is used to calculate the influence line of the beam midpoint displacement components by neglecting the inertial part of the beam in the principle of virtual work.

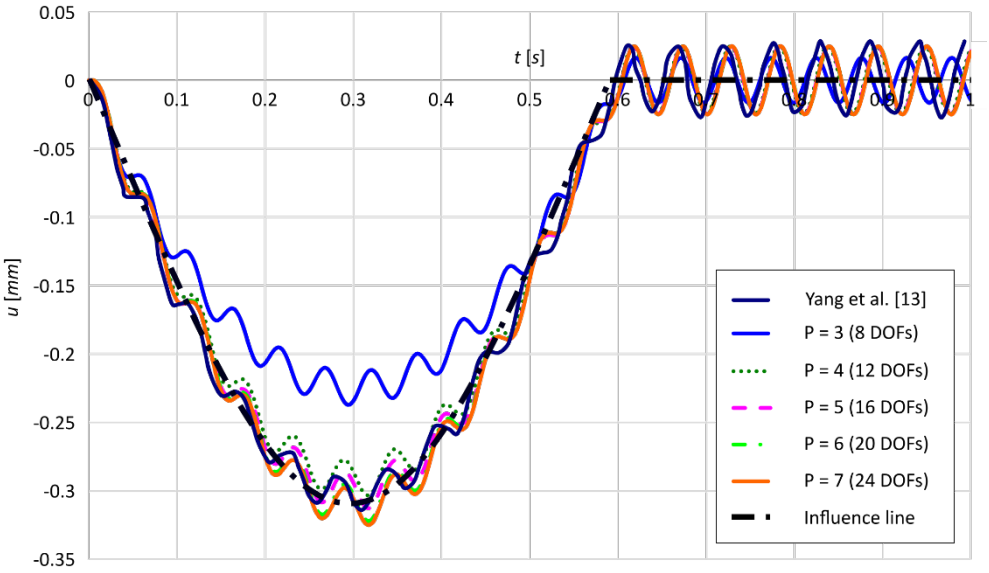

Figure 3. Comparison of the in-plane displacement component (u) of the beam midpoint

By comparing the results of the beam midpoint displacements obtained using the dynamic and static analysis, a significant difference can be observed, especially for the case of the out-of-plane displacement.

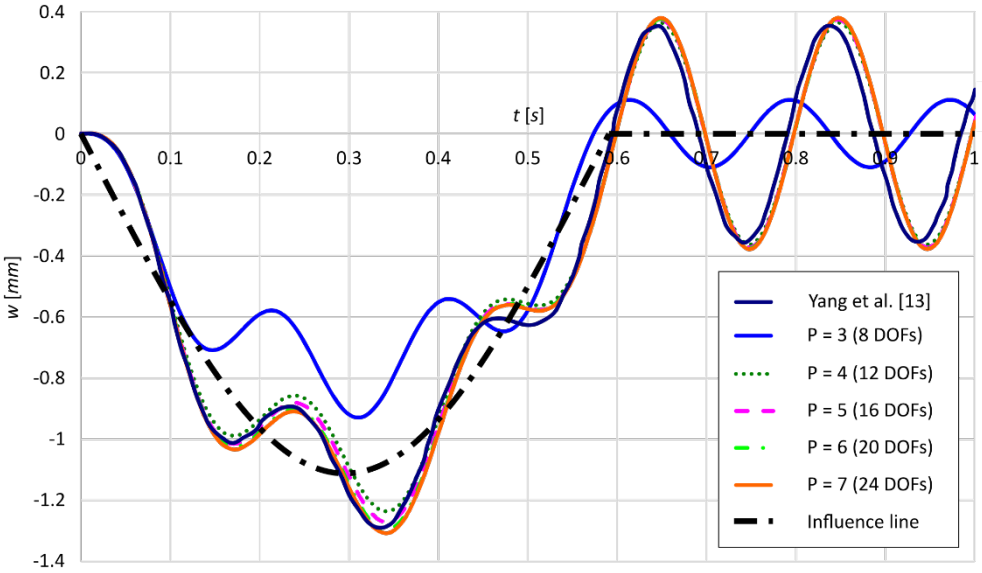

Figure 4. Comparison of the out-of-plane displacement component (w) of the beam midpoint

6.2. PARAMETRIC STUDY

In this example, the effects of the moving load velocity on the dynamic response of a curved cantilever beam are investigated. The geometry of the beam is defined using five control points with a unit weight vector and 3rd order B-Spline basis functions, Figure 5. The beam is clamped at the first beam control point $\mathbf{C}_1(0,0,0)$. The beam material is defined using the Young's modulus E = 32.2 *GPa*, the Poisson's ration ν = 0.2 and the mass density ρ = 2400

kg/m^3. The cross-section of the beam is circular with the diameter R = 0.1 m. Moving load has constant direction and magnitude F = 100 kN. The load is moving along the beam with constant velocity V. In order to investigate the influence of the moving load velocity on the response of the curved beam, the displacement components at the free end were calculated. The calculations have been conducted using the isogeometric beam model with the 7th order B-Spline basis function (46 DOFs) obtained using the P-refinement procedure.

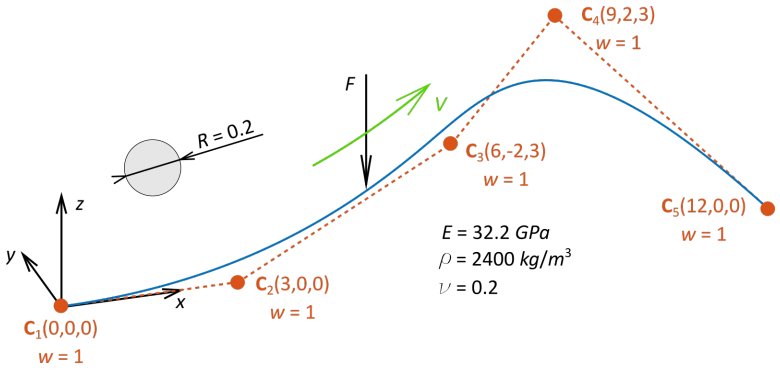

Figure 5. Cantilever spatial beam subjected to moving load

To compare the displacement components of the beam at the free end, the traveling time of the moving load has been divided by the total traveling time, forming a normalized dimensionless time coordinate, t[-]. Components of the beam displacements at the free end are presented in Figures 6 – 8. As the linear relation between the moving load magnitude and beam response holds for the linear dynamic formulation, the components of displacement are divided by the moving load magnitude, forming normalized displacements. Maximum values for u and w displacement components were detected for the moving load velocity of V = 9.25 m/s, while the maximum displacement component v occurred for the velocity of V = 22.5 m/s. In addition, the influence line has been calculated. The difference between the displacement components obtained using static analysis and dynamic analysis in case of the load velocity V = 1 m/s is not significant. However, the differences between displacement components increase as the load velocity increases, which can be observed in the case of the w displacement component. In addition, in the case of u and v displacement components, the moving load velocity can also affect the sign of the displacement components.

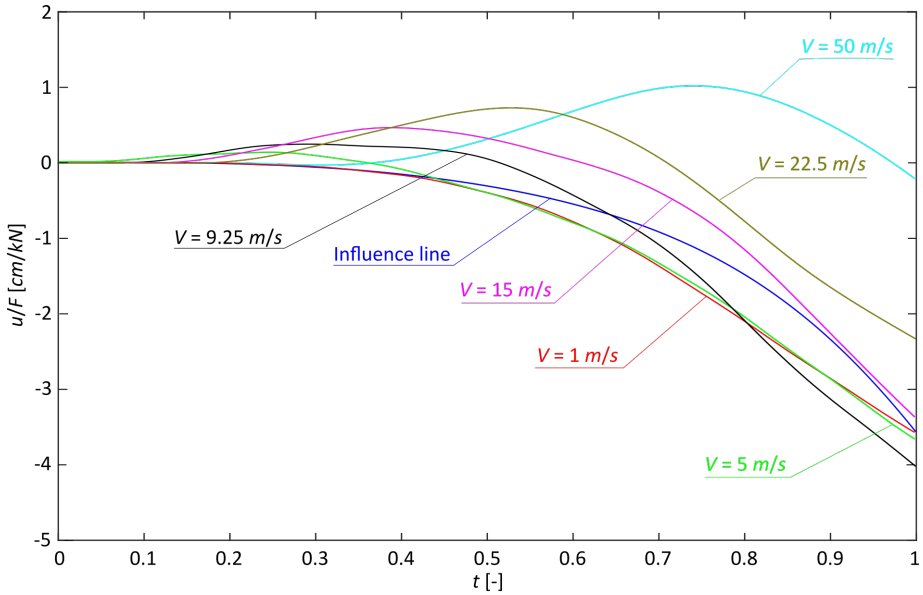

Figure 6. Normalized displacement component u with respect to the moving load velocity

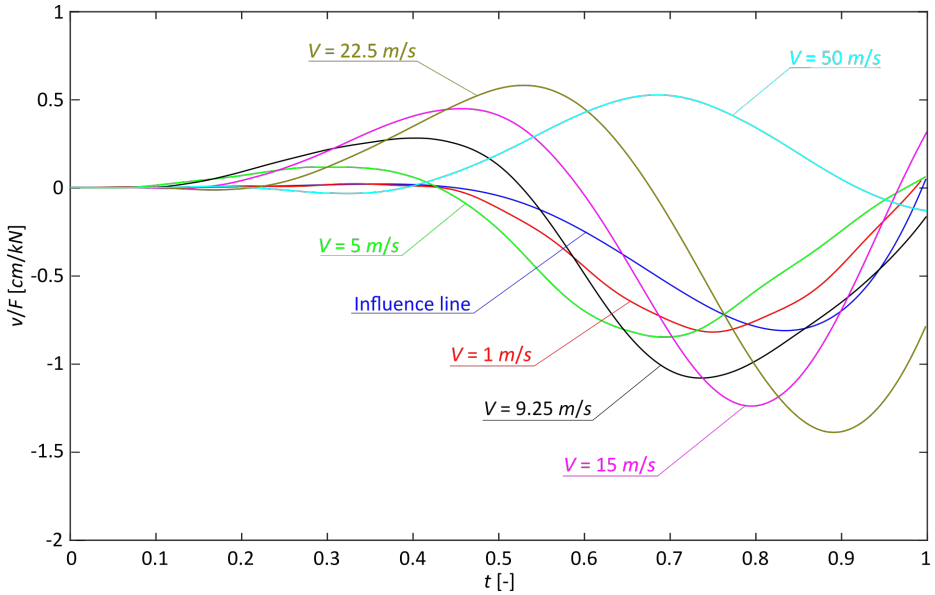

Figure 7. Normalized displacement component v with respect to the moving load velocity

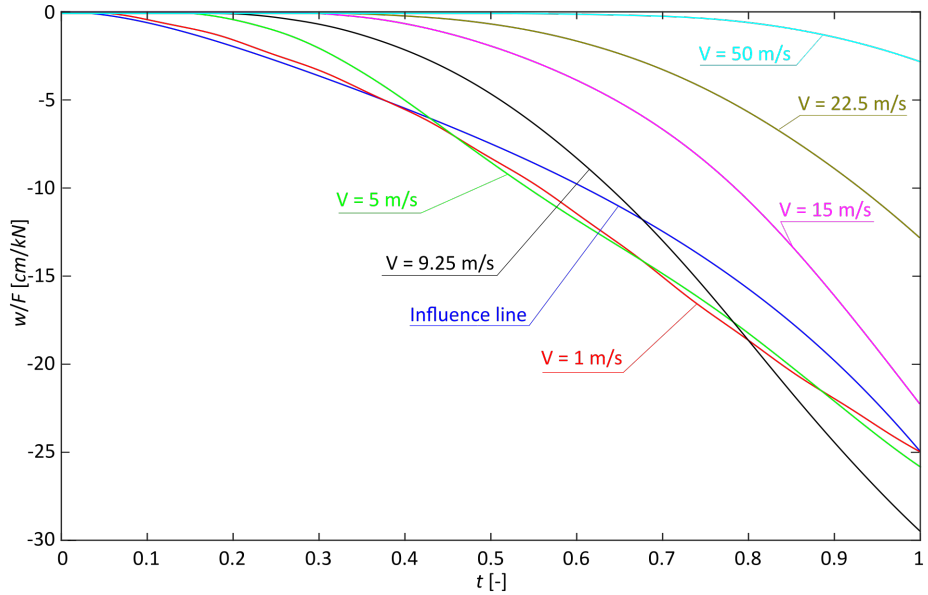

Figure 8. Normalized displacement component w with respect to the moving load velocity

7. CONCLUSIONS

The linear dynamic analysis of a spatially curved Bernoulli-Euler beam subjected to a moving load is presented. Spatial discretization is performed by the isogeometric approach, while the explicit procedure is used for the time integration. To validate the proposed method, the numerical study of the curved spatial beam subjected to the point load has been carried out. A satisfactory agreement has been observed between the results obtained using the proposed method and the results from the literature. In addition, the influence line for the displacement of the beam midpoint has been calculated, and the difference between the static and dynamic results is shown.

The influence of the moving load velocity on the arbitrary curved spatial beam has been investigated. It can be observed that the maximum displacement has occurred for the specific moving load velocity (critical velocity), and it is not the same for all beam displacement components. Also, the moving load velocity can affect the sign of the displacement. The accurate modeling of the moving load is crucial for the dynamic analysis of engineering structures such as bridges. In future work, more accurate models will be studied, taking into consideration the inertial part of the moving load. In addition, a nonlinear analysis, implicit procedures, and effects of the higher-order metric will be considered as well [14, 15].

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AUTHOR'S BIOGRAPHIES

Miloš Jočković

Miloš Jočković was born on April 6th 1988 in Sremska Mitrovica, Republic of Serbia. He defended his PhD thesis, "Isogeometric approach in dynamic analysis of spatial curved beam", in 2021 at the Faculty of Civil Engineering, University of Belgrade, where he is employed as an assistant professor.

Since 2013 he has been working as a researcher in the Project "Towards Development of Sustainable Cities: Influence of traffic-induced vibrations on buildings and humans". During 2013 he participated in the Project "Implementing MATLAB tool for analysing flutter instability". Since 2014 he has been working at the Faculty of Civil Engineering, University of Belgrade, as a Teaching Assistant - PhD Student in the scientific field of Engineering Mechanics and Theory of Structures.

His main scientific interests focus on structural dynamics, nonlinear analysis, isogeometric analysis and finite element method.

Marija Nefovska-Danilović

Marija Nefovska-Danilović was born on October 9th 1972, in Skopje, Republic of North Macedonia. She obtained her PhD in the field of Engineering Mechanics and Theory of Structures in 2013. Since 1997 she has been employed at the Faculty of Civil Engineering, University of Belgrade. Since 2018 she has been appointed as Associate Professor.

Her main research expertise includes vibration of plates and shells, dynamic stiffness method, dynamic soil-structure interaction, isogeometric analysis, vibration of multilayer composites and vibration serviceability of civil engineering structures.

Aleksandar Borković

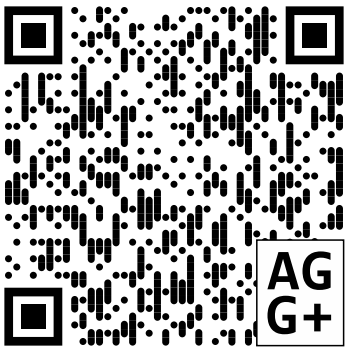
Aleksandar Borković was born on January 12th, 1982 in Gradiška. He obtained his PhD in the field of Civil Engineering in 2014, and has been appointed as Associate Professor since 2019 at the Faculty of Architecture, Civil Engineering and Geodesy, University of Banja Luka. Since 2020, he has been a Researcher at the Institute for Applied Mechanics, Graz University of Technology.

The focus of his research are numerical, analytical and experimental methods for the analysis of engineering structures.

ЛИНЕАРНА ДИНАМИЧКА АНАЛИЗА УТИЦАЈА ПОКРЕТНОГ ОПТЕРЕЋЕЊА НА ПРОСТОРНОЈ КРИВОЛИНИЈСКОЈ БЕРНУЛИ-ОЈЛЕРОВОЈ ГРЕДИ

Сажетак: У овом раду је приказана динамичка анализа просторне криволинијске Бернули-Ојлерове греде под утицајем покретног оптерећења. Изогеометријски приступ је примењен у циљу просторне дискретизације слабе форме једначина кретања греде. Овај приступ се базира на примени истих базних NURBS функција за описивање геометрије и кинематике криволинијске греде, чиме је омогућен тачан приказ системне линије греде. Временска интеграција једначина је извршена применом експлицитне методе. Приказана формулација је валидирана поређењем са резултатима из литературе за случај криволинијске греде оптерећене покретном силом константног интензитета и брзине. Такође је извршена и анализа утицаја брзине кретања покрене силе на динамички одговор просторне криволинијске греде.

Кључне ријечи: *изогеометријски приступ, Бернули-Ојлерова крива греда, покретна сила*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Jakob Šušteršič
IRMA Institute for Research in Materials and Applications, Slovenia, jakob.sustersic@irma.si

Rok Ercegovič
IRMA Institute for Research in Materials and Applications, Slovenia, rok.ercegovic@guest.arnes.si

David Polanec
IRMA Institute for Research in Materials and Applications, Slovenia, david.polanec@irma.si

Bojana Grujić
University of Banja Luka, Faculty of Architecture, Civil Engineering and Geodesy, Bosnia and Herzegovina, bojana.grujic@aggf.unibl.org

EVALUATION OF THE RESISTANCE TO CRACK PROPAGATION OF HIGH-PERFORMANCE CONCRETES BY THE WEDGE SPLITTING TEST METHOD

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* corresponding author

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Jakob Šušteršič
IRMA Institute for Research in Materials and Applications, Slovenia, jakob.sustersic@irma.si

Rok Ercegovič
IRMA Institute for Research in Materials and Applications, Slovenia, rok.ercegovic@guest.arnes.si

David Polanec
IRMA Institute for Research in Materials and Applications, Slovenia, david.polanec@irma.si

Bojana Grujić *
University of Banja Luka, Faculty of Architecture, Civil Engineering and Geodesy, Bosnia and Herzegovina, bojana.grujic@agqf.unibl.org

EVALUATION OF THE RESISTANCE TO CRACK PROPAGATION OF HIGH-PERFORMANCE CONCRETES BY THE WEDGE SPLITTING TEST METHOD

ABSTRACT

This paper describes the key elements of the results of investigations on the resistance to crack propagation carried out as part of a large-scale project to develop high-performance concretes (HPCs) for the secondary lining of a low and intermediate-level waste disposal shaft. Four HPCs were investigated, in which the quantity of the binder component and the proportions of the two cements and the silica fume in it were varied. We have also added steel fibers to one HPC. The wedgesplitting test method was used to determine the resistance to crack propagation. The results obtained show that all the HPC investigated achieve good resistance to crack propagation. The addition of steel fibers further improves this resistance.

***Keywords**: resistance to crack propagation, high-performance concrete, wedge splitting test*

1. INTRODUCTION

High-performance concrete (HPC) differs from normal concrete in at least one individual property (compressive strength, permeability, workability or other) and in structure, composition, and production [1]. Research during the 1970s, highly effective plasticizers or superplasticizers for concrete introduced the possibility of significantly reducing the value of the w/c ratio and achieving, regardless of the moderate content of cement, a high degree of workability. The low value of the w/c ratio, with good compaction, has a significant contribution to high strengths. Strength was an important parameter in distinguishing HPC from normal concrete.

In the 1950s, the compressive strength of concrete was considered to be 35 MPa high strength [2]. In the 1960s, concretes with compressive strengths of up to 40 and 50 MPa were used. The European Standard for Concrete EN 206:2013 defines in clause 4.3.1 "Compressive strength classes" in Table 12 "Compressive strength classes for normal and heavy concrete", ending at compressive strength class C 100/115, and Table 13 "Compressive strength classes for lightweight concrete", ending at compressive strength class LC 80/88. The tables are identical to those in the previous edition of EN 206-1:2003. Neither of the two editions of the concrete standard gives any rules for high-strength concretes. It should be noted that the old edition of EN 206-1:2003, among the definitions in Chapter 3 "Definitions, symbols and abbreviations", clause 3.1.10 defined that high-strength concretes are normal concretes of strength class C 55/67 and above and lightweight concretes of strength class LC 50/55 and above. This definition is not in the new edition of EN 206:2013.

Strengths up to 150 MPa were a sensation [3]. Using special technologies and materials in laboratories and experimental productions, compressive strengths of 230 MPa and 460 MPa [2] and up to 800 MPa and more have been achieved [4], so-called concretes with reactive powder RPC (Reactive Powder Concrete) [5, 6]. The first applications of high-strength concretes were recorded during the construction of highly loaded columns of tall buildings (skyscrapers) [7, 8].

Over time, it became known that high-strength concrete improves other properties, such as abrasion resistance, capillary absorption, gas permeability and water permeability, diffusion resistance, resistance to freezing-thawing in the presence of de-icing salts, etc. Due to these improvements, the term high-performance concrete (HPC) [9] was introduced. The HPC concept has been extended to fresh concrete so that self-consolidating concrete (SCC) [10] is also considered HPC.

High-strength concrete is achieved by maximizing the densification of the structure of the hardened cement paste and the densification of the transition zone of the interfaces between the hardened cement paste and the aggregate grains. First, we need to achieve a good "packing" of the aggregate grains [11] or a compacted aggregate structure that is "glued" with cement paste.

Mineral admixtures as well as polymers are very often used to achieve the densest structure of the hardened cement paste and the most dense transition zone. In this case, we are not talking about a water-cement (w/c) ratio but a water-binder (w/b) ratio. Higher concrete strength is achieved by increasing the quantity of mineral admixtures and decreasing the w/b ratio. But often, increasing the quantity of mineral admixtures increases the need for water. In such a case, when the critical quantity of a given mineral admixture is exceeded,

the strength of concrete is reduced because the w/b ratio is increased. Therefore, when mineral admixtures are used, highly effective plasticizers are added to concrete to evenly distribute the fine particles of the mineral admixture and reduce the amount of water, thus increasing the strength of the concrete. In any case, the amount of mineral admixtures is also limited for other reasons, which were discussed in much more detail at the 22nd Slovenian Colloquium on Concretes: Use of mineral admixtures in cement and/or concrete [12].

Typically, the w/b ratio values of high-strength concretes are between 0,25 and 0,40. At such low w/b ratios, not all the binding components (cement and mineral admixtures) hydrate. The lower the w/b ratio, the more non-hydrated particles there are, the density increases and the strength of the concrete increases [13]. Non-hydrated cement and mineral additive particles act as mineral fillers.

Hardened cement paste binds the aggregate grains together. Physical interactions are mainly dominant, and chemical bonding is rare. On the surfaces of the aggregate grains, crystals grow from the highly saturated solution, i.e., calcium-hydroxyl lamellae. Investigations show that conventional cement paste produces a porous layer with a crystalline orientation on the surfaces of the aggregate grains, with a thickness of about 40 µm. This layer has a lower hardness and strength than hardened cement paste. Investigations show that the thickness of the transition zone is difficult to influence by varying the w/c ratio, like the average aggregate grain spacing in concrete, which is approximately 75 to 100 µm [14]. As a consequence, the mechanical properties of concrete are highly dependent on the transition zone. SEM photos [15] show that there is a dense, irregular zone with a thickness of 1 µm on the surface of the aggregate grains. This zone is followed by a porous transition zone about 10 µm thick.

It can be observed that the porosity of the transition zone decreases as the concrete hardens, while that of the compact cement paste remains relatively constant. However, the transition zone can be significantly densified by adding mineral admixtures. Silica fume is the most effective because the small particles increase the volume around the cement particle and hydrate significantly faster than fly ash or slag due to their large specific surface area. In addition, CH is transformed into CSH, reducing the amount of CH crystals at the interface between the hardened cement paste and the aggregate grains.

The reduction of porosity, or densification of the transition zone by mineral admixtures, greatly reduces the possibility of cracks forming during the application of external loads at the interface between the hardened cement paste and the aggregate grains. This increases the strength of the concrete.

The influence of the good bond between the hardened cement paste and the aggregate grains, or the densified transition zone due to the addition of silica fume, can be seen in the photographs in Figure 1, which show the surfaces of the concrete test specimens (cubes) after the wedge splitting test [16].

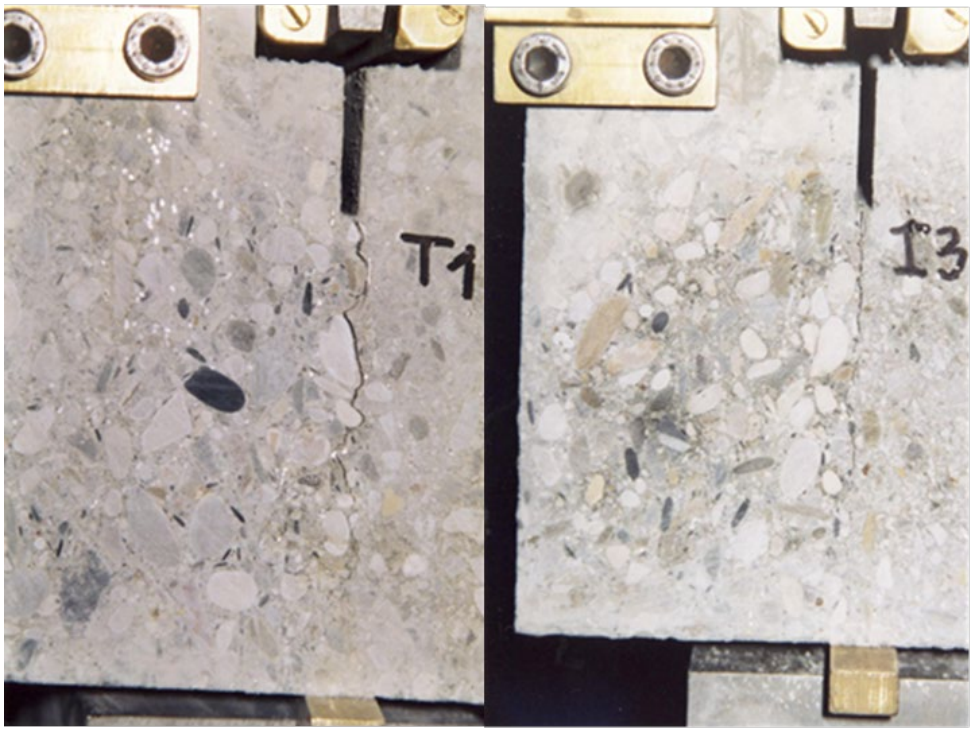


***Figure 1**. Surface photographs of concrete cubes after wedge splitting test: (a) concrete without mineral admixture, (b) concrete with added silica fume [16].*

The addition of silica fume (7,5 % w/w of cement) to the concrete - right picture (b) in Figure 1 - has densified the transition zones, and they no longer represent the weak or porous regions in the concrete that would be the cause of the crack initiation and propagation. Also, adding silica fume makes the cement paste denser, which means there are far fewer weak regions in the concrete where cracks would start to form. As the external load continues to be applied, these cracks join to form a single dominant crack, which ultimately leads to the concrete test specimen collapsing.

In general, the propagation of cracks can be said to depend on the magnitude and duration of stresses that caused their formation and the external loads. Concrete resists this expansion by bridging the cracks with aggregate grains and, additionally if present, with fibers or polymer. We are talking about the resistance of concrete to crack propagation or the ability of concrete to absorb as much energy as possible up to a certain (chosen) crack width.

2. METHOD FOR DETERMINING THE RESISTANCE TO CRACK PROPAGATION

The resistance to crack propagation of concrete is determined by the following equation:

$$RCP = \frac{f_{ct}}{f_{cw}} \tag{1}$$

where:

RCP - resistance to crack propagation,

f_{ct} - ultimate splitting tensile strength (MPa),

f_{CW} - equivalent splitting tensile strength up to the selected crack width (MPa).

In practice, the equivalent splitting tensile strength up to a crack width of 0.2 mm ($f_{0,2}$) is most used to calculate the resistance of concrete to crack propagation, and equation (1) takes the following form [21]:

$$RCP = \frac{f_{ct}}{f_{0,2}} \quad (2)$$

where:

RCP - resistance to crack propagation,

f_{ct} - ultimate splitting tensile strength (MPa),

$f_{0,2}$ - equivalent splitting tensile strength up to the crack width of 0,2 mm (MPa).

From the load - CMOD (Crack Mouth Opening Displacement) diagrams, the ultimate splitting tensile strength (f_{ct}) and the equivalent splitting tensile strengths up to crack widths CW = 0,1, 0,2, 0,3 and 0,4 mm (f_{CW}) are determined or calculated. The load - CMOD diagram was obtained during the wedge splitting test of concrete. The wedge splitting test (WST) method, which produces a load - CMOD diagram, is one of many test methods developed to determine the behavior of cement-based composites in the cracked state. The WST method we use was developed by Tschegg and Linsbauer [17-20] and is briefly described below.

A test specimen (cube) with a rectangular groove and a notch at the bottom of the groove is placed on a flat linear support in a compression testing machine (Figure 2). The two transfer pieces inserted in the groove cause the test specimen to split by pushing the wedge in.

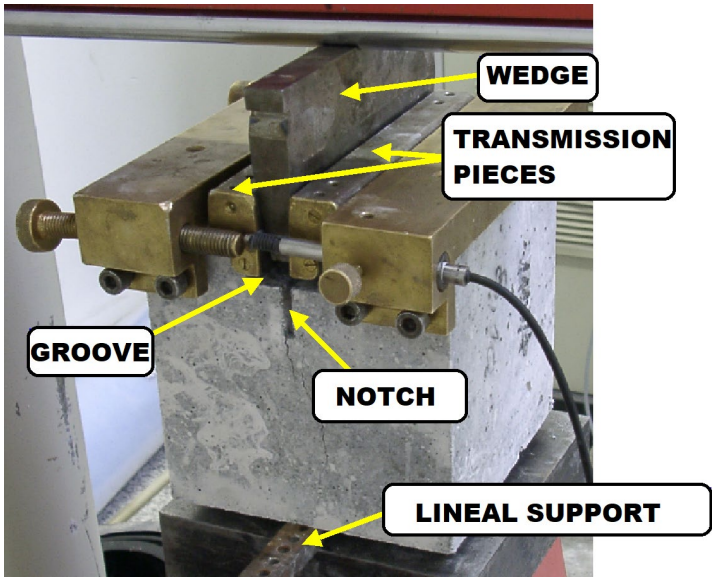


***Figure 2**: Individual components of the wedge splitting test device*

The force F (Figure 3) caused by the compression testing machine is transmitted by the wedge to the test specimen by dividing it into two components. The larger horizontal component F_H splits the test specimen.

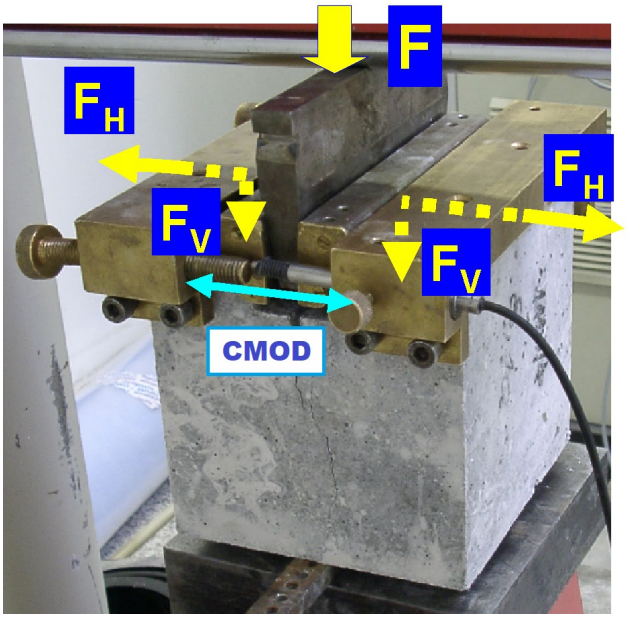


***Figure 3**: Principle of the wedge splitting test method*

The smaller vertical component F_V helps to control the direction of crack propagation in the plane connecting the support and the notch. As the wedge angle is small, the F_V component does not affect the test results. The deformation is determined by measuring the Crack Mouth Opening Displacement (CMOD) in the line of action of the F_H component during the splitting of the test specimen.

During the application of a load to the test specimen, small individual cracks within the concrete begin to appear at a given load. These cracks join to form a continuous crack that can be seen on the surface of the test specimen. At this point in the load - CMOD diagram, the slope of the diagram increases sharply. The load and CMOD at this point are referred to as the load at the first crack F_{fc} and the Crack Mouth Opening Displacement at the first crack $CMOD_{fc}$, respectively.

There are difficulties relating to the precise determination of the location of the first crack (FC). ASTM C 1018 defines the first crack as the point on the load – CMOD diagram at which the curve form first becomes non-linear. Determination of the point of FC has been proposed [22, 23] as the point at which the slope of the curve departs from linearity by more than 5 % and lasts for an interval of more than 0,01 mm.

At our Institute (IRMA), a computer program, which works in graphical form, has been developed for automatically drawing load - CMOD curves, calculation of parameters for evaluation of concrete behavior, and determination of the point of FC [24].

At the moment when the point FC is reached, the crack width begins to propagate with further loading. From the point FC, the fracture zone of the concrete begins to form. In the

fracture zone, all further fracture processes proceed until the final separation of the test specimen.

3. EXPERIMENTAL BASIS

3.1. SHORT INTRODUCTION TO THE PROJECT

The project briefly reviewed here is entitled “Study on the production, placeability and characteristics of final concrete mixtures for the construction of secondary reinforced concrete lining of the silo of the LILW repository” [25]. The project was carried out at the Institute for Research in Materials and Applications (IRMA), in the laboratory and the test field. The implementation was carried out by the laboratories of the Slovenian National Building and Civil Engineering Institute (ZAG), the Faculty of Civil and Geodetic Engineering of the University of Ljubljana, the Geological Survey of Slovenia, Salonit Anhovo and the Faculty of Civil Engineering of the University of Zagreb. HSE Invest and IBE, the designer of the LILW repository, worked together on specific areas of expertise. During the project implementation, we worked closely with the project sponsor, the Agency for Radioactive Waste (ARAO).

The project was implemented in three phases. The results and findings of each phase served as a basis for the continuation of the project in the next phase. So, in the first phase, we selected the basic materials and carried out preliminary tests on the concretes. Based on the results obtained, four optimum concrete mix proportions were identified and tested in the laboratories as part of the second phase. We investigated the properties of fresh and hardened concretes relevant for achieving extremely high concrete durability and service life of the secondary lining and, indirectly, of the entire LILW silo. These results were confirmed by measurements and investigations in the test field during the first part of the third phase of the project. The measurements and investigations in the test field also provided new results and findings, which were used to develop the basic technological parameters for the construction of the secondary reinforced concrete lining of the silo of the LILW repository. These were prepared as part of the second part of the third phase of the project.

3.2. SELECTION OF BASIC MATERIALS AND IDENTIFICATION OF CONCRETE MIX PROPORTIONS

3.2.1. Binder

The selection of the binder was based on the key required characteristics of the concrete:

- high compressive strength,
- low development of hydration heat,
- low permeability,
- sulphate resistance,
- extremely high durability of the concrete and the service life of the completed structure.

There is no such binder on the market that meets the above requirements. Therefore, we selected a binder component consisting of two types of cement (CEM I 42,5 N SRO and CEM III/B 32,5 N - LH/SR) and Silica Fume (SF).

3.2.2. Aggregate

The gravels from the Lower Sava separations, which are located close to the LILW disposal site, are not an option due to the presence of coal grains. Dolomite or limestone crushed aggregate have been proposed as possible aggregate types. Based on a literature review of the findings of several studies of concretes with dolomite and limestone aggregate, we chose limestone aggregate mainly because of the potential for an alkali-dolomite reaction in concrete with dolomite aggregate at high concrete ages. The concretes investigated in this project were prepared using crushed quarry aggregate of carbonate origin with more than 96% limestone or calcium carbonate.

3.2.3. Chemical admixtures

The selection of the chemical admixtures was carried out in the framework of preliminary tests of the concretes regarding the workability and air content of the fresh concrete.

3.2.4. Steel fibers

To obtain the optimum concrete mix proportion according to the given criteria, the mix proportions were modified by adding steel fibers. To minimize the effect of the fibers on the workability of the fresh concrete and to maximize the uniform distribution of fibers in the fresh concrete mass, short (16 mm long) and thin (0,4 mm thick) steel fibers with anchors at the ends were selected to allow good anchorage in the hardened concrete matrix.

3.2.5. Concrete mix-proportions

Based on the results of the preliminary investigations, four mix-proportions of concrete or High-Performance Concrete (HPC), respectively (Table 1) were determined, which were investigated in the laboratories during the second phase of the project, placed in the test field and investigated during the first part of the third phase.

Table 1. *Mix-proportions of High-Performance Concrete (HPC)*

Parameter	Unit	Designations of HPC			
		PP-1	PP-1-JV	PP-2	PP-3
Binder (CEM I + CEM III + SF)	(kg/m^3)	405	405	405	425
CEM I / CEM III	-	0.43	0.43	1.00	1.00
Hyper-plasticizer	(% m/m)	0.47	0.47	0.47	0.78
Antifoaming admixture	(% m/m)	1.00	1.00	1.00	1.00
$(w/b)_{eff.design}$	-	0.38	0.38	0.38	0.38
Steel fibers	(% v/v)	-	0.77	-	-
D_{max} of limestone aggregate	(mm)	32	32	32	32

3.3. OVERVIEW OF THE RESULTS OF SOME PROPERTIES OF HARDENED HPC

In this section, we would like to provide additional information on only some of the properties of all four HPCs that sufficiently represent their characteristics.

3.3.1. Compressive strength

The compressive strength according to SIST EN 12390-3:2009 of the hardened HPC was tested at ages 1, 2, 3, 7, 28, 56 and 154 days. Figure 4 shows the average compressive strength results as a function of the age of the HPC.

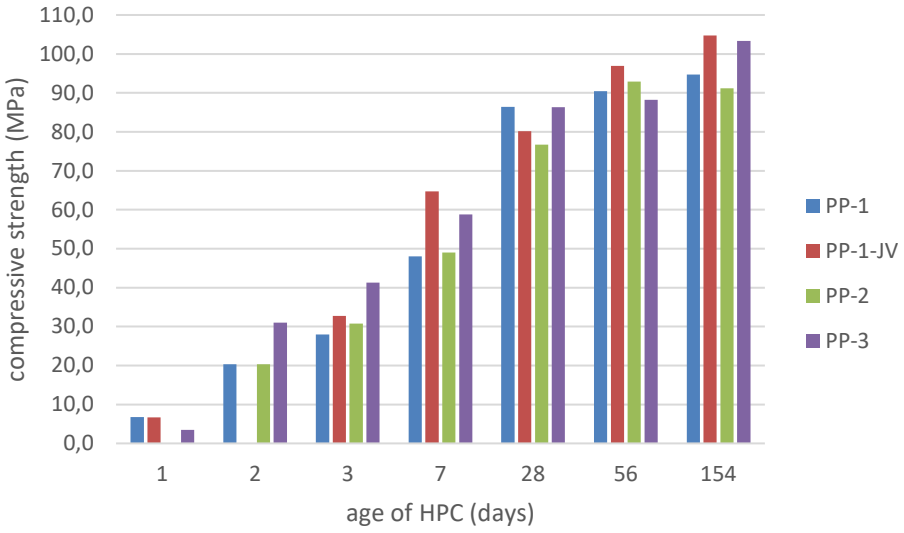


***Figure 4**. Average compressive strength values as a function of HPC age*

The project requires a compressive strength class of C60/75 at 90 days. As we have not been able to determine the compressive strength of the HPC at 90 days of age, we give an estimate of the compressive strength class achieved at 56 and 154 days of age. The assessment (according to SIST EN 206:2013, Appendix A) shows that all HPCs meet the criteria of the required compressive strength class C60/75 at 56 and 154 days of age, which means that they also meet this criterion at 90 days. PP-1-JV and PP-3 also meet the criteria for the higher class C70/85 at 154 days of age.

3.3.2. Static modulus of elasticity

Static modulus of elasticity tests were carried out according to DIN 1048-5:1991 at HPC ages of 7, 28, 56 and 90 days. Figure 5 shows the average results of the static modulus of elasticity as a function of the age of the HPC.

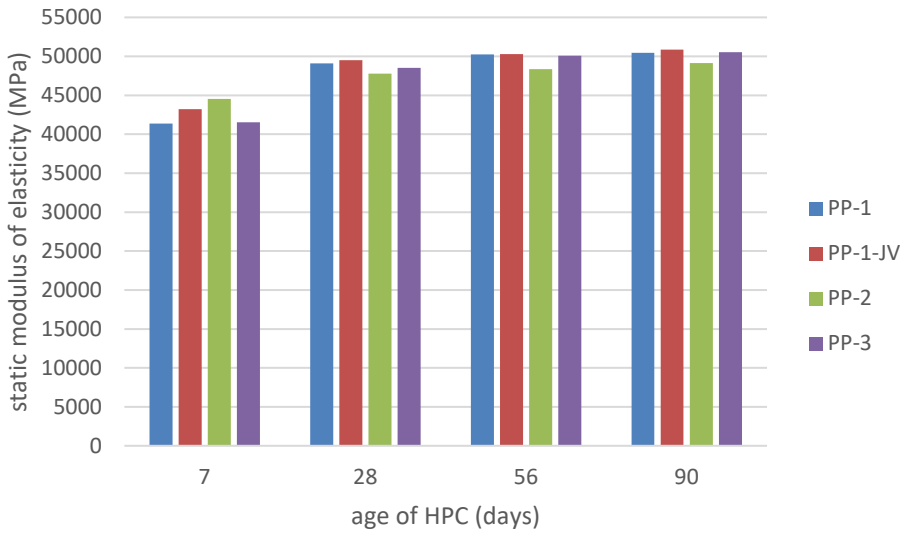


***Figure 5**. Average static modulus of elasticity as a function of HPC age*

The average test results of all HPC at 28 days of age meet the criterion ($E_{stat,28} \leq 50000$ MPa). At ages 56 and 90 days, the E_{stat} values increase only slightly and are slightly greater than 50000 MPa for PP-1, PP-1-JV and PP-3. For PP-2, the E_{stat} is < 50000 MPa even at age 90 days.

3.3.3. Resistance to water penetration

Water penetration tests according to SIST EN 12390-8.2009 were carried out at HPC ages of 7, 28, 56 and 90 days. Figure 6 shows the average results of the water penetration tests as a function of the age of the HPC.

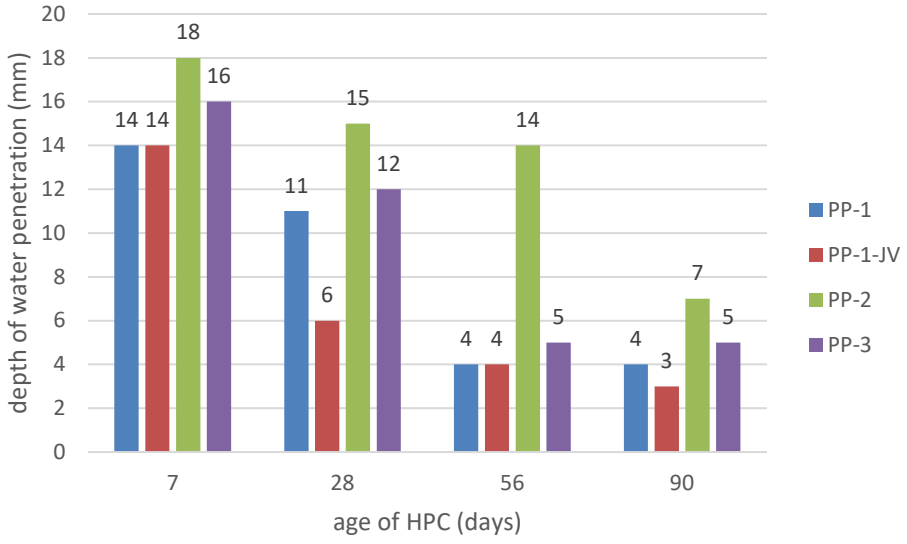


***Figure 6.** Average depth of water penetration as a function of HPC age.*

The following project requirements are given:

- maximum average allowed depth of water penetration: $e_{aver,allow}$ = 10 mm,
- maximum individual allowed result: $e_{max,allow}$ = 15 mm.

As HPC increase in age, their resistance to water penetration increases. PP-1-JV already meets the required criterion at 28 days of age, PP-1 and PP-3 at 56 days of age and PP-2 only at 90 days of age.

3.3.4. Internal freeze/thaw resistance

The internal freeze/thaw resistance test is performed at HPC ages 56 and 90 days, according to SIST 1026:2016, Appendix ND. In Table 2, we report the average and minimum relative dynamic modulus of elasticity after n freeze/thaw cycles of all four HPC mixtures that we started testing at ages 56 and 90 days.

Table 2. *Average and minimum relative dynamic modulus of elasticity after n freeze/thaw cycles*

HPC	Age of HPC at the start of the test (days)	Number of cycles n	Relative dynamic modulus of elasticity	
			Average (%)	Minimum (%)
PP-1	56	375	95.8	92.1
	90	325	97.4	97.0
PP-1-JV	56	375	98.1	97.7
	90	300	98.8	98.5
PP-2	56	375	96.8	92.1
	90	300	97.4	95.5
PP-3	56	350	99.9	98.9
	90	275	99.0	98.4

Although the required criterion for internal freeze/thaw resistance is up to 200 cycles, all HPCs were tested up to n cycles (see Table 2). Even after n cycles, all HPCs met the criterion: average relative dynamic modulus of elasticity > 80% and minimum relative dynamic modulus of elasticity > 75%. Based on these results, it can also be roughly estimated that all four HPCs have a quality structure that can assure the long service life of the LILW repository.

3.3.5. Resistance to chloride diffusion

According to the method given in NT BUILD 492:1999, the resistance to chloride diffusion test was carried out at HPC ages of 56 and 90 days. Table 3 gives the results of the average chloride diffusion coefficients.

Table 3*. Average coefficients of chloride diffusion*

HPC	$D_{nssm,} \times 10^{-12}$ m²/s	$D_{nssm,} \times 10^{-12}$ m²/s
	Age of HPC 56 days	Age of HPC 90 days
PP-1	0,77 ± 0,28	0,55 ± 0,05
PP-1-JV	1,48 ± 0,23	1,01 ± 0,18
PP-2	1,16 ± 0,13	0,71 ± 0,05
PP-3	0,86 ± 0,09	0,68 ± 0,10

All HPCs meet the criterion for the coefficient of chloride diffusion $D_{nssm} \leq 9{,}0\ 10^{-12}\ m^2/s$.

4. RESULTS OF RESISTANCE TO CRACK PROPAGATION TESTS AND DISCUSSION

All four HPCs were tested by the WST method described in section 2 at 3, 7, 28, 56 and 90 days of age. For each test specimen, we first determined the load – CMOD diagram. From the shape of the diagram, we can already assess the behavior of the test specimen during the application of the splitting load. As an example, we give in Figure 7 the typical load - CMOD diagrams determined for PP-1, PP-1-JV, PP-2 and PP-3 at their age of 90 days.

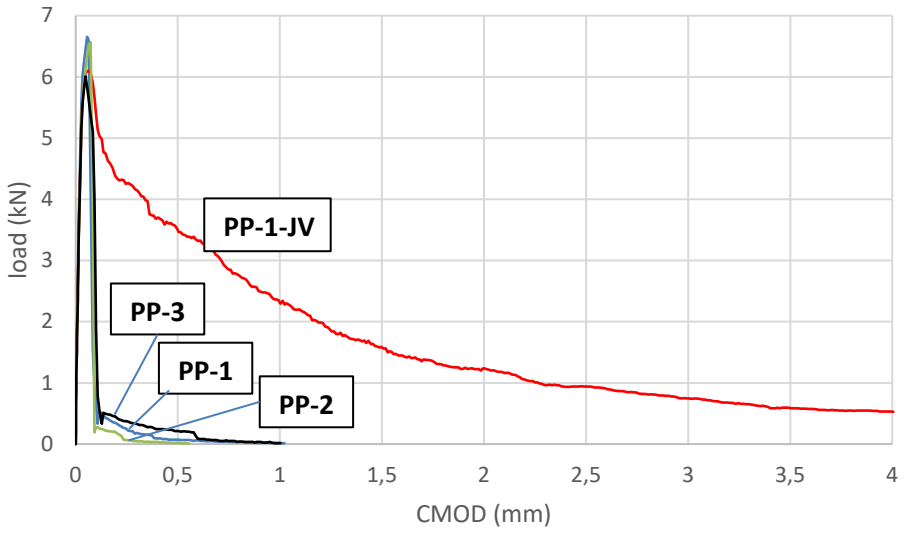
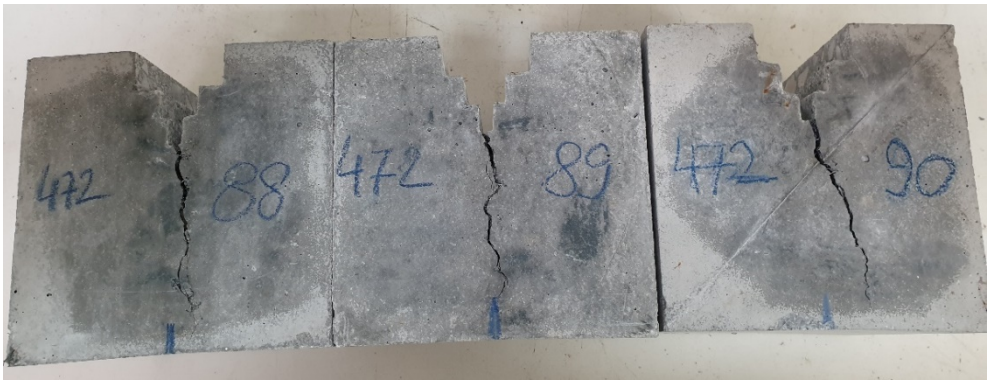


***Figure 7**. Typical load - CMOD diagrams of PP-1, PP-1-JV, PP-2 and PP-3 at 90 days of age.*

We can immediately estimate that much more energy was absorbed during the PP-1-JV test compared to the other HPCs. This is understandable, of course, because PP-1-JV contains steel fibers, while the other HPCs are without fibers. A similar assessment can be made based on a visual inspection of the test specimens after the WST (Figure 8a, b, c). The cracks on test specimens PP-1 (a) and PP-3 (b) run more or less vertically to the lower edge - the cubes have split into two parts. In contrast, the cracks on the PP-1-JV (c) specimens are very branched and do not reach the lower edge of the cube. The cube does not break because the fibers bridge the crack and offer great resistance to crack propagation.

(a)

(b)



(c)

Figure 8. *Crack shape and course after completion of WST on PP-1 (a), PP-3 (b) and PP-1-JV (c) specimens at 90 days of age.*

The estimate described above is rough and relative. However, if we want to have a more accurate and measurably comparable estimate, we need to determine and calculate the parameters from the load - CMOD diagrams, as we have already described in section 2.

These parameters are:

- f_{ct} - ultimate splitting tensile strength,
- f_{fc} - splitting tensile strength at the first crack,

- f_{CW} - equivalent splitting tensile strength up to the crack width CW = 0,1, 0,2, 0,3 and 0,4 mm,
- RCP (Resistance to Crack Propagation) = $f_{0,2}/f_{ct}$.

For all HPCs, we summarize the resulting parameters in Table 4 for PP-1, Table 5 for PP-1-JV, Table 6 for PP-2 and Table 7 for PP-3. For each table, the corresponding equivalent splitting tensile strengths f_{CW} versus crack width CW are given in the graphical form.

Table 4. *Results of the wedge splitting test for PP-1.*

designation of the test specimen	age of PP-1	ultimate splitting tesnile strength - f_{ct}	splitting tensile strength at first crack - f_{fc}	equivalent splitting tensile strength up to the crack width (mm)				resistance to crack propagation RCP=$f_{0,2}/f_{ct}$
				0,1	0,2	0,3	0,4	
				$f_{0,1}$	$f_{0,2}$	$f_{0,3}$	$f_{0,4}$	
	(days)	(MPa)	(MPa)	(MPa)	(MPa)	(MPa)	(MPa)	-
PP-1/19	6	3,47	3,33	2,72	2,03	1,60	1,36	0,59
PP-1/20		3,78	3,54	3,28	2,51	2,01	1,67	0,66
PP-1/21		3,39	3,09	2,81	2,36	1,93	1,61	0,70
average		**3,55**	**3,32**	**2,94**	**2,30**	**1,85**	**1,55**	**0,65**
PP-1/22	8	4,22	3,94	3,64	2,69	2,00	1,60	0,64
PP-1/23		4,08	3,61	3,28	2,58	2,00	1,62	0,63
PP-1/24		4,38	4,15	3,46	2,88	2,36	1,97	0,66
average		**4,23**	**3,90**	**3,46**	**2,72**	**2,12**	**1,73**	**0,64**
PP-1/25	28	4,90	4,78	4,07	3,21	2,40	1,90	0,66
PP-1/26		4,94	4,78	4,36	3,40	2,60	2,11	0,69
PP-1/27		4,64	3,53	3,55	2,84	2,21	1,78	0,61
average		**4,83**	**4,36**	**3,99**	**3,15**	**2,40**	**1,93**	**0,65**
PP-1/28	56	5,71	5,32	4,68	3,92	3,03	2,34	0,69
PP-1/29		5,84	5,63	4,36	3,61	2,65	2,08	0,62
PP-1/30		5,45	5,16	4,65	3,81	2,85	2,25	0,70
average		**5,67**	**5,37**	**4,56**	**3,78**	**2,84**	**2,22**	**0,67**
PP-1/88	90	6,91	6,23	5,27	4,22	3,09	2,41	0,61
PP-1/89		6,35	5,74	4,36	3,93	2,85	2,24	0,62
PP-1/90		5,72	5,29	4,53	3,67	2,69	2,11	0,64
average		**6,33**	**5,75**	**4,72**	**3,94**	**2,88**	**2,25**	**0,62**

After the first crack, and as the crack width increases, the equivalent strengths decrease (Figure 8). This is known as softening. The increase in equivalent strengths at a given crack width is more moderate compared to the increase in f_{ct} (third column in table 4) up to the age of PP-1 56 days. Thereafter, the equivalent strengths increase only slightly up to 90 days of age.

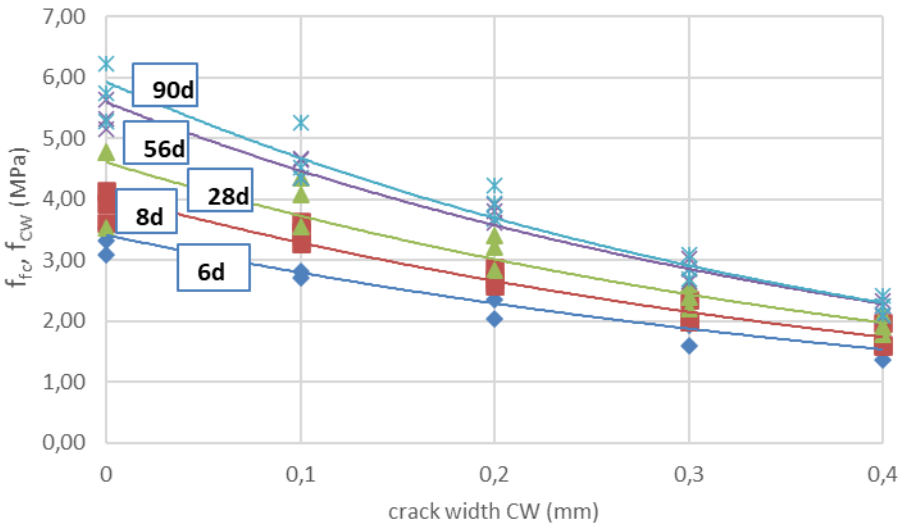


Figure 8. *Equivalent splitting tensile strengths f_{cw} and splitting tensile strength at first crack f_{fc} of PP-1 as a function of crack width.*

In the light of the above observation, a moderate increase in resistance to crack propagation RCP up to the age of PP-1 56 days is understandable, and then it decreases at the age of 90 days (last column in Table 4). RCP > 0.60 at all ages PP-1.

Table 5. *Results of the wedge splitting test for PP-1-JV.*

designation of the test specimen	age of PP-1-JV	ultimate splitting tesnile strength - f_{ct}	splitting tensile strength at first crack - f_{fc}	equivalent splitting tensile strength up to the crack width (mm)				resistance to crack propagation RCP=$f_{0,2}/f_{ct}$
				0,1	0,2	0,3	0,4	
				$f_{0,1}$	$f_{0,2}$	$f_{0,3}$	$f_{0,4}$	
	(days)	(MPa)	(MPa)	(MPa)	(MPa)	(MPa)	(MPa)	-
PP-1-JV/1	3	3,50	3,01	3,15	2,87	2,72	2,59	0,82
PP-1-JV/2		3,99	3,49	3,55	3,39	3,20	3,15	0,85
PP-1-JV/2		3,63	3,27	3,05	2,72	2,50	2,43	0,75
average		**3,71**	**3,26**	**3,25**	**2,99**	**2,81**	**2,72**	**0,81**
PP-1-JV/2	8	6,07	5,81	4,79	4,54	4,13	3,97	0,75
PP-1-JV/2		5,54	4,49	4,83	4,37	3,83	3,60	0,79
PP-1-JV/2		4,86	3,72	4,07	3,87	3,51	3,37	0,80
average		**5,49**	**4,67**	**4,56**	**4,26**	**3,82**	**3,65**	**0,78**
PP-1-JV/2	28	5,36	4,34	4,31	4,70	4,73	4,82	0,88
PP-1-JV/2		4,79	4,14	4,01	4,30	4,32	4,29	0,90
PP-1-JV/2		4,82	4,25	4,18	4,42	4,28	4,25	0,92
average		**4,99**	**4,24**	**4,17**	**4,47**	**4,44**	**4,45**	**0,90**
PP-1-JV/2	56	5,79	4,36	5,05	4,63	4,16	3,97	0,80
PP-1-JV/2		6,01	4,42	4,93	4,54	4,06	3,86	0,76
PP-1-JV/3		6,24	5,00	4,96	4,68	4,38	4,28	0,75
average		**6,01**	**4,59**	**4,98**	**4,62**	**4,20**	**4,04**	**0,77**
PP-1-JV/8	90	5,41	4,13	4,62	4,53	4,46	4,41	0,84
PP-1-JV/8		5,95	5,11	5,00	4,67	4,60	4,32	0,78
PP-1-JV/9		6,10	5,22	4,94	4,83	2,69	2,11	0,79
average		**5,82**	**4,82**	**4,85**	**4,68**	**3,92**	**3,61**	**0,80**

The ultimate splitting tensile strength f_{ct} increases unevenly with the age of PP-1-JV (third column in Table 5). After the first crack, and as the crack width increases, the equivalent strengths decrease moderately (Figure 9). Softening is moderate. For a given crack width, the equivalent strengths increase significantly from PP-1-JV age of 3 days to 8 days. Thereafter, the equivalent strengths increase relatively less and rather unevenly up to the age of 90 days.

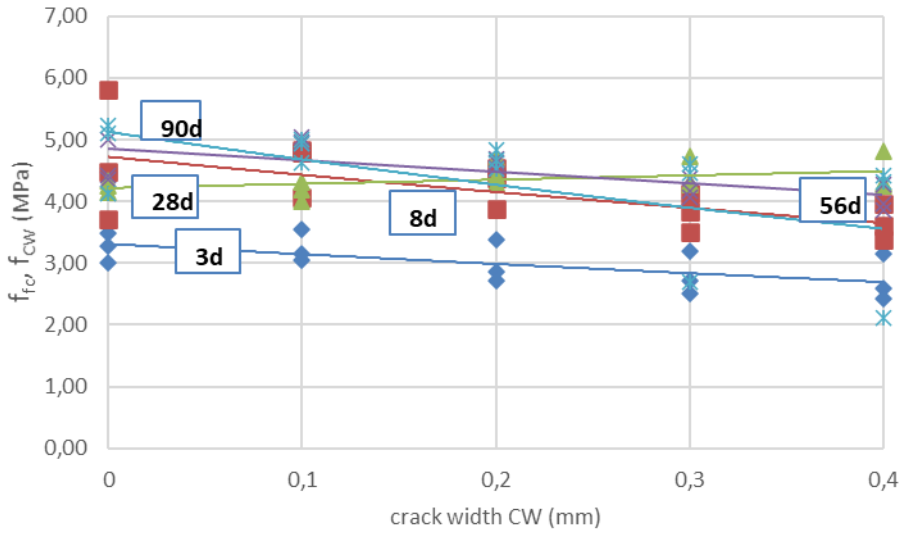


Figure 9. *Equivalent splitting tensile strengths f_{cw} and splitting tensile strength at first crack f_{fc} of PP-1-JV as a function of crack width.*

The RCP also varies in a similar way at different ages of PP-1-JV; average RCP values from age 3 to 90 days are around 0,80 (last column in Table 5). Regardless of the heterogeneity, all individual RCP results ≥ 0,75, which means that PP-1-JV shows good resistance to crack propagation.

Table 6. *Results of the wedge splitting test for PP-2.*

designation of the test specimen	age of PP-2	ultimate splitting tesnile strength - f_{ct}	splitting tensile strength at first crack - f_{fc}	equivalent splitting tensile strength up to the crack width (mm)				resistance to crack propagation RCP=$f_{0,2}/f_{ct}$
				0,1	0,2	0,3	0,4	
				$f_{0,1}$	$f_{0,2}$	$f_{0,3}$	$f_{0,4}$	
	(days)	(MPa)	(MPa)	(MPa)	(MPa)	(MPa)	(MPa)	-
PP-2/19	4	3,42	2,41	2,58	2,20	1,86	1,59	0,64
PP-2/20		3,55	2,67	2,94	2,48	2,10	1,80	0,70
PP-2/21		3,20	2,18	2,78	2,19	1,92	1,70	0,68
average		**3,39**	**2,42**	**2,77**	**2,29**	**1,96**	**1,70**	**0,68**
PP-2/22	7	4,89	3,78	3,99	2,94	2,30	1,88	0,60
PP-2/23		3,81	2,63	3,07	2,25	1,75	1,44	0,59
PP-2/24		3,90	3,06	3,44	2,72	2,18	1,78	0,70
average		**4,20**	**3,16**	**3,50**	**2,64**	**2,08**	**1,70**	**0,63**
PP-2/25	27	5,65	5,11	4,61	3,54	2,75	2,25	0,63
PP-2/26		4,74	3,45	4,03	3,41	2,51	1,99	0,72
PP-2/27		4,96	4,82	4,18	3,18	2,34	1,87	0,64
average		**5,12**	**4,46**	**4,27**	**3,38**	**2,53**	**2,04**	**0,66**
PP-2/28	56	5,43	4,20	4,36	3,75	2,87	2,30	0,69
PP-2/29		6,04	4,40	4,81	3,98	2,97	2,39	0,66
PP-2/30		5,97	5,94	4,56	3,66	3,09	2,62	0,61
average		**5,81**	**4,85**	**4,58**	**3,80**	**2,98**	**2,44**	**0,65**
PP-2/88	90	6,26	5,61	4,81	3,55	2,57	1,89	0,57
PP-2/89		5,85	4,59	4,76	3,79	2,81	2,23	0,65
PP-2/90		6,45	4,92	5,35	4,39	3,29	2,59	0,68
average		**6,19**	**5,04**	**4,97**	**3,91**	**2,89**	**2,24**	**0,63**

The ultimate splitting tensile strength f_{ct} increases uniformly with the age of PP-2 (third column in Table 6). After the first crack, the equivalent strengths decrease as the crack width increases (Figure 10). Softening occurs. The equivalent strengths at a given crack width increase more rapidly from 4 to 27 days of age than from 27 to 90 days.

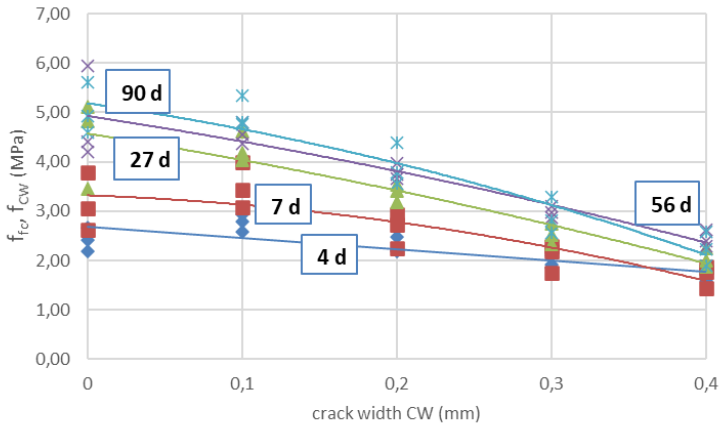


Figure 10*. Equivalent splitting tensile strengths f_{CW} and splitting tensile strength at the first crack f_{fc} of PP-2 as a function of crack width.*

The RCP decreases moderately from age 27 to 90 days (last column in Table 6). All average values are > 0,60

Table 7. *Results of the wedge splitting test for PP-3.*

designation of the test specimen	age of PP-3	ultimate splitting tesnile strength - f_{ct}	splitting tensile strength at first crack - f_{fc}	equivalent splitting tensile strength up to the crack width (mm)				resistance to crack propagation RCP=$f_{0,2}/f_{ct}$
				0,1	0,2	0,3	0,4	
				$f_{0,1}$	$f_{0,2}$	$f_{0,3}$	$f_{0,4}$	
	(days)	(MPa)	(MPa)	(MPa)	(MPa)	(MPa)	(MPa)	-
PP-3/19	3	3,20	2,78	2,73	2,03	1,64	1,37	0,63
PP-3/20		3,27	2,81	2,68	2,28	1,82	1,50	0,70
PP-3/21		3,21	2,03	2,90	2,50	2,19	1,95	0,78
average		**3,23**	**2,54**	**2,77**	**2,27**	**1,88**	**1,61**	**0,70**
PP-3/22	7	5,01	4,14	4,23	3,39	2,59	2,09	0,68
PP-3/23		4,61	3,46	3,60	2,94	2,35	1,95	0,64
PP-3/24		5,16	3,92	4,31	3,29	2,47	1,98	0,64
average		**4,93**	**3,84**	**4,05**	**3,21**	**2,47**	**2,01**	**0,65**
PP-3/25	28	5,41	4,45	4,49	4,03	3,40	2,72	0,74
PP-3/26		5,78	4,40	4,62	3,95	3,06	2,40	0,68
PP-3/27		5,83	3,68	4,47	4,33	3,89	3,01	0,74
average		**5,67**	**4,18**	**4,53**	**4,10**	**3,45**	**2,71**	**0,72**
PP-3/28	56	5,78	4,03	4,62	3,71	2,67	2,06	0,64
PP-3/29		6,03	5,37	4,77	3,81	2,82	2,23	0,63
PP-3/30		5,92	4,85	4,74	3,93	2,85	2,25	0,66
average		**5,91**	**4,75**	**4,71**	**3,82**	**2,78**	**2,18**	**0,65**
PP-3/88	90	5,80	4,07	4,67	3,83	2,85	2,20	0,66
PP-3/89		5,33	4,42	4,56	3,73	2,74	2,14	0,70
PP-3/90		5,72	4,49	4,41	3,69	2,83	2,25	0,65
average		**5,62**	**4,33**	**4,55**	**3,75**	**2,81**	**2,20**	**0,67**

The ultimate splitting tensile strength f_{ct} increases uniformly with the age of PP-3 up to 56 days of age (third column in Table 7). After the first crack, the equivalent strengths decrease as the crack width increases (Figure 11). Softening occurs. The equivalent strengths at a given crack width increase from 3 to 28 days of age and then decrease so that the values at 56 and 90 days are of the same magnitude but less than those of 28-day-old PP-3.

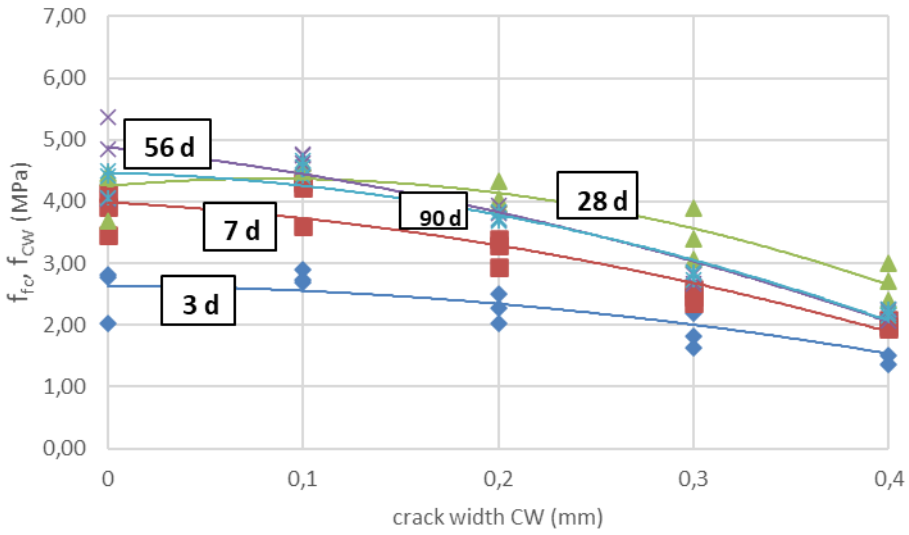


Figure 11. *Equivalent splitting tensile strengths f_{cw} and splitting tensile strength at first crack f_{fc} of PP-3 as a function of crack width.*

The resistance to crack propagation varies at different ages of PP-3; average RCP values from age 3 to 90 days are around 0,68 (last column in Table 7). All individual results are > 0,60.

In Figure 12, we give the results of the ultimate splitting tensile strength f_{ct} as a function of age for all HPC (PP-1, PP-1-JV, PP-2 and PP-3).

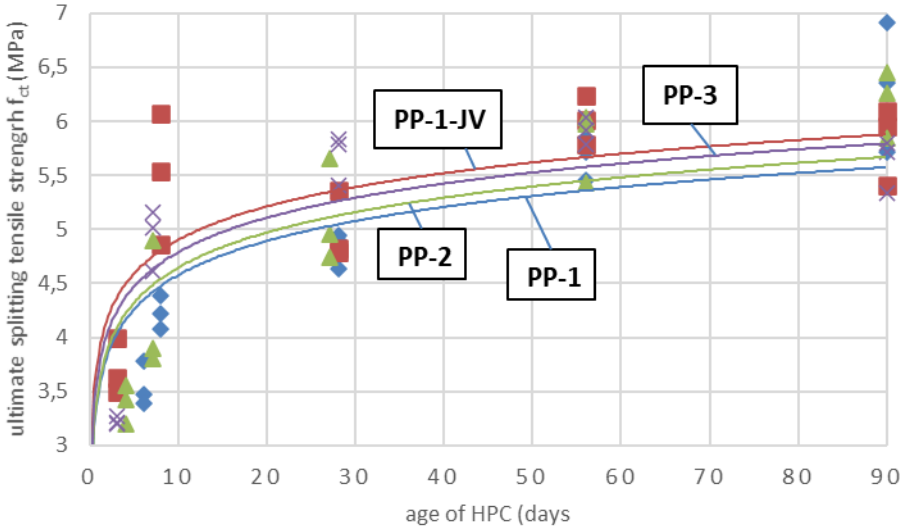


Figure 12*. Ultimate splitting tensile strength f_{ct} as a function of age for all HPC tested*

There are relatively small differences between the ultimate splitting tensile strengths f_{ct} at all HPC ages. There is also a significant dispersion of results.

However, there is a larger difference between the RCPs of PP-1-JV, which deviates in magnitude from the RCPs of the other three HPCs (Figure 13).

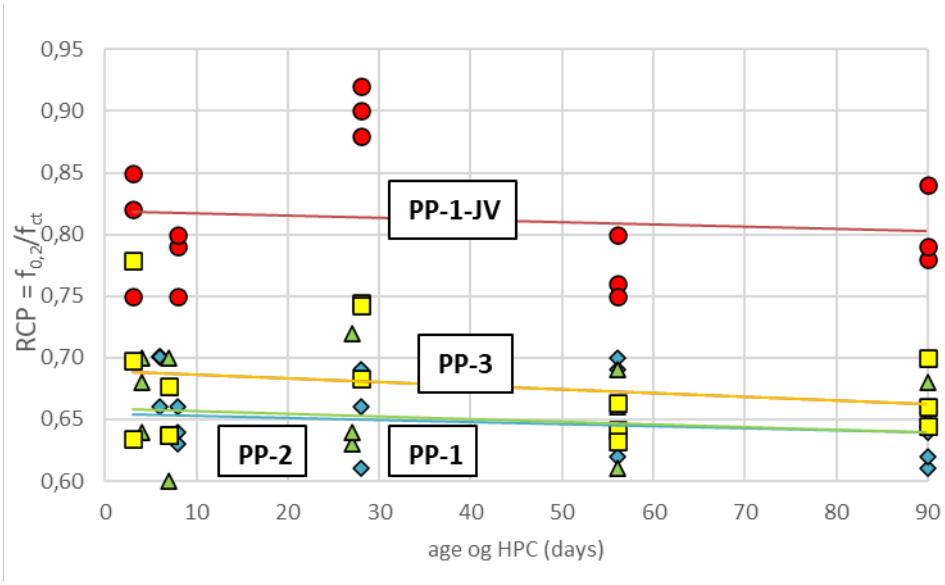


***Figure 13**. Resistance to crack propagation as a function of the age of HPC (PP-1, PP-1-JV, PP-2 and PP-3).*

This figure also shows that there is no correlation between RCP and HPC age; the RCP values of all HPCs do not change much on average with the age of the HPC, and there is a slight trend of decreasing average RCP values with the age of the HPC.

The RCP results of all HPCs meet the required criterion of RCP ≥ 0,60, which means that all HPCs show resistance to crack propagation. The RCP results obtained from PP-1-JV are relatively highest, around 0,80. All results for all ages PP-1-JV are greater than 0,75.

5. CONCLUSIONS

All the High-Performance Concretes (HPC) investigated in the project achieved very high durability in addition to high compressive strength due to their high-quality structure. However, to achieve a long service life of the structure, it is important that good resistance to crack propagation has been achieved in the HPC. The required RCP ≥ 0,60 was achieved at all HPC ages. The added steel fibers further improve the resistance of the HPC to crack propagation. The RCP = 0,75, which is often required in practice for Fiber Reinforced Concrete structures, was easily exceeded.

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AUTHOR'S BIOGRAPHIES

Jakob Šušteršič

Professor, employed at the IRMA Institute for Research in Materials and Applications, Slovenia

Rok Ercegovič

Civil engineer, employed at the IRMA Institute for Research in Materials and Applications, Slovenia.

David Polanec

Civil engineer with a Master's degree, employed at the IRMA Institute for Research in Materials and Applications, Slovenia.

Bojana Grujić

Professor at the Faculty of Architecture, Civil Engineering and Geodesy at the University of Banja Luka and Postdoctoral Researcher at Yamaguchi University in Japan.

ИСПИТИВАЊЕ ОТПОРНОСТИ БЕТОНА ВИСОКИХ ПЕРФОРМАНСИ НА ШИРЕЊЕ ПУКОТИНА МЕТОДОМ ЦИЈЕПАЊА КЛИНОМ

Сажетак: У овом раду се описују кључни елементи резултата истраживања отпорности на ширење пукотина спроведених у оквиру обимног пројекта развоја бетона високих перформанси (БВП) за секундарну облогу окна за одлагање радиоактивног отпада ниског и средњег нивоа. Истраживали смо четири састава БВП, у којима смо варирали количину везивне компоненте и међусобне односе два цемента и силикатне прашине. Такође смо додали челична влакна у један БВП. За одређивање отпорности на ширење пукотине кориштена је метода испитивања цијепања клином. Добијени резултати показују да сви испитивани БВП постижу добру отпорност на ширење пукптине. Додатак челичних влакана додатно побољшава ову отпорност.

Кључне ријечи: *отпорност на ширење пукотина, бетон високих перформанси, испитивање цепања клином*

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Igor Jokanović
University of Novi Sad, Faculty of Civil Engineering in Subotica, Serbia,
jokanovici@gf.uns.ac.rs, https://orcid.org/0000-0002-6511-8398

Milica Pavić
University of Novi Sad, Faculty of Civil Engineering in Subotica, Serbia,
pavic953@gmail.com

ENVIRONMENTAL PROTECTION - SUSTAINABLE DEVELOPMENT - TRANSPORT: CHRONOLOGY OF THE APPROACH AND POLITICAL-STRATEGIC FRAMEWORK

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* corresponding author

Igor Jokanović *

University of Novi Sad, Faculty of Civil Engineering in Subotica, Serbia, jokanovici@gf.uns.ac.rs, https://orcid.org/0000-0002-6511-8398

Milica Pavić

University of Novi Sad, Faculty of Civil Engineering in Subotica, Serbia, pavic953@gmail.com

ENVIRONMENTAL PROTECTION - SUSTAINABLE DEVELOPMENT - TRANSPORT: CHRONOLOGY OF THE APPROACH AND POLITICAL-STRATEGIC FRAMEWORK

ABSTRACT

Since the need for movement/transport has conditioned the development of transport networks, the management of the transport infrastructure largely depends on the guidelines or the policies for the development and management of transport. However, although there were concerns about the impact on the environment in the past five decades, it was only in the early 21st century that the effects of transport on the environment were adequately evaluated through the formulation of transport policies. It is important that a global consensus has been reached on the fact that the impacts of transport infrastructure and transport on the environment are essential. Still, it is far more important for the policies of protecting and improving the environment not to conflict with economic competitiveness so that properly formulated regulation could lead to discoveries and improvements, which would result in a win-win situation for both the public and the manufacturers and the improvement of the credibility of competent institutions and organisations in particular. Through a chronological summary of the transformation, this paper moves from the basic environmental protection toward sustainable development in global and European frameworks, and it emphasises the essential aspects that must be addressed in defining a political and strategic framework for the management of transport infrastructure and transport in underdeveloped and developing countries to meet the requirements for sustainable development.

Keywords: *transport infrastructure, transport, sustainable development, policy, integration*

1. INTRODUCTION

An important basis for all considerations related to the future development of society, not only within one country but also on a global scale, is the concept of sustainability. The Brundtland Commission [1] defined sustainability as the ability to meet the needs of the present without compromising the ability of future generations to meet their own needs while integrating the compatibility of the environment, economy, and society (Figure 1) with the goal of meeting the present and future human needs.

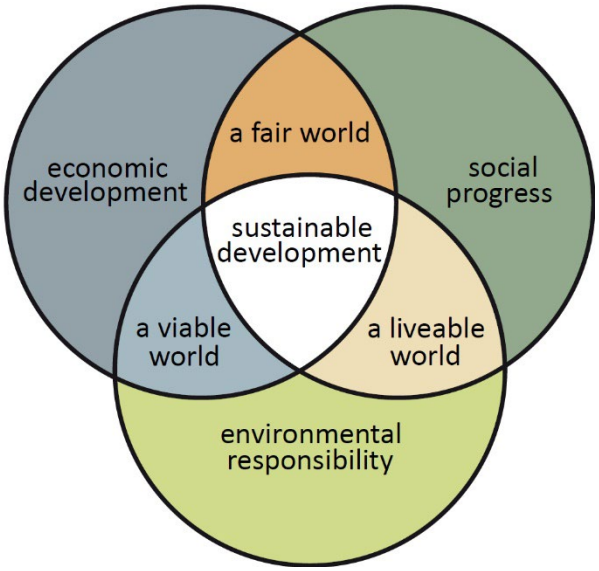

Figure 1. Common sustainability dimensions [2]

All human activities take place in the context of specific relations that exist between society, economy and environment, i.e. bio-physical world. Any form of development must necessarily include the change in these relations. The changes in nature and the environment are the product of natural events and the implementation in specific development models, practices, and lifestyles. Similarly, any change in the natural environment has significant social and economic consequences for the quality of life.

The development of society has also changed these relations. In some instances, the development resulted in benefits for both sides. In some other cases, there were benefits for the human population to the detriment of the abilities of the ecosystem, which resulted in the reduction of their capacity for the future. Such negative changes were not particularly relevant when they took place on a scale insignificant for the natural environment. At a time when the human population was smaller and new territories could be conquered after the local capacities were depleted, the abandoned areas had sufficient time to recover and return to their initial capacity. However, with the growth of the human population, particularly during the 20th century, a serious problem of disbalance occurred in which the society could no longer function as if economy and ecology were two independent disciplines without the need to rely on one another. Human activities would be reduced to a pattern that can be sustained in the future by approaching the problems of the environment and development with the goal of harmonizing human needs with the planet's capacity to deal with the consequences of human activities.

1.1. GROWTH AND SUSTAINABILITY

Modern economic thought has long been under the influence of the doctrine that production is the driving force of economic growth, that the capital is made through the economy and the natural resources are interchangeable, and that nature is free. The growth of production and consumption as basic driving forces has led to the attitude that clean air, water, and ecosystems are, in fact, "free" raw materials, which are consumed in the production process without restrictions and bring larger profit. Everything was subordinated to the growth of production and consumption at any cost, which has tragically degraded the human reputation. Consumer society was created, a society which abuses the scientific and technical achievements by its treatment of nature and fails to establish a balance between human abilities and needs. A logical consequence of such behaviour is the creation of a new image of scientific rationality as an imperative of power and technical and technological prestige. Modern technology thus serves the economic and financial endeavours, political goals, exploitation and dominance systems, i.e. the system of power and social control.

According to the changed perspective, the concept of sustainable development was introduced instead of the concept of economic growth. The difference is in that growth refers to the increase in the physical volume of production, while sustainable development refers to the qualitative changes in the physically unchanged economic system. The basic concept of this approach is the creation of a new efficient resource distribution and uses a system based on the principle that the reserves of natural resources should not be wasted beyond the limits of the ability of the natural system to recover. The concept of sustainable development emphasizes the maintenance of natural resources and the natural environment as a prerequisite for developing any economic activity to achieve human well-being and quality of life. Nature provides "life support mechanisms and services" as a basis for social environment and progress. Economic activities are the means to utilize these resources and to release their potential value to society to meet human needs. According to this model, economization is the human activity that continually converts natural resources into the quality of life as expressed in terms of goods and services. Clearly, a healthy environment and wise use of natural resources are indispensable for sustainable development providing the basis for long-term quality of life.

Sustainability should not, as it often is, be regarded as a finished concept but as a development goal. Today's understanding of the concept of sustainable development is based on equal treatment of components of ecology, economy and society when formulating development policies and strategies. An integral approach and consideration of the interdependence of these factors become the foundation for development planning. In the long run, sustainable development of the human community can only be expected if all three aspects of sustainability are balanced in development planning. In this way, adequate development quality is achieved as a goal, which basically represents sustainability.

Sustainability is far more related to the human species and its activities than the environment. Nature "recognizes" all possible ways of managing its own systems in a sustainable way, and has been creating and developing strong, sophisticated ecological systems and very complex species for an immeasurable number of years. Sustainable development, therefore, represents a roadmap for the progress of mankind by which the

human species would manage its systems in a manner that is consistent with nature's ways, rather than systematically damaging such systems as it is today.

When the environment is observed in the framework of sustainable development, it is not implied that the best solution for the environment is to remain unchanged forever, or that the return to its initial condition is necessary. The human population is constantly introducing changes to its environment, and clearly, the needs of the growing population cannot be met without any change in the environment. However, changes must be introduced carefully and methodically, especially when they relate to possible effects that cannot yet be fully comprehended.

When designing development strategies based on the idea of sustainable development, it is necessary to bear in mind that this concept implies certain, but not absolute limitations that are imposed on natural resources by the existing state of technology and social organization, as well as the ability or capacity of the biosphere to absorb all kinds of harmful and waste matter primarily resulting from the economic activities. However, the technology and social organization can be managed satisfactorily and thus can be significantly improved to create the necessary prerequisites for a new, qualitatively different economic development. Sustainable development, as the middle way between very rapid development with low tech-economic efficiency and development with huge costs and a significant reduction in the country's social product, is a philosophy that is characterized by the integration of economics, technology, sociology and ecology in development planning and realization, where investments in the environment give immediate positive financial results.

1.2. SUSTAINABLE TRANSPORT INFRASTRUCTURE

As an essential basis for achieving inclusive development, a sustainable infrastructure that also includes transport infrastructure supports all economic activities. Inadequate infrastructure remains one of the most prominent obstacles to growth and sustainable development and, therefore, to fight against poverty. Good infrastructure removes economic growth constraints and affects the increase in production and productivity. Investments in sustainable infrastructure can help create jobs, increase international trade, and promote industrial growth and competitiveness while reducing inequalities both within and across countries.

Sustainable transport infrastructure is essential for reducing poverty and extreme hunger, and achieving social prosperity, as it partially improves access to basic services and facilitates access and knowledge of job opportunities, thereby increasing human capital and the quality of life. It also improves the level of health and education, helps to achieve gender equality, and provides clean water and sanitary conditions as well as access to responsive energy and housing. Sustainable infrastructure promotes sustainable consumption, production and use of resources to ensure the resilience of habitats and settlements and sustainable ways of using the ecosystems and associated resources. On the one hand, quality infrastructure increases food safety through more efficient use of resources and reduces vulnerability to environmental shocks. On the other hand, poor infrastructure may even kill people, largely by air and other types of pollution and traffic accidents. Also, it exerts pressure on the use of land and natural resources to the extent that can threaten the sustainability of future generations and create an unsustainable economic burden in the future.

Transport infrastructure management systems, through the transport network planning and construction, operation planning, as well as system maintenance at a satisfactory quality level, have some of the key implications for implementing the concept of sustainable development since there is a task to meet the social and economic needs of individuals and communities in relation to the movement of goods and people while ensuring the conditions for rational use of natural resources and healthy life of the population.

2. ON THE JOURNEY FROM PROTECTING THE ENVIRONMENT TO SUSTAINABLE DEVELOPMENT

At the end of 2001 [3], a survey was organized in 30 countries, including OECD (Organization for Economic Co-operation and Development) countries, developing countries in Africa, Asia, and Latin America, as well as the Eastern European and Central Asia countries with economies in transition. Around 30,000 people participated in the survey. The results showed that 44% of respondents identified the degradation of natural resources (12% of respondents) and the pollution of the environment (32% of respondents) as the biggest threats to future generations. Other important issues included economic hardship (22% of respondents), wars and conflicts (13% of respondents), diseases (12% of respondents) and lack of food (6% of respondents). Although a survey showed a high general concern for the environment, there were also significant differences in approaches depending on the countries' development levels. In countries with a high gross domestic product (GDP), residents are more concerned about the general problem of environmental endangerment, compared to countries with low or medium GDP, where the concern is of local or national character, especially in relation to air and water pollution. This high level of concern provides a political basis for additional strategies and financing activities relating to the environment and sustainable development. Accordingly, and under the auspices of the UN (United Nations Organisation), significant actions are taking place. Various aid organisations are formed to preserve what can be preserved in developed societies and to protect and preserve the large sources of resources found in the underdeveloped world.

Up until 30-40 years ago, the focus was mainly on mitigating the pollution and destructive use of natural resources. Today we are interested in integrating the care for the environment into the notion of economic growth and development. The initial understanding of the environment as a barrier or a limiting factor for economic activities has changed to the understanding that sound and sustainable economic development can only be achieved by respecting the ecosystem functionalities and by using the benefits from new opportunities resulting from the appropriate use and/or preservation of the environment.

2.1. GLOBAL ACTIONS

The first organized responses to the humankind environmental crisis appeared in the 1960s. Initiatives to protect and improve the environment have been launched by the UN.

At the first UN Conference on Human Environment, held in Stockholm in 1972, a declaration was published with 26 principles concerning the major issues of the environment, from social and economic development issues, resource consumption and the pollution of the environment, to the role of education and science in the environment protection [4, 5]. In addition, the Conference established a set of new principles, including the following:

- sovereign right of States to exploit their own natural resources;
- responsibility for cross-border pollution;
- integral development planning;
- "the polluter pays" and alike.

An important result of the conference was the establishment of the United Nations Environmental Programme (UNEP), an institution whose task is to assist the actions to solve problems related to the impact on the environment within the membership framework. The conference also gave a strong incentive for the preparation of international recommendations and regulations for environmental protection, as well as national legislations. At this stage, the institutionalization of environmental policies took place in many countries, accompanied by the establishment of ministries or agencies for the environment, the adoption of laws and by-laws on environmental protection, as well as the adoption of certain economic instruments and set up of national environmental monitoring systems. All over the world, NGOs and groups for environmental protection were established having an increasing influence on the environmental protection policy. The characteristic of this period is a passive defence of the environment from pollution in manufacturing processes using different filters and/or purifiers.

In 1987, the World Commission on Environment and Development published a report entitled "Our common future", which came to be known as the "Brundtland Report" [1]. It was concluded that the existing relationship between the economy and the environment has resulted in numerous problems, such as: global warming, ozone depletion, acidification, deforestation, the disappearance of biological species, desertification, and radioactive and other hazardous waste. This report promotes the idea of sustainable development, the concept of which is integrated into the documents of the Conference on Environment and Development, held in Rio de Janeiro in 1992. The documents adopted in Rio represent the basis for a new attitude of the international community towards the environment, with sustainable development as the basic strategy for the relations between the economy and ecology. The conference will be remembered for the following five official agreements:

- Declaration on Environment and Development;
- Framework Convention on Climate Change;
- Convention on Biological Diversity;
- Principles for a global consensus on management, conservation and sustainable development of all kinds of forests;
- Agenda 21.

Agenda 21 [6], i.e. the action plan for the achievement of sustainable development, is particularly important as a detailed programme dealing with the basic requirements for sustainable development in the 21st century. It consists of 40 chapters organized into four sections, in particular the following: social and economic dimension, conservation and management of development resources, the role of social groups, and means of implementation. The approach from the lower local communities towards the higher international forms of organization is emphasized in many areas. This is probably one of the reasons why many of the results stipulated by the Agenda at the international level have not been successfully achieved. On the other hand, numerous successes have been achieved at the level of local communities.

Agenda 21, as well as the other key documents produced by the conference, do not represent a binding agreement. It may need to be understood as a set of harmonized views on the nature of the problem, the relevant principles, and the framework of desirable and possible pathways towards solutions, considering the national and other interests. Due to the significance of the transport infrastructure management activities, it is necessary to specify the activities proposed to achieve the goals:

- achieving the integration between the environmental protection and economic development approaches;
- improving decision-making processes;
- improving planning and management systems;
- improving the information resources;
- building of sustainable development institutions at the national and international level;
- adopting a national strategy for sustainable development.

This document, as well as the concept of sustainable development, were both praised and criticized. Still, Agenda 21 undoubtedly represented an instruction and reference document for economic development and environmental issues in the coming years.

At the same time, the UN principles of environment and development, known as the Principles of Sustainable Development, were also adopted. Since then, the concept of sustainable development has been considered the basic strategy for the development and future relationship between the economy and ecology. It reaffirms the human right to a healthy and productive life in line with nature, as well as the need for close cooperation between countries with a view to achieving sustainable development.

Five years after Rio, a UN Conference was held in New York, the “Earth Summit +5”, with the aim of showing the extent and how the tasks set in 1992 were accomplished, especially how Agenda 21 was implemented. The general conclusion was that very little was done from what was agreed upon in Rio, although there was indisputable progress [7]. This summit dedicated special attention to the worrying climate changes, deforestation, piling of hazardous and other waste in all three states of matter, the increasing need for clean drinking water, and at the same time, to growing poverty and other trends.

The third Summit took place in 2002 in Johannesburg. However, significant results in terms of protection and improvement of the environment on Earth were lacking. It is particularly important to emphasize that there has been a major divergence in the attitudes of the world’s most advanced countries that should actually be beacons for other countries when it comes to ensuring the sustainable development of the planet [8]. A similar trend continued in Rio de Janeiro in 2012 and New York in 2015. The 2012 outcome document, entitled “Future we want”, reaffirmed the principles set in Rio in 1997, established a plan to define sustainable development goals by 2015 and give clear support to the so-called “green economy”. One of the emphasized elements was sustainable transport as a component of sustainable development that can help economic growth and improve accessibility. It expressed support for the development of sustainable transport systems, including energy-efficient systems of multimodal transport (mass public transport systems in particular), clean fuels and vehicles, as well as the improvement of transport systems in rural areas.

The most important result of the Summit on Sustainable Development (New York, 2015) was the preparation of a new Agenda for Sustainable Development by 2030 and its 17

Sustainable Development Goals (SDG). The agenda was later adopted at the session of the UN General Assembly in September of the same year [9]. SDGs, also known as the Global Goals, represent a universal call for action to eliminate poverty, protect the environment and ensure peace and prosperity for all. The goals are interconnected since the key to the success of one goal often lies in considering challenges inherent to another goal. A strong emphasis has been placed on the need to establish new forms of partnerships between governments, business sectors and civil society, as well as on the strengthening of international institutions. Sustainable development goals are defined in detail by their targets, i.e. results.

The transport infrastructure and transport are mutually interconnected through SDGs [9]. Thus, target 11.2 (SDG 11 - Sustainable cities and communicates) is to provide access to safe, affordable, accessible, and sustainable transport systems for all, improving road safety, notably by expanding public transport. In support of economic development and the well-being of society, it is necessary to ensure quality, reliable, sustainable, and resilient infrastructure, with a focus on affordable and equitable access for all (target 9.1 of the SDG 9 - Industry, innovation and infrastructure). From the point of view of environmental protection, target 3.9 (SDG 3 - Good health and well-being) requires to substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water, and soil pollution, while target 9.4 requires upgrading infrastructure and retrofitting industries to make them sustainable, with increased resource-use efficiency and greater adoption of clean and environmentally sound technologies and industrial processes.

If it is necessary to quantify the transport that could be achieved by meeting the set sustainable development goals, it should be stressed that sustainable transport represents the provision of infrastructure and services for the movement of people and goods (enhancing economic and social development for the benefit of the present and future generations) in a way that is safe, responsive, accessible, effective and resilient, while minimizing the carbon emissions and other emissions, as well as the impact on the environment [10]. Sustainable transport supports inclusive growth, job creation, poverty reduction, access to markets, empowerment of women and the well-being of people with disabilities and other vulnerable groups. It is also essential as the support for the efforts intended to combat climate change, reduce air pollution, and improve safety on the transport infrastructure.

2.2. EUROPE

Radical changes in the policies of developed countries, from the protection of the environment towards sustainable development, lead to the integration of environmental aspects into the development policies in other areas: energy, industry, agriculture, transport, trade and alike. However, members of the European Union (EU), the Netherlands and Scandinavian countries, in particular, have, over time, spread their proactive attitude across the EU.

Important determinants for policymaking within the EU were the adoption of the Single European Act [11] and the Treaty on the European Union [12], which practically created the basis for achieving the goals and guiding principles when it comes to the environment. These acts also contain the determinants allowing for the introduction of the need for protection and the improvement of the environment in other community documents of any level and bring environmental protection to the policy level. The only differences that could

not have been agreed upon at the community level were: “environmental” fees, spatial and urban planning, and land use, where the Member States retained their right to form their own attitudes.

An important document for actions in the field of transport is the resolution of the European Conference of Ministers of Transport dated November 23, 1989 [13]. The resolution reflects the harmonized attitudes of the official government representatives in the field of transport that will continue to act both at the national and international levels in the spirit of these very concrete commitments.

The first part of the resolution clearly states that it was adopted because the problem of the impact of transport on the environment became acute in Europe, because of the obvious tendency to increase the volume of transport, especially road transport, as well as the emergence of very endangered areas, such as the mountain regions and river valleys.

The preamble to the resolution emphasizes that there is strong scientific evidence of the severity of the problem and the need for immediate action. Although the users of transport services should have the freedom to choose the means of transport, specific measures in relation to vehicles (emission control, vehicle improvement, quality of fuel), transport and infrastructure management in urban and interurban areas (project assessment, design, assessment of the need for new construction) are recommended.

While assessing the projects, it was recommended that infrastructure investment projects should, from the very beginning, include the assessment of direct and indirect effects on the environment, and that the assessment of the proposed investment must include the transport and the assessment of the impact on the environment in evaluating the options, including those options based on the expansion of rail or other public transport infrastructure and those without such expansion. Furthermore, it is also important to address the recommendations regarding public involvement in project planning, particularly where no voting is organized in the national parliaments, with the right to access detailed information on projects and potential realistic alternatives. Design recommendations include the choice of route, the use of techniques and materials that are not detrimental to the environment, and the obligation to exchange information at the international level.

In 1992, the European Commission also published a White Paper on the Common Transport Policy, which was adopted the following year [14]. The White Paper provides a broader approach to the transport policy with a focus on promoting sustainable mobility through improving the quality of transport systems in relation to competition, safety, and environmental impact. The trend of a proactive approach to sustainable mobility is also maintained in the following policies adopted for the EU territory. The current transport policy (White paper for the period up to 2050 [15]) raises serious issues for the EU member states with an obligation to decide on the direction of action and development of transport in line with the basic principles of sustainability, with the aim of creating a single European transport territory with a prominent competition and fully integrated transport networks. The main objective of European policy is to respond to the increasing mobility needs of citizens, goods, and services within the EU through the development of a modern network of transport infrastructure allowing faster and safer journeys, while promoting sustainable and digital solutions. The main challenges and obstacles encountered in the achievement of this goal include the following:

- congestions, which primarily affect road and air transport;
- sustainability, since the transport is still dependent on oil in meeting the majority of energy needs, which is environmentally and economically unsustainable;
- air quality, since the EU committed to reduce emissions by 60% by 2050 compared to 1990 levels and to continue to reduce pollution from vehicles;
- infrastructure that does not have a uniform quality across the EU;
- competition, where the fast-growing transport markets in other regions threaten the EU transport sector.

Since 1972, the EU has adopted seven Environmental Action Plans (EAP), while the eighth is in the final stage of preparation. In the first two action plans (1973-1981), the basic principles were: prevention is better than cure, the polluter pays principle, the obligation to assess the impact of investment projects on the environment and alike. The third and fourth action plans (1982-1986, 1987-1992) sought to provide a more comprehensive strategy to protect the environment and natural resources, shifting the focus of action from the protection against pollution to the prevention of pollution of the environment.

The fifth EAP (1993-2000) is clearly based on the concept of sustainable development, relying on the institutional framework established in the 1992 Maastricht Agreement. The plan defines the goals, targets, and deadlines for achieving the basic goal, which was not characteristic of the previous plans. This plan strived to establish a normal balance between human needs for economic and social progress, on the one hand, and the precautions and concerns aimed at preserving the environment and conserving natural resources, on the other hand. The main goals of the plan are to improve the implementation of regulations on the environmental impacts, to integrate the policies on the control of the environmental impact in all sectoral policies, and to ensure the participation of the public and the private sector in making development decisions. The plan specifically elaborates on the basis for the implementation of the sustainable development concept, namely the integration of requirements for environmental protection in five sectors, in particular the following: energy production, transport, tourism, agriculture, and industry.

The sixth EAP (2002-2012) provides strategic direction for EU policies on the control of the environmental impacts during the decade in question, which includes the following priority areas:

- climate changes,
- nature and biodiversity,
- environment and health, and
- natural resources and waste.

It is of particular importance to emphasize that the sixth EAP provides an environmental protection component for the implementation of the sustainable development strategy. In this context, key approaches should be underlined which allow the implementation of the adopted concept:

- ensure the implementation of the legislation in force;
- ensure the integration of the issues pertaining to the protection and improvement of the environment in all relevant sectoral policies;
- development of partnerships between countries, manufacturers and consumers in order to find solutions in a joint effort;

- provide better and more accessible information on the environment for the citizens;
- develop a much more comprehensive attitude towards the use of land.

The seventh EAP (2014-2020) highlighted the following as the main goals:

- to protect, conserve and enhance the natural capital;
- to reduce emissions and provide more efficient use of renewable and non-renewable natural resources in the economy;
- to safeguard the citizens from environment-related pressures and risks to health and well-being.

The main tools identified as the assistance in the achievement of these goals are the following:

- better implementation of legislation;
- better quality of information by improving the knowledge base;
- more and wiser investment related to requirements of environment and climate policy;
- full integration of environmental requirements and considerations into other policies.

The proposal of the eighth EAP (for the period until 2030) aims to speed up the transition to a climate-neutral, resource-efficient economy that would return to the planet more than it needs. The plan basically recognizes that human well-being and prosperity depend on healthy ecosystems in which we live and work.

It is important to emphasize that the previous seventh and the future eighth EAP do not replace the EU Sustainable Development Strategy but complement and support it. The first EU strategy was adopted in 2001 [16] with the aim to identify and design the activities that would allow for continuous improvement of the quality of life through the creation of sustainable communities capable of using and efficiently managing the resources, to use the potential ecological and social-economic innovations in commerce, and to ensure the prosperity, environmental protection, and social cohesion. The main areas covered by the strategy were the following:

- climate change and clean energy;
- sustainable transport;
- sustainable consumption and production;
- conservation and management of natural resources;
- public health;
- social inclusion, demography and migration;
- global poverty and the challenges of sustainable development.

The strategy was revised in 2006 [15] primarily because of the unsatisfactory results (transport, problems in urban areas, poverty, health) and new challenges (climate changes). The main threats to sustainable development are highlighted as follows: global warming, resistance of certain diseases to antibiotics, long-term effects of hazardous chemicals, food safety, poverty, population ageing, loss of biodiversity and land, increase in the amount of waste, congestion in traffic, especially in urban settlements, and regional imbalances. There is a pronounced need for gradual changes in relation to unsustainable consumption and production processes, as well as towards an integrated approach to policy-making and global cooperation.

In 2010, the EU adopted a Europe 2020 Strategy [17] with the aim of helping the EU countries exit the economic crisis so that the economy of Europe would become smart, sustainable, and inclusive. The priorities of this strategy included the following:

- smart growth - the development of a knowledge-based and innovation-based economy;
- sustainable growth - promoting a more competitive economy that uses the resources effectively and takes care of the environment;
- inclusive growth - promoting an economy with a high degree of employment that generates economic, social, and territorial cohesion.

Transport plays a significant role in the implementation of the Europe 2020 Strategy through the implementation of activities related to the use of renewable energy sources, modernization and decarbonization of transport, promotion of energy efficiency, improvement of infrastructure, development of smart transport systems, improvement of the efficiency of the EU transport system, tackling the problem of congestion and emissions in urban areas, and providing support for the industry. In line with its aspirations, strategies and goals, the EU has significantly influenced the design of the global sustainable development agenda [9].

3. TRANSPORT POLICY AS SUPPORT TO SUSTAINABILITY

The transport policy is a part of society's economic policy and represents a synthesis of public interests in the domain of transport and an important component of social activities in the domain of development, even in countries with a highly competitive economy. While the market principles have applied or still apply in such countries, due to market imperfections and the need to combine some of the more general interests and attitudes, the need for society to have and implement a predefined policy in the field of transport has been loudly or silently recognized to a lesser or greater extent. The transport policy as part of the general economic policy of each country is, above all, conditioned by socio-economic development, the goals of such development and the targets set in a certain period. On the other, the achieved level and the structure of the transport system of a country also define the policy. The transport policy in most developed countries has begun to gain new significance and dimensions since the middle of the last century, especially after the first energy crisis (October 1973 - March 1974) and after noticing the negative effects of transport on the environment.

During the 1980s, a shift in the formulation of transport policies took place in developed countries, primarily because of forecasting a very rapid increase in the traffic volume on roads. With investments in the construction of new transport capacities, the investments were mostly focused on expanding the existing capacities and preventing congestion, while in the 1990s, a sustainable transport policy model was promoted, with a focus on the quality of the environment, in line with the set principles of sustainable development. This came because of the unsustainability of policies based on continuous demand satisfaction and the inability to meet the criteria of economic, social, and environmental justification.

The economic justification of the policies could not be met due to congestion in the transport network. Congestions have caused massive business costs, and the construction of infrastructure was unable to eliminate them. This happened because the construction of the transport infrastructure, in particular the road infrastructure, generates and attracts traffic, and thus results in the increase of the length and duration of the journey, as well as

in the transition to car transport from other forms of transport, rather than increasing the number of journeys and the quantity of goods transported by means of mass transport. While the transport planners have assessed the increase in transport due to the improvement in infrastructure as positive, the fact is that the construction of roads leads to such an increase of transport that relatively quickly cancels all the achieved savings in time and costs of transport, as well as to the creation of larger traffic congestions.

The social unsustainability of the transport network development is reflected in the fact that there is an increased use of land for roads and stationary transport and the change of the purpose of land along roads, whereas reducing the use of public transport causes the increase of dependence on cars, which endangers people who do not own their own vehicles. Therefore, poorer households tend to give up on some other necessities and decide to procure cars, which is accompanied by the negative health effects of loneliness and isolation among those who do not own vehicles, as well as health problems caused by air, soil, and water pollution. Another category, having both a social and economy impact are traffic accidents. Costs of traffic accidents are very difficult to quantify and significantly differ between rich and poor countries.

Following modern trends, transport policies and strategies have been developed and adopted in the former Socialist Federal Republic of Yugoslavia (SFRY) from time to time. However, the need to invest in new road and rail routes represented a great burden, given the lack of a modern network encountered by the country in the mid-20th century.

After World War II, there were very few roads with modern pavement built on the territory of SFRY (only about 1,200 km of roads covered with stone blocks or asphalt), which had a very significant impact on the transport infrastructure development policy. The emphasis was on the construction of modern roads and the interconnection of major regional centres with the rest of the country. The situation was somewhat better in terms of railways (about 7,400 km of normal gauge and about 2,300 km of narrow gauge), but a significant amount was destroyed during World War II. In the 1990s, due to the reduction of the economic power of the country and the wars, there was first a period of stagnation, followed by a complete cessation of investments in new transport infrastructure. The trend of investing in a new infrastructure was mostly renewed at the end of the 20th and the beginning of the 21st century (depending on the newly formed countries). Still, the needs for improvement, rehabilitation and reconstruction of the existing roads and railways have increased significantly, as well as the infrastructure needed for other modes of transport. At the same time, it must be emphasized that most countries in the region face a significant population decline due to migration towards developed countries. This impacts their potential to increase internal traffic demand, except in large cities. Also, former SFRY states that are not yet EU members have limited potential for increasing transit traffic.

At the current stage of development, considering the current situation and the recommendations of experts, it is necessary to accept the fact that most of the transport activities in the region, as in most Central and Eastern European countries [18], take place on the roads, and that the trend of growth will continue to be very high in the next (at least) ten years. So, it is important to provide the necessary infrastructure for such needs, with maximum observance of the human right to a quality environment. Trends in road traffic lead to even greater inefficiency, congestions, pollution, damage to health and dangers to life, which is particularly favoured by the long service life of existing vehicles. To develop

the country's transport policy, it is necessary to adopt certain recommendations that pertain to the following:

- development of a long-term, ambitious, and realistic vision of the transport future, which would lead to the shaping of sustainable transport,
- changing the fact that the transport policy is based on demand,
- significant improvement of the quality and offer of public transport,
- development of means and centres of multimodal and intermodal transport as an alternative form of transport demand management,
- increasing traffic safety,
- use of advanced transport management systems to increase the efficiency of transport networks, especially in urban areas,
- introduction of consideration of external effects of transport, both in terms of costs and benefits, while adopting the policies,
- development of national strategies and programs that would include the setting of national goals and targets for reducing the impact of transport on the environment, based on international conventions and other binding documents,
- introduction of a tariff system for road use that would reflect unfavourable conditions of congestion and other types of external costs,
- establishing a system for monitoring basic environmental indicators related to transport impacts,
- construction of new roads only in places where it is extremely necessary to meet the needs, and
- introducing mandatory strategic environmental impact study when considering the adoption of transport policy.

With these recommendations in mind, three questions are raised that emphasize the potentially contradictory goals of the transport policy:

- whether the existing relationship between economic development, environmental protection, and support for the right to personal choice is appropriate,
- whether it is necessary to change this relationship (e.g. towards a higher degree of protection or greater competitiveness by reducing congestions), what measures should be taken and how their goals will be achieved, and
- whether we are ready to accept the wider consequences (for the environment, personal choice, industry competitiveness, employment, and the economy as a whole) of any of these measures.

As previously mentioned, the decision is related to the current relations in a specific country and the level of its economic development. It often happens that the desire for better and more efficient transport connections prevails over the desire for protection and improvement of the environment, which is not in line with sustainable development goals. In many underdeveloped and developing countries, the length of transport infrastructure is still one of the main indicators of development, which is a very big obstacle in formulating the transport policy in accordance with the principles of sustainable development. Related to this is the idea of the need to separate economic and environmental development goals. This option does not reject the strategic goals pertaining to environmental protection and improvement, but their solution is left for later, after the "appropriate" economic progress is achieved. This approach is not promising because if new investments would not take

environmental protection measures and their costs into account, there would be unjustifiably large environmental damage and significantly higher costs in the future.

Regardless of the choice of development strategy, the price of its implementation must be paid, either by the current generation or by transferring the costs to future generations. Each of these alternatives will have long-term consequences for the national economy, the environment, and the social status of citizens. Therefore, most underdeveloped and developing countries still do not have a clearly formulated environmental protection and transport development strategies within the concept of sustainable development, nor the development strategies in other spheres of human activities.

Without ignoring the basic goals of formulating the transport policy, such as economic development, better connectivity, industrial development, etc., it is necessary to formulate certain goals that would make the transport policy sustainable:

- ensure that transport policy at all levels of government is linked to land use planning, and reduce the need for mobility accordingly;
- stop endangering the land by transport infrastructure in areas that are under a certain type of protection, such as conservation zones, national and natural parks, cultural goods, etc.;
- achieve a level of air quality that will prevent threats to human health and the environment, according to the recommendations of the World Health Organization;
- reduce carbon dioxide emissions from traffic;
- reduce traffic noise emissions;
- improve the quality of life, especially in cities and settlements, by reducing the dominance of passenger and freight vehicles, and by providing and encouraging alternative modes of transport and means of mass passenger transport;
- increase the share of individual travel and the transport of goods by transport means that are less harmful to the environment, with the best possible use of the existing infrastructure;
- reduce subsidies for inefficient modes of transport;
- significantly reduce the share of materials and energy sources in transport infrastructure and the vehicle industry that cannot be recycled or renewed;
- change the travel behaviour of individual participants;
- improve the safety of all the transport participants.

In accordance with the said goals, it is necessary to recommend appropriate measures by developing strategies, where all possible options should first be studied well in the light of the three previously mentioned questions and considering the experiences of developed countries that faced the problem of sustainable transport much earlier. In each of these domains, both in theory and in practice, some countries have developed complex, more or less coherent programs from the technical, technological and economic points of view that provide a certain reduction of negative effects on the environment in acute situations.

4. CONCLUSION

For underdeveloped and developing countries faced with numerous problems on which their further course of development depends, the concept of sustainable development is a

major challenge. While acknowledging its necessity, especially in the domain of transport, such societies must act gradually since complex factors of the concept of "how and in what way" give way to the decisive "by which means" concept. The specific characteristics of individual Member States also impose additional difficulties for which the solution must be found in the regulatory framework, laws and documents that guide further development and protect the environment in accordance with proclaimed global trends. It should be borne in mind that developing countries are often among the countries in which the technical and technological equipment of the population has developed faster than the development of their consciousness and wisdom of the state to avoid the traps and the negative effects of such development.

The most important thing is to define sustainable transport with established goals based on the quality of the environment and the health of the population, as well as to adopt criteria by using international standards, goals, and guidelines, which at the same time meet the local, regional, and global requirements. Through consistent and balanced measures focused on vehicle technology, fuel, and infrastructure, on the one hand, and the shift in transport activities and management, on the other hand, it is possible to achieve the set goals. Meeting the goals requires coordinated cross-sectoral action, with the establishment of certain priorities.

Experiences from developed countries show that measures, such as the increase in fuel prices and the introduction of various fees and taxes for using private vehicles during peak periods of congestion in cities, do not significantly affect the quality of the environment [19]. There is a need to focus on important improvements in vehicle technology, better integration of public transport systems, better connectivity of transport planning and land use planning, better transport management strategies and strategies that emphasize the modal distribution of transport. Of course, it should be borne in mind that the implementation of the policy would also require appropriate regulations, establishing of simple, measurable indicators, ensuring sufficient financial resources and involving all levels of government in solving problems, with adequate awareness raising among the public.

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AUTHOR'S BIOGRAPHIES

Igor Jokanović

Born in 1969 in Belgrade. Graduated in 1993 from the Faculty of Civil Engineering in Belgrade, where he also received his master's degree in 2000. Received his doctorate in 2009 from the Faculty of Architecture and Civil Engineering in Banja Luka. He is employed at the Faculty of Civil Engineering in Subotica as an associate professor. He is a teacher at the undergraduate and master's studies at the Faculty of Civil Engineering in Subotica and Faculty of Architecture, Civil Engineering and Geodesy in Banja Luka in the field of planning, design, construction and maintenance of roads and railways. Areas of professional interest and work include planning and development of transport and transport networks, maintenance and management of transport infrastructure, protection and management of environmental and socio-economic aspects, application of geotechnics in the field of transport infrastructure, project management, institutional strengthening and procurement of works, goods, and services.

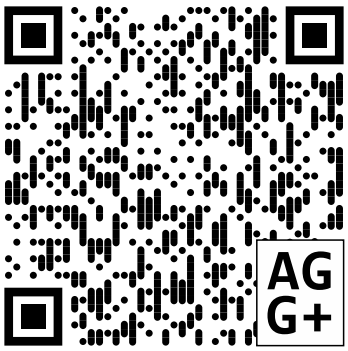
Milica Pavić

Born in 1996 in Valjevo. Graduated in 2019 from the Faculty of Civil Engineering in Subotica, where she also received her master's degree in 2020. Since 2020, she has been a student of doctoral studies at the Faculty of Civil Engineering in Subotica. Areas of professional interest and work include climate change, critical infrastructure, maintenance and management of transport infrastructure, protection and management of environmental and socio-economic aspects.

ЗАШТИТА ЖИВОТНЕ СРЕДИНЕ - ОДРЖИВИ РАЗВОЈ - САОБРАЋАЈ: ХРОНОЛОГИЈА ПРИСТУПА И ПОЛИТИЧКО-СТРАТЕШКИ ОКВИР

Сажетак: Како је потреба за кретањем, односно саобраћајем условила развој саобраћајних мрежа, управљање саобраћајном инфраструктуром у великој мери зависи од смерница односно политике развоја и управљања саобраћајем. Међутим, иако је у последњих педесетак година постојала забринутост везана за утицаје на животну средину, тек је почетком XXИ века утицај саобраћаја на животну средину адекватно вредновaн кроз формулисање саобраћајних политика. Значајна чињеница је да је на глобалној основи постигнута сагласност да су утицаји саобраћајница и саобраћаја на животну средину битни, али је далеко важније да политике заштите и унапређења животне средине не буду у сукобу са економском конкурентношћу, како би одговарајуће формулисана регулатива могла да доведе до проналазака и унапређења, што би резултирало добитном ситуацијом и код јавности и код произвођача, а нарочито у порасту кредибилитета надлежних институција и организација. У раду се, кроз хронолошки преглед трансформације приступа од базичне заштите животне средине ка одрживом развоју у глобалним и европским оквирима, указује на битне аспекте који морају бити обрађени приликом дефинисања политичко-стратешког оквира за управљање саобраћајном инфраструктуром и саобраћајем у неразвијеним и земљама у развоју са циљем испуњавања захтева за одрживи развој.

Кључне речи: *саобраћајна инфраструктура, саобраћај, одрживи развој, политика, интеграција*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Dragana Skorup
University of Banja Luka, Faculty of Architecture, Civil Engineering, and Geodesy, Bosnia and Herzegovina, dragana.skorup@aggf.unibl.org

Slavko Vasiljević
University of Banja Luka, Faculty of Architecture, Civil Engineering, and Geodesy, Bosnia and Herzegovina, slavko.vasiljevic@aggf.unibl.org

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* corresponding author

Dragana Skorup *

University of Banja Luka, Faculty of Architecture, Civil Engineering, and Geodesy, Bosnia and Herzegovina, dragana.skorup@aggf.unibl.org

Slavko Vasiljević

University of Banja Luka, Faculty of Architecture, Civil Engineering, and Geodesy, Bosnia and Herzegovina, slavko.vasiljevic@aggf.unibl.org

CORS NETWORKS, ASPECTS OF BUSINESS MODELS IN EUROPE AND THE REGION

ABSTRACT

The paper describes the functioning of CORS permanent networks in the world. Special attention has been paid to the EPN network and the regional CORS networks in Bosnia and Herzegovina, Serbia, Montenegro, and Croatia. BiHPOS: SRPOS and FBiHPOS, AGROS, CROPOS, and MONTEPOS were analyzed from the aspect of mutual data exchange with the aim of achieving better location accuracy and removing deficiencies in the network geometries. Due to their individual development, as well as mutually concluded agreements on data exchange, measurements obtained using GNSS today have a wide range of applications, such as maritime communication, aviation, engineering work, earth monitoring, and many more. Also, the points of the region included in the EPN network with the aim of exchanging data at the European level are shown.

Keywords: *GNSS, CORS networks, EPN*

1. INTRODUCTION

GNSS (Global Navigation Satellite Systems) are satellite-based systems that enable the calculation of the 3D position of any point on the earth's surface. The essence of the measurement is determining the distance based on the product of the time required for the GNSS signal to propagate from a satellite to the receiver and the speed of light. [1]. The most famous global navigation systems are the American GPS (Global Positioning System), the Russian GLONASS (GLObalnaya NAvigazionnaya Sputnikovaya Sistema), the European satellite navigation system Galileo, and the Chinese satellite navigation system BDS (BeiDou System).

GNSS technology has become indispensable in positioning, navigation, and timing, known in the literature as PNT (Positioning, Navigation, and Timing) in a wide range of military and civilian applications. Accordingly, GNSS is being supported by CORS (Continuously Operating Reference System), which is a common type of GNSS ground-based augmentation infrastructure used by governments to distribute centimeter-accurate PNT information worldwide [1].

The paper will focus on the basic concepts of CORS networks, the standards used for data exchange, as well as the models represented in Europe and the world. First, the operation of CORS networks on the European continent was examined, followed by an examination of networks in Europe and the region. Finally, the possibility of improving communication and data exchange was presented to provide more efficient, reliable, and cost-effective information.

2. CORS NETWORKS

A continuously operating reference system is the primary technique for establishing regional three-dimensional geodetic data. CORS networks, including global large-scale and regional small-scale networks, are used globally, owing primarily to the rapid development of satellite positioning technology, information technology, and network technology. The three-dimensional coordinate system is defined and extended by CORS and GPS networks [2].

Each CORS network consists of a series of GNSS stations interconnected by reliable communications to achieve real-time computations and controls. Each station requires, as a minimum, a receiver, an antenna, a communication device, and a power supply. In certain cases, additional equipment is installed for data transmission and control. Also, additional customer service is required for network configuration and maintenance, which can be carried out remotely using radio communication, mobile network, or internet connection. CORS networks are established for numerous reasons, but the accuracy of the final information depends on how the network is constructed. There is a difference between DGPS (Differential GPS), which uses code observations, and PDGPS (Precise DGPS), which uses carrier phase observations [3].

2.1. BASIC COMPONENTS OF CORS

CORS, as the three-dimensional control network datum, is the result of advanced new technologies such as satellite positioning technology, network computer technology, and so on. It consists of [2]:

- datum station network (network of reference stations);
- data processing center;
- data transmission system;
- data broadcasting system;
- user application system.

The reference stations are connected to the monitoring and analysis center through the data monitoring system, which again forms a special-purpose network.

The network of reference stations consists of a large number of evenly distributed reference stations that collect data from satellites, send them to the data processing center and provide a service for monitoring the integrity of the entire system.

As the system control center*, the data processing center* receives data from all reference stations, stores them, converts them, and calculates coordinates and corrections. Then the data files, saved in certain formats, are distributed to users. The control center is the core part of CORS and the key to realizing high-precision real-time dynamics positioning. The whole system is based on the principle of continuous observation of all reference stations in real time. The control center itself automatically generates a virtual reference station (including coordinates of reference stations and GPS observations) that corresponds to the mobile station and provides information to users (who require measurements and navigation with information on differential phase-carrier phase correction in a universal format) to be able to calculate the exact position of mobile stations in real time.

The data transmission system serves to transmit data from the reference stations to the analysis and monitoring center using fiber lines. The system consists of the following:

- hardware part - data transmission system and
- software control module.

The data broadcast system sends positioning and navigation data to users using mobile networks, UHF radio, the Internet, and so on.

The user application system consists of a system for receiving user information, a network-based RTK (Real-Time Kinematic) positioning system, a precision post-processing system, an autonomous navigation system, a positioning monitoring system, etc.

2.2. HISTORY OF THE ESTABLISHMENT OF THE CORS NETWORK

The history of CORS is related to NOAA's (National Oceanic and Atmospheric Administration) and NGS's (National Geodetic Survey) to define, maintain, and provide access to the NSRS (U.S. National Spatial Reference System). The concept of covering the US (United States) with a CORS network to improve NSRS was first introduced by Strange in 1994, and a year later, a preliminary description of the CORS system was published by Strange and Weston [4]. Along with them, many other organizations realized that they would receive great benefits in the future from the development of such a system. Some of them are US Coast Guard, US Army Corps, Federal Aviation Administration, US Geological Survey, and so on. Some countries have developed their navigation systems [1]:

- The United States of America – GPS;
- Russia - GLONASS;
- China – BDS;
- European Union - Galileo.

3. STANDARDS OF CORS NETWORK

Most GNSS receiver manufacturers are developing their data formats. They are mostly coded, binary formats that require the use of software/hardware supplied by the manufacturer and imply maximum system reliability in real time. Since CORS systems use different brands and types of receivers, the problem occurs with data interoperability. International formats are introduced to overcome this problem [5].

3.1. POST-PROCESSED DATA FORMATS

When archiving GNSS data, original formats are used to adapt the data to the internal application in terms of compatibility with applications and technologies for further processing. However, the internal formats do not allow software from other companies to process that data, so the general recommendation is to use the open standard RINEX (Receiver INdependent EXchange) [6].

The main advantage of the RINEX format is reflected in the possibility of its use for GNSS data independently of the equipment manufacturer. Also, the RINEX format can be used in a wide variety of post-processing software and analysis tools. There are currently several versions of the RINEX format used for GNSS data exchange, and the latest accepted version is RINEX v. 3.05. In the current version, easier and clearer reading is enabled, the addition of BDS signals and codes to fully support the second and third generation of BDS, as well as the addition of values in GLONASS navigation systems [7]. RINEX file specifications can be obtained from the IGS (International GNSS Service) website. IGS is an international GNSS service providing open access to high-quality GNSS data, products, and services to support the terrestrial reference frame, Earth observation, research data, PNT, and many applications that have played a major role in the development of science and society since 1994. It comprises over 200 self-financing agencies, universities, and research institutions in more than 100 countries [8].

3.2. REAL-TIME DATA FORMATS

The RTCM-SC104 (Radio Technical Commission for Maritime Service – Special Committee 104) data format is recommended for real-time GNSS services. RTCM has published global standards that enable the exchange of GNSS data [6]:

- RTCM 10402.3 RTCM Recommended Standards for Differential GNSS Service Version 2.3. A standard used to distribute real-time differential GNSS data from a single reference station directly to the user;
- RTCM 10403.1 Differential GNSS Services - Version 3 - Amendments 1, 2, and 3. Standards used for the distribution of real-time differential GNSS data that includes GNSS network corrections;
- RTCM 10410.1 Standard for NTRIP (Networked Transport of RTCM via Internet Protocol) is an application-level protocol that supports GNSS data sharing over the Internet. It is a generic protocol based on HTTP/1.1. (Hypertext Transfer Protocol). NTRIP is designed to have the ability to disseminate differential correction data and other information to GNSS stationary and mobile users over the Internet. Also, it enables wireless access to the Internet via Mobile IP networks such as GSM, GPRS, EDGE, or UMTS.

NTRIP is conceived as an open, non-proprietary protocol characterized by the following [9]:

- Based on the popular HTTP standard for streaming;
- Ability to share any type of GNSS data;
- Sharing a large amount of information simultaneously for thousands of users using modified Internet Radio broadcasting software;
- Independence of service providers and users;
- The possibility of sharing over any IP mobile network due to the use of TCP/IP.

4. DIFFERENT MODELS OF THE CORS NETWORK

CORS networks have been developed at local, national, and global levels for scientific and commercial purposes in various sectors. The operating model of CORS networks can be different between countries, starting with government organizations playing their role, and ending with the private sector or a network of private companies [10].

CORS systems have been developed by the government, the private sector, and academia. Local government agencies provide GNSS positioning information for a limited geographic area, such as a city. Regional transport departments aim to support research and mapping at the national or regional level. Federal geodetic organizations support the relative positioning and generation of data related to the entire country. Global interagency services enable the expansion of GNSS activities around the world. The private sector provides differential correction information to users who pay for these services [10].

The ICSM (Intergovernmental Committee on Survey and Mapping) has developed its CORS hierarchy based on Rizos's idea (2008) [6]:

- *Level 1 (Tier 1):* IGS, more precisely, international GNSS services that contribute to the development of the international terrestrial geodetic reference frame ITRF (International Terrestrial Reference Frame);
- *Level 2 (Tier 2):* national geodetic network or backbone of the national geospatial reference system and framework or datum;
- *Level 3 (Tier 3):* state or private GNSS networks which provide access to data realization through positioning services.

Rizos proposed a model for establishing CORS networks and services derived from them [11]:

- Institutional CORS infrastructure - without commercial services;
- State CORS infrastructure - manages commercial services;
- State CORS infrastructure - licenses data to the private sector;
- Corporate CORS infrastructure in private ownership - performs commercial services;
- CORS infrastructure in private ownership - performs commercial services.

Which of these models or combinations will prevail varies from country to country.

4.1. THE UNITED STATES OF AMERICA

No private or government service in the USA has built high-level, nationwide precise positioning services. The CORS network for the Federal Government and other infrastructure was set up by NGS within NOAA [1]. It was formed up of 137 GPS reference stations, including those from the NGS tracking network, the USCG (the United States Coast Guard) differential network, the WAAS (Wide Area Augmentation System) of the US FAA (US Federal Aviation Administration), and the tracking networks developed by the USACE (USA Corps of Engineers) [2].

The role of NGS is to provide a geodetic framework for all positioning of national importance. The agency coordinates with over 1800 multi-purpose CORS stations across the country (including Alaska) established by the government, researchers, or for private use and constitutes a new generation of the American national kinematic reference system. Each organization shares its data with the NGS, which analyses and monitors the data that is then published to users for processing. This system's stations are all fully equipped with dual-frequency GPS receivers and ground ring antenna. Every day they unload data and record them in RINEX format in intervals of 1s, 5s, 15s, and 30s. This system provides reference station coordinates and data from GPS satellite tracking stations to users worldwide via the Internet. Other services include coordinate system transformation and geoid determination. When observations at the endpoints last at least 4 hours, using the CORS relative positioning accuracy of the baseline endpoints of 26-300km, an accuracy of 1cm in the horizontal direction and 3.7cm in the vertical direction is achieved with a 95% confidence level [2].

Meanwhile, industry services have begun to connect positioning services such as SmartNet North America, which uses a licensing model to connect 600 CORS across the region, where data is licensed by the government and private CORS. Different suppliers can use the same CORS infrastructure to increase the consistency of providing PNT information thanks to the data licensing model [1].

4.2. EUROPE

The EPN (EUREF Permanent Network) is a network of continuously operating stations built by European countries and individual organizations (academic groups and universities). The EPN was established by the Sub-Commission of Europe for the Regional Reference Frame EUREF (Regional Reference Frame Sub - Commission for Europe) and the IAG (International Association of Geodesy) as a cooperative regional network with constant work [12]. EPN's current task is to maintain the European spatial regional reference framework. In addition to being a frame of reference, CORS in European countries such as Germany, Great Britain, and Switzerland still provides post-processing and precise positioning based on real-time differential and kinematic techniques.

The primary purpose of the EPN is to provide access to ETRS89 (European Terrestrial Reference System 89), which represents the standard GNSS coordinate system of the EU (European Union) [13].

The central EPN system managed by ROB (Royal Observatory of Belgium) performs the daily connection and acts as a link between the reference stations, the data, the analysis center, and users, and also maintains the EPN information system.

RINEX data from EPN stations are available via FTP (File Transfer Protocol) from two regional centers positioned in Germany and Austria and one historical center managed by ROB. Real-time EPN data is obtained from three regional NTRIP transmitters located at the Italian space agency, the German BKG (Bundesamt für Kartographie und Geodäsie), and the ROB.

INSPIRE (INfrastructure for Spatial InfoRmation in Europe) is a directive that sets the rules for the establishment of a spatial data infrastructure in the EU. The implementation rules explain how the various components of the infrastructure work. Metadata, data interoperability, service network, and data sharing are covered in the Implementing Rules. The INSPIRE directive requires that member states exchange data between themselves and the EU institutions, as stated in the implementation rules "Data sharing" [14].

4.2.1. The United Kingdom

The CORS network in the United Kingdom is controlled by a single organization. The National Mapping Authority, represented by the Ordnance Survey, is in charge of managing the national geospatial reference system as well as producing, maintaining, and distributing geospatial data [15]. It has partnered with a few commercial information providers, including Leica Geosystems, SmartNet (UK and Ireland), Trimble's VRS Now, Topcon Positioning System's TopNetPlus, AXIO-FarmRTK, NET's, and Soil Essential's Essentials Net, to offer positioning services in addition to managing over 100 CORS stations for their OSnet service. OS Net, a raw data distributor, is licensed by Ordnance Survey [1].

4.2.2. Sweden

Sweden was among the first European countries to use GPS for navigation, research, and mapping. Lantmateriet, the Swedish authority in charge of mapping, cadastre, and land registry, manages the national CORS network known as SWEPOS and is responsible for geodata coordination throughout the country. The Swedish reference networks, as well as national development, research, and support, are managed by the department of geodesy at Lantmateriet. The control center has access to GNSS data in real time from around 300 stations spread across the nation [1].

4.2.3. Germany

The satellite positioning service SAPOS (der SAtellitenPOSitionierungsdienst) of the German Surveying and Mapping Authority is responsible for the realization of a network of about 270 CORS stations. CORS is owned by the state. SAPOS is a joint project of the Working Committee of the German Geodetic Administration and the authorities of the Federal Republic of Germany, AdV (Arbeitsgemeinschaft der Vermessungsverwaltungen der Länder der Bundesrepublik Deutschland). It has a fee-based commercial business model and offers consumers three positioning services. With the proper licenses, industry services nationwide can access SAPOS data [1].

5. CASE STUDY IN EUROPE AND THE REGION

In Europe, there are thousands of CORS stations whose data are used for high precision in various applications ranging from reference frame maintenance, monitoring of tectonic deformations and sea-level variations, long-term climate monitoring, weather prediction, space weather, and so on [16].

The EPN was created in 1995 and was a European attempt to coordinate the exchange of GNSS CORS data and metadata. Today, it consists of more than 300 participating stations that follow the EUREF guidelines and whose data and metadata are coordinated by the EUREF station. EUREF also took the initiative to coordinate and analyze data of the EPN Dens. (EPN densification), with 1800 GNSS stations for which metadata is collected and analyzed. In addition to EUREF, there is also E-GVAP (EUMETNET EIG GNSS water VApour Program), which collects and distributes GNSS tropospheric delays and water vapor data from more than 3500 GNSS stations worldwide, but most of which (3000) are located in Europe [16].

Also, Europe is currently building the EPOS (European Plate Observing System), which aims to support Earth science based on 800 GNSS stations. The layout of the European analytical centers, showing the systems for which data is collected, is shown in Figure 1.

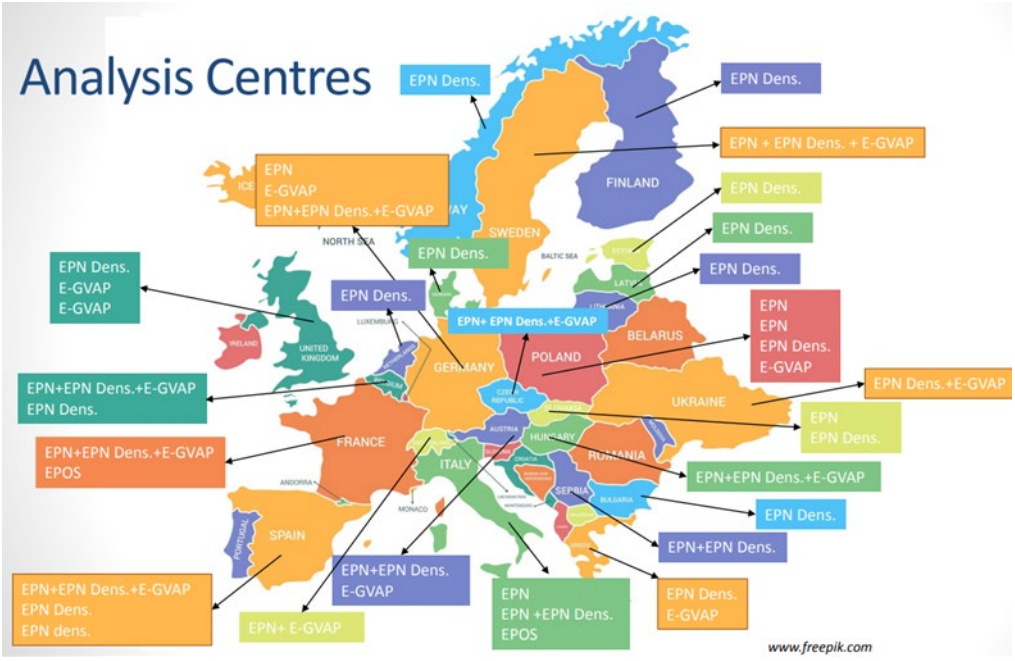

Figure 1. Analysis centers in Europe [16].

The EPN monitoring network has grown significantly from the initial 35 continuously operating stations in 1996 to the 330 multi-GNSS reference stations today. Figure 2 shows the stations of the EPN network. All stations deliver daily data, while 55% deliver data in real time.

83 European agencies work on the EPN monitoring network, based on data from 2019. Of these, 33% are universities, 28% are research-space agencies, 36% are mapping agencies, and several private companies [12].

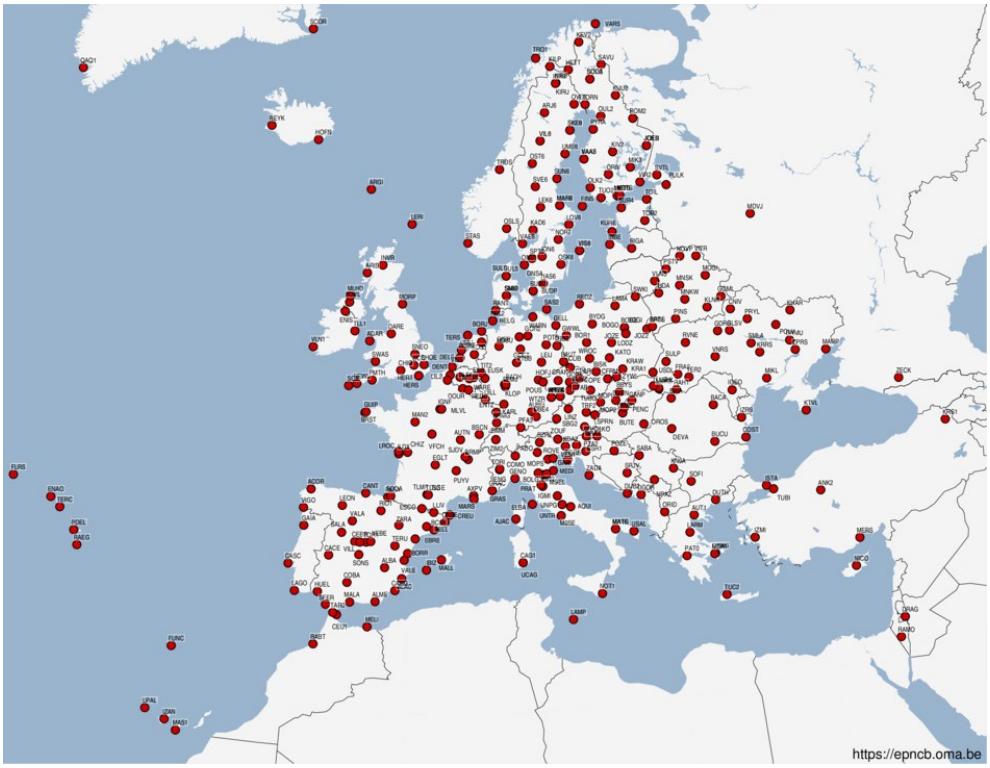

Figure 2. The stations of the EPN network [7].

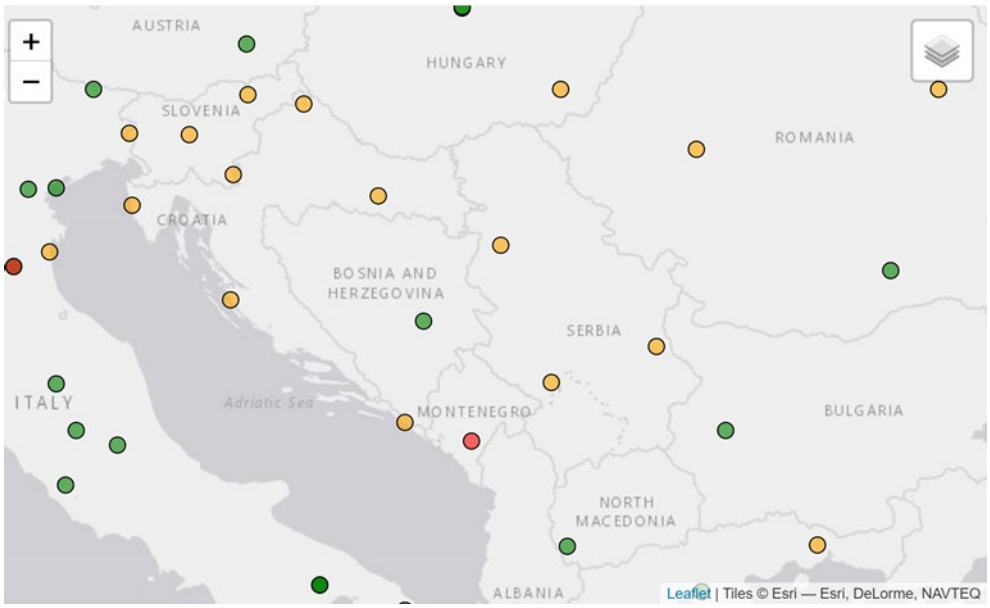

Figure 3. The position of CORS stations in the region which are included in the EUREF network [7].

The position of CORS permanent stations included in the EUREF network is shown in Figure 3. Green-marked stations provide daily, hourly and real-time data, the orange ones only provide daily and hourly data, while red-marked stations provide only daily data.

Table 1. *List of stations in the region that are included in EPN with their specifications [7].*

COUNTRY		Bosnia and Herzegovina	SERBIA	CROATIA	MONTENEGRO
NUMBER OF STATIONS		1	3	5	1
NAME OF STATION		SRJV00BIH	KNJA00SRB (Knjaževac, SRB) NPAZ00SRB (Novi Pazar, SRB) SABA00SRB (Šabac, SRB)	POZE00HRV (Požega, HRV) CAKO00HRV (Čakovec, HRV) PORE00HRV (Poreč, HRV) ZADA00HRV (Zadar, HRV) DUB200HRV (Dubrovnik, HRV)	DGOR00MNE (Podgorica, MNE)
SPECIFICATIONS	RECEIVER TYPE	LEICA GR30	All stations: TRIMBLE NETR9	All stations: TRIMBLE ALLOY	COMNAV M300 MINI
	SATELLITE SYSTEM	GPS+GLONASS+GALILEO+BDS	GPS+GLONASS+GALILEO+BDS GPS+GLONASS+GALILEO+BDS GPS+GLONASS	GPS+GLONASS+GALILEO+BDS+QZSS[1]	GPS+GLONASS+GALILEO+BDS
	ANTENNA	LEIAR25.R4 LEIT	TRM41249.00 TZGD TRM115000.00 TZGD TRM55971.00 TZGD	TRM115000.00	CNTAT350
	DATA PROVIDED	Daily, hourly and real-time data	Only daily data	Only daily and hourly data	Only daily data
	DATE ROUTINELY ANALYSED BY	ASI[2], BEK[3], BEV[4], RGA[5], UPA[6].	ASI, BEV, RGA, UPA. BEV, RGA, SGO[7], SUT[8], WUT[9]. BEV, RGA, SGO, SUT, UPA	ASI, BEV, MUT[10], SGO, WUT. ASI, BEV, MUT, SGO, UPA. ASI, BEV, MUT, SGO, WUT. ASI, BKG, MUT, SGO, SUT. ASI, BKG, SGO, SUT, UPA.	ASI, BEV, RGA, UPA.
	INCLUDED IN EPN	28. 11. 1999.	27. 9. 2015 21. 6. 2015. 21. 6. 2015.	16. 6. 2013.	15. 12. 2019.

CORS in Bosnia and Herzegovina and countries in the region will be described below.

The first EUREF campaign in the Balkans, called "Balkan98", was realised in 1998 to include the Balkan countries in EUREF. The participating countries were the Federal Republic of Yugoslavia, Bosnia and Herzegovina, and Albania. The BIHREF 98 GPS campaign was organized and implemented on the territory of Bosnia and Herzegovina as part of the EUREF 98 GPS campaign. With this campaign, Bosnia and Herzegovina joined EUREF with Albania and Yugoslavia [17]. As part of the project, 29 new permanent stations are planned.

1 QZSS (Quasi-Zenith Satellite System).
2 Centro di Geodesia Spaziale G. Colombo, Matera.
3 Kommission für Erdmessung und Glaziologie (Bayerische Akademie der Wissenschaften), Munich.
4 Federal Office of Metrology and Surveying Austria.
5 Republic Geodetic Authority, Serbia.
6 University of Padova, Padova.
7 FOMI Satellite Geodetic Observatory, Budapest.
8 Slovak University of Technology, Bratislava.
9 Warsaw University of Technology, Warsaw.
10 Military University of Technology, Poland.

The second EUREF campaign started in 2010 and had the following objectives [18]:

- Densification of points in the Republic of Serbia and Macedonia;
- Control over the existing reference system;
- Integration of the Republic of Serbia into European geodetic activities.

5.1. BIHPOS: SRPOS AND FBIHPOS

The network of permanent GNSS stations in the Republic of Srpska SRPOS was implemented in the "BiHPOS" Project. The initial position of BiHPOS network points is shown in Figure 4. The project was a joint venture of institutions in Bosnia and Herzegovina and was supported by the European Commission. The main goal of the Project is the integration of two systems of SRPOS permanent stations for the territory of the RS (Republic of Srpska), which is under the jurisdiction of the Republic Administration for Geodetic and Property Affairs, RUGIPP (Republička Uprava za Geodetske i Imovinsko-Pravne Poslove) and FBiHPOS for the territory of the FBiH (Federation of Bosnia and Herzegovina), which is under the jurisdiction of the Federal Administration for Geodetic and Property Affairs, FGU (Federalna Geodetska Uprava). With their synchronization, the entire territory of Bosnia and Herzegovina is covered with satellite positioning [19].

The initial constellations of the SRPOS system are:

- 17 permanent GNSS stations;
- control center in Banja Luka;
- jurisdiction (Administrator and owner) – RUGIPP.

The FBiHPOS network was initially characterised by the following:

- 17 permanent GNSS stations;
- a control center in Sarajevo;
- jurisdiction Administrator - FGU.

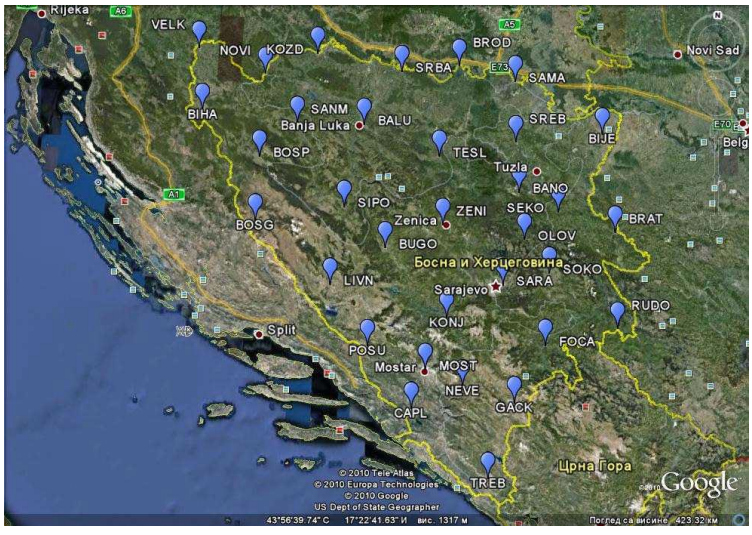

Figure 4. The position of the BiHPOS network [20].

Today, the **SRPOS** network consists of 22 permanently operational reference GNSS stations (Figure 5) at an average distance of 50 km to 70 km. SRPOS is under the jurisdiction of

RUGIPP. The network was expanded with five additional stations compared to the initial state. Mutual data exchange is carried out to provide adequate geometry for both networks, so SRPOS uses the data of additional eight FBiHPOS stations. Data is exchanged with the networks of permanent stations in Croatia, Serbia, and Montenegro - CROPOS, AGROS, and MontePOS – in order to connect the BiHPOS network with the EPN and to improve service coverage in border areas [21].

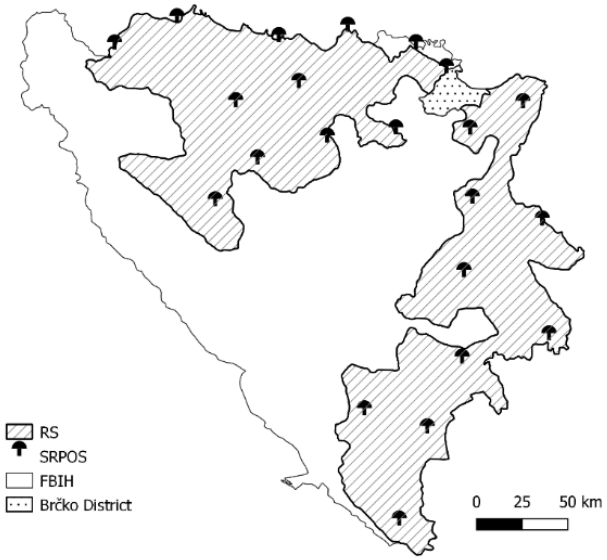

Figure 5. The position of the SRPOS points [21].

The **FBiHPOS** network was expanded with two additional permanent stations and is characterized by the following [22]:

- 19 permanent GNSS stations;
- Permanent GNSS stations are located in an urban environment to facilitate access, management, and security;
- The stations are located near the state border to achieve the level of autonomous functioning, assuming that the full operability of the network enables functioning up to 20 km outside the network polygon;
- 12 stations from the Republic of Srpska and three from the neighboring Republic of Croatia are included in the permanent network to optimize the geometric shape.

In Sarajevo, there is only one CORS permanent station (Figure 6) included in the EPN.

Figure 6. CORS station in Sarajevo [7].

5.2. CROPOS

The Croatian positioning system, CROPOS, was launched on 9 December 2008 by the State Geodetic Administration. During the following period, maintenance, development, and upgrading of the CROPOS system were carried out to ensure work reliability and also to improve existing services. Based on signed agreements, with the aim of better coverage of the border area, as well as preventing loss of reliability in case of interruption of operation of individual reference stations, the Republic of Croatia exchanges data with the Republic of Slovenia, Hungary, the Republic of Montenegro and Bosnia and Herzegovina. Fifty-one reference stations are included in this networked solution and the calculation of correction parameters [23].

The system developed at high speed, so from the day it was put into use until 2018, the availability of the system increased by 99.9%. The number of registered users is also continuously growing, so by 2018, as many as 869 companies with a total of 1293 user names were registered using the VPPS (High Precision Positioning Service), more precisely, the application of the GNSS RTK measurement method in real-time.

During the system establishment, 30 reference GNSS stations were installed, evenly distributed throughout the country at a distance of 70 km from each other. Subsequently, three more reference stations (Nova Gradiška, Hvar, and Dubrovnik) were established to congest the network. The layout of CROPOS network points is shown in Figure 7.

In 2011, the State Geodetic Administration proposed five CROPOS stations for inclusion in the EPN. After a period of control and data analysis, all five stations were successfully included in EPN in June 2013. The stations included are: CAKO (Čakovec), DUB2 (Dubrovnik), PORE (Poreč), POZE (Požega) and ZADA (Zadar).

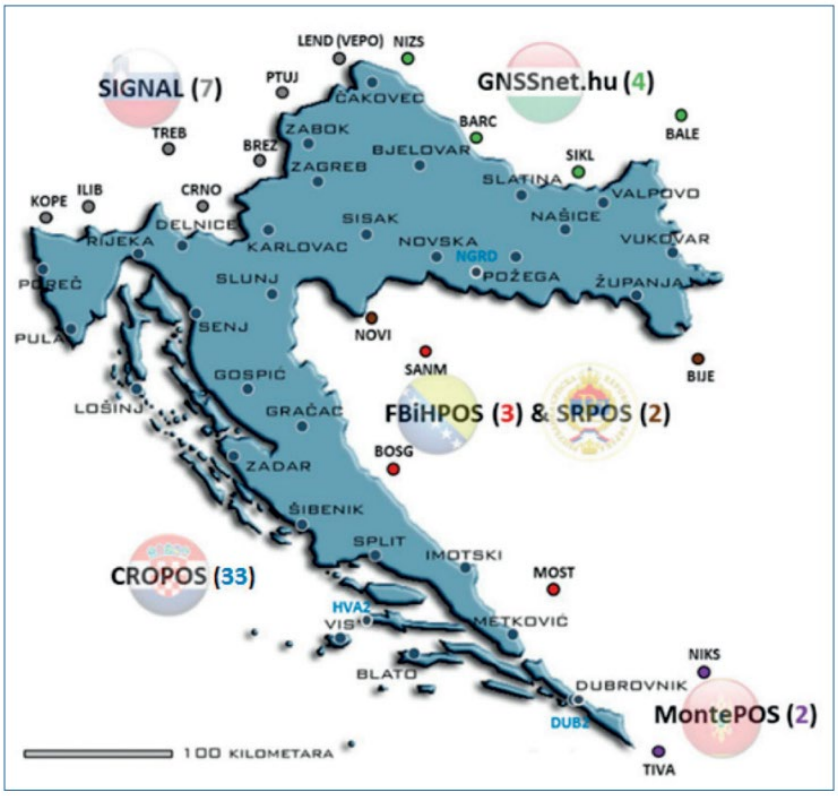

Figure 7. The position of the CROPOS points [23].

5.3. AGROS

In 2001 the network of permanent stations was proposed by the Republic Geodetic Authority in Serbia. The network was established in December 2005 as part of the EUPOS (EUropean Position Determination System) program. The EUPOS was organised by the Berlin Senate Department for Urban Development, which is supported by the European Academy of the Urban Environment. AGROS consists of 30 stations, one control center in Novi Sad, and fully established RTK and DGNSS services, both based on the VRS (Virtual Reference Station) concept. Permanent stations are installed at the buildings of local Real Estate Cadastre offices. AGROS currently consists of 29 permanent GNSS stations (Figure 8) equipped with Trimble receivers. Three AGROS stations (Šabac, Novi Pazar, and Knjaževac) have been included in the EPN since 2015 [18].

Figure 8. The position of the AGROS points [18].

5.4. MONTEPOS

MontePos is composed of nine continuously operating stations and is part of the state infrastructure implemented by the Real Estate Administration in 2005 as the patronizing institution for the field of geodesy in Montenegro.

Network-RTK is a centimeter-accurate, phase-based, real-time positioning technique that can operate at distances of several tens of kilometers while using the nearest station method to provide corrections to ground receivers, but without the ability to receive Galileo and BDS. Nine continuously operating MontePOS permanent stations are relatively regularly distributed throughout the entire territory of Montenegro, at an average distance of about 70 km (Figure 9).

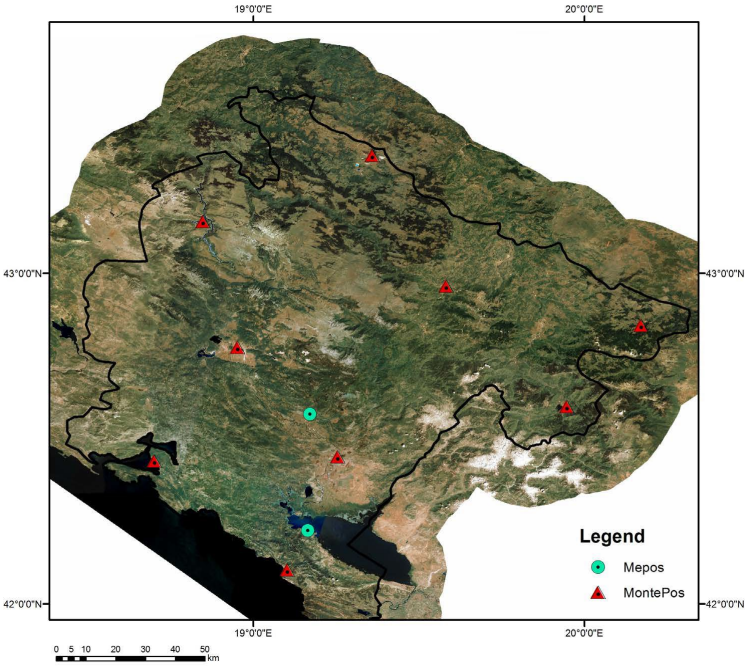

Figure 9. The position of the MontePOS points [24].

At the beginning of 2019, the implementation of the MontePN project was started by the Ministry of Science of Montenegro. It aimed to establish a permanent station network infrastructure, with the possibility of receiving GPS, GLONASS, Galileo, and BDS signals. According to the recommendations for the densification of the EUREF network and the given guidelines for connecting GNSS permanent station networks in the EPN, the establishment of the MontePN network (Figure 10) was realized by the tendency to join the EPN [24].

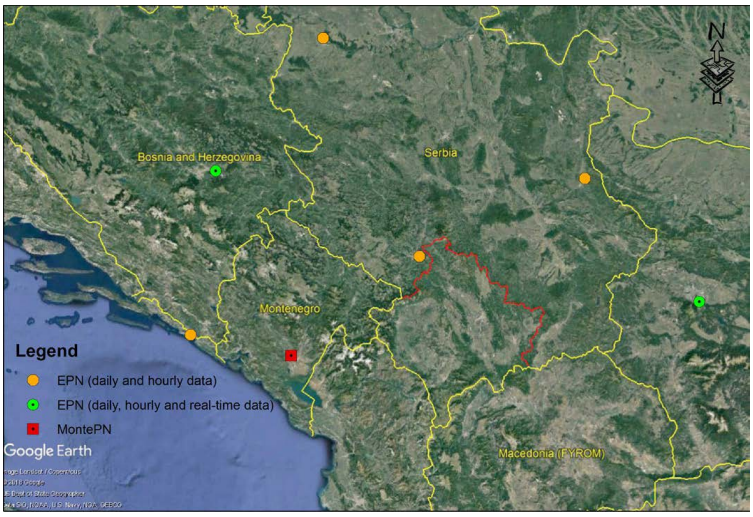

Figure 10. The position of the permanent station of the MontePN network [24].

Montenegro has not yet been included with any MontePOS station within the EPN network. The accession of the MontePN point will significantly contribute to the effort of Montenegro through the improvement of the existing legal regulations related to the field of geodesy, to work towards the adoption of ETRS as the official coordinate system in Montenegro, and the recommendations of EUREF [24].

6. LEGAL REGULATIONS IN THE REGION

Quality legislation can influence the implementation and establishment of a network of permanent GNSS stations. The following regulations regulate this area into a region:

- Regulation on the application of satellite measurements in geodesy - Federation of Bosnia and Herzegovina;
- Regulation on establishing a network of GNSS permanent stations - Republic of Serbia;
- Regulation on the application of global navigation satellite system technology in the fields of survey and cadastre - Republic of Serbia;
- Regulation on the method of performing basic geodetic works - Republic of Croatia;
- Regulation on cadastral survey of Republika Srpska - Republika Srpska.

In the RS, there are no law regulations in this area. However, basic guidelines of the GNSS surveying method for the cadastre needs are given as part of the Regulation on the cadastral survey of the Republic of Srpska [25]. Also, there is an Instruction for the application of the Global Positioning System method for determining detail points [26], as well as a brochure for using the SRPOS network of permanent stations [19].

In the FBiH, the Regulation on the application of satellite measurements in geodesy is in force [27]. This regulation determines the geodetic works during real estate surveys that can be realized using GNSS methods, as well as the methodology, accuracy, and calculation procedures used on that occasion. Also, the Rulebook describes the BiHPOS state network of reference GNSS stations of Bosnia and Herzegovina, as well as the transformation of WGS84/ETRS89 coordinates into the state coordinate system.

In the Republic of Croatia, this area is defined by the Regulation of the method of performing basic geodetic works [28]. The CROPOS network is described in Section 1 of this Regulation, and the method of using the CROPOS network and GNSS measurement methods are explained in more detail in the Annex to the regulation on geodetic studies.

In the Republic of Serbia, there is a Regulation on the establishment of a network of GNSS permanent stations [29] and a Regulation on the application of global navigation satellite system technology in the fields of state survey and cadastre [30]. The Regulation on the establishment of a network of GNSS permanent stations regulates the manner and conditions under which networks of permanent stations using GNSS technology are established on the part of the entire territory of the Republic of Serbia.

7. CONCLUSIONS

Today, CORS networks are used worldwide for scientific and commercial needs in various application sectors. Data should be made available with minimal restrictions to optimize the benefits of these networks. Also, it is important for users to contribute to the system by

sharing data to improve the application system. By sharing information and using international standards, redundancies are reduced, and the scope of use is expanded.

The paper describes the CORS network in Europe and the region, as well as how the current infrastructure was perceived, in order to identify potential areas for progress and collaboration in data exchange. It was concluded that in order to achieve complete transparency, it would be necessary to resolve the so-called "gray" zone between public and private GNSS users. With an open exchange model, the advantage of GNSS can be optimized, resulting in continued government support for the GNSS program and development.

By analysing the experience and structure of CORS networks in Europe, the subject of further research could be the examination of the optimality of local CORS networks from the point of densification of existing ones, the quality of PNT services at each spatial point, and the need for modernization of existing stations from the aspect of signal reception from new global satellite systems, application of modern algorithms and equipment for eliminating sources of errors.

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AUTHOR'S BIOGRAPHIES

Dragana Skorup

Dragana Skorup was born on 20 September 1992 in Nevesinje. She completed undergraduate studies in 2015 at the Faculty of Architecture, Civil Engineering and Geodesy, University of Banja Luka. In the same year, she enrolled in master's studies at the Faculty of Technical Sciences, University of Novi Sad, study programme of Geodesy and Geomatics, which she completed in 2016. She is a PhD candidate at the Faculty of Technical Sciences, University of Novi Sad.

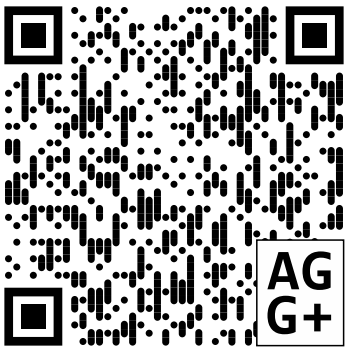
Slavko Vasiljević

Born in 1989 in Zagreb. He graduated in 2012 from the Department of Geodesy, Faculty of Architecture, Civil Engineering and Geodesy with a GPA of 10.00. He was awarded the Golden plaque from the University of Banja Luka as the best student of the FACEG. He earned his master's degree in 2015 from the Department of Geodesy and Geoinformatics, Faculty of Civil Engineering, University of Belgrade, with a 10.00 GPA. He is currently working on his doctoral thesis at the Faculty of Civil Engineering, University of Belgrade. His research focuses on engineering geodesy and deformation analysis of engineering structures.

CORS МРЕЖЕ, АСПЕКТИ ПОСЛОВАЊА У ЕВРОПИ И РЕГИОНУ

Сажетак: У раду је приказан начин функционисања CORS перманентних мрежа у свијету. Посебна пажња дата је EPN мрежи, као и регионалним CORS мрежама у Босни и Херцеговини, Србији, Црној Гори и Хрватској. BiHPOS: SRPOS и FBiHPOS, AGROS, CROPOS и MONTEPOS анализиране су са аспекта међусобне размјене података с циљем постизања боље прецизности локација и уклањања недостатака у геометријама мрежа. Њиховим појединачним развојем, као и међусобно склопљеним споразумима о размјени података, мјерења добијена помоћу GNSS данас имају широку примјену, почевши од морског саобраћаја, авијације, па до инжењерских послова, праћења земље и слично. Такође, приказане су тачке региона које су укључене у EPN мрежу с циљем размјене података на европском нивоу.

Кључне ријечи: *GNSS, CORS перманентне мреже, EPN*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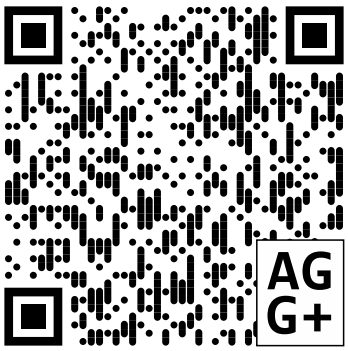
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