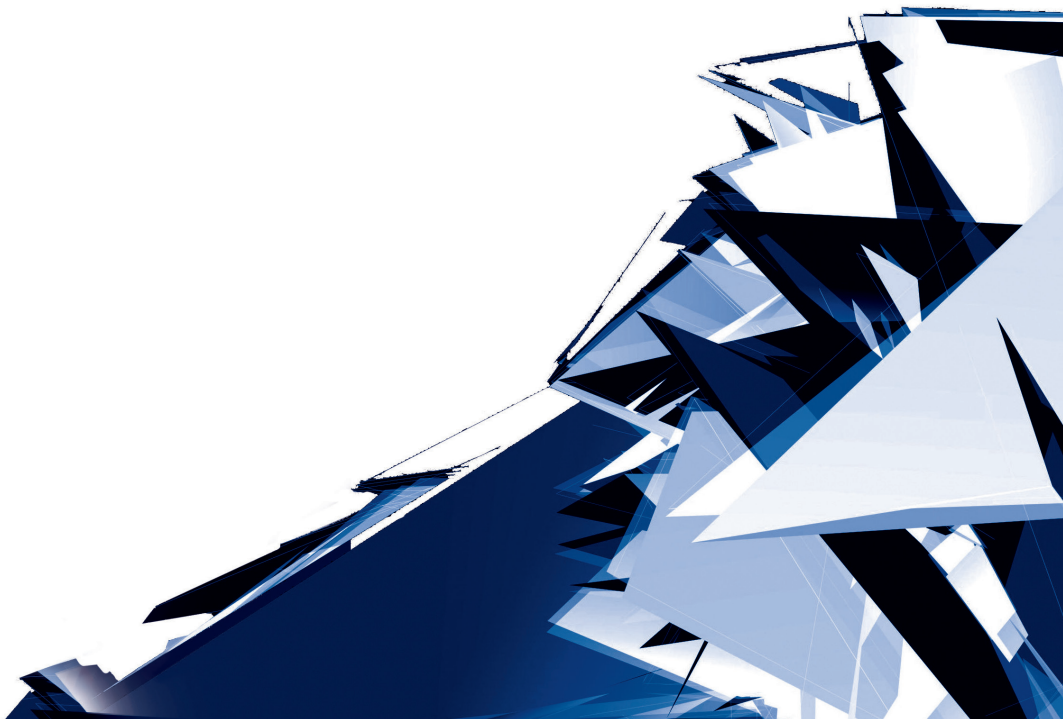
# Technical Transactions

## Czasopismo Techniczne

Issue 6
Volume 2019 (116)



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Pierwotną wersją każdego zeszytu Czasopisma Technicznego jest jego wersja online

ISSN 0011-4561
eISSN 2353-737X

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ARCHITECTURE AND URBAN PLANNING
DOI: 10.4467/2353737XCT.19.057.10610
SUBMISSION OF THE FINAL VERSION: 7/06/2019

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# Common places – analysis of spatial structures conducive to their functioning

# Miejsca wspólne – analiza struktury przestrzennej sprzyjającej ich funkcjonowaniu

**Abstract**

The safety and comfort of the housing environment concerns both its functional, spatial and social structure. Current tendencies in the design of housing areas typically do not take the latter factor into account. Based on an analysis of the spatial structure of European housing areas, an attempt was made to determine a number of the principles of shaping space that beneficially affect the formation of informal social relationships. The research method was based on a case study of three housing areas and their spatial structure, in reference to the principles concerning the shaping of social spaces inside housing areas as described in co-housing schemes proposed by (Durrett and McCamant).

**Keywords:** spatial structure, public space, common places

**Streszczenie**

Bezpieczeństwo i komfort środowiska mieszkaniowego dotyczy zarówno jego struktury funkcjonalnej, przestrzennej, jak i społecznej. Obecnie tendencje w projektowaniu obszarów mieszkaniowych zazwyczaj nie uwzględniają ostatniego czynnika. Na podstawie analizy struktury przestrzennej europejskich obszarów mieszkaniowych podjęto próbę odnalezienia kilku zasad kształtowania przestrzeni, które w sposób korzystny wpływają na zawiązywanie nieformalnych relacji społecznych. Metoda badawcza obejmowana studium przypadku trzech obszarów mieszkaniowych oraz ich struktury przestrzennej, w odniesieniu do opisywanych przez twórców koncepcji co-cousingu (Durretta oraz McCamant) zasad dotyczących kształtowania przestrzeni społecznych wewnątrz obszarów zamieszkania.

**Słowa kluczowe:** struktura przestrzenna, przestrzeń publiczna, miejsca wspólne

## 1. INTRODUCTION

At present, technological progress appears to be, among other things, the cause of the weakening and even the disappearance of neighbourly ties. Global transformations that have taken place over the course of the past decade affect social relationships. Uneven spatial development and the dynamic transformation of the urban and social structure cause an increase in reported feelings of being at risk and of unpredictability. These problems primarily affect city residents, while maintaining a sense of community appears to be a very difficult task. The home and the housing environment along with it are becoming an increasingly significant factor in forming one's identity under these circumstances, becoming a sphere that is free from socio-economic uncertainty [3, p. 90]. The words of the sociologist S. Ossowski, who mentioned the matter of "...a social bond that is of particular interest to the urbanist – neighbourly ties. They are about social connectivity formed on the basis of spatial connectivity", remain topical [9, p. 364]. "...The shape of a housing estate itself can fulfil a significant social function; the shape of a housing estate can suggest to us a feeling of connectedness, it can suggest the 'shape' of a social group" [9, p. 348].

The fact that neighbourly relationships carry with them numerous benefits, such as a feeling of security or identification with one's place of residence, giving aid in crisis situations, the lack of conflict associated with everyday functioning or the variety of habits, remains significant [11, p. 157].

The increase in the pace of life as well as the pressure concerning quicker functioning while working longer and more intensely leads to an increase in the difficulty or even the lack of the possibility of tending to personal or family needs. Hence the necessity to consider spaces that make it possible to both form social ties and to relax or participate in recreation while having contact with greenery even during the design stage.

The element of contact with nature is a very important factor when these issues are considered. It has found confirmation in studies by F. Ming Kuo and W. Sullivan [8, p. 826], who – when observing Chicago's housing areas – observed that the presence of greenery in the spaces between residential buildings affects their use. These studies suggest that the formation of neighbourly social ties (called NST hereon in the text) significantly depends on informal social contact that can be made in a neighbourhood. Common spaces in downtown areas are often a "barren no-man's land", while the presence of trees and grass aids in the use of these commonly accessible spaces and facilitates informal social contact between neighbours.

Attractive, well-used neighbourhood spaces and common spaces in city centres can provide significant benefits to both residents and other users. Eco-friendlier green public and semi-public spaces encourage people to go outside, increasing the possibility of the forming of ties in the form of social gatherings and support the development of NST. As a result, the significant amount of work towards the development and spread of ecology can be very helpful in uniting entire social groups in their areas of residence. To people who reside in poor inner city districts and who face a series of difficult life circumstances, greener neighbourhood common spaces can make their place of residence a friendlier place [8].

The housing areas discussed in the article: Ecolonia in Alphen aan den Rijn, Tinggarden in Herfloge and Bo01 in Malmö, are examples of architecture that includes the creation of a common space that is conducive to the formation of NST and is characterised by sustainable construction solutions, as well as a high dose of greenery within the place of residence. The selection criteria for the abovementioned cases encompass "living" social spaces, which, despite differences in size and the time in which they were completed, function in a manner that satisfies the needs of residents and users.

## 2. THE SPATIAL STRUCTURE OF COMMON SPACES

### 2.1. Tinggarden, Herfloge in Denmark

We can distinguish numerous forms of initiating informal contact and forming neighbourhood communities. One of these forms is creating a common spatial structure that can facilitate interactions between residents. Tinggarden is an example of a co-housing complex, which is discussed here not because of the ideology behind co-housing, but because of a certain model of spatial structure that has formed thanks to this concept.

'Community housing' is a term that was coined by American architects – Charles Durrett and Kathryn McCamant [2]. It denotes a housing complex whose construction is completely dependent on the initiative of its future residents. With aid from specialists, they design their housing complexes, in which a considerable portion of space is taken up by common places. "Common space itself makes more intense community life possible by organising meetings, creating various types of projects and building a secure space free from vehicular traffic, encouraging spontaneous interaction and building a sense of community" [12, p. 13]. The sense of community is upheld by organising resident meetings and discussing current problems or events, said meetings typically taking place in the Common House, providing a sense of having an actual impact on the shape and organisation of social life in one's place of residence.

The authors, based on the example of the housing area discussed in the article, wanted to take an in-depth look at the spatial structure itself, based on schemes that repeat themselves in numerous housing complexes (including those that do not fit with the idea of co-housing).

From the point of view of the formation of NST, it is important to discuss the notion of the *soft edge*, which is the point of contact between the building and the city/public space in housing areas and their impact on the life of residents. This space is absolutly essential, as it becomes the zone of exchange between the private and public sphere – "here activities are transferred from the domain of the apartment onto the terrace or front yard – they come into contact with public space" [4, p. 82].

In housing areas where a common space was designed intentionally, the role of the soft edge is fulfilled by patios and verandas. They belong to the homes, but are nevertheless located on the border between the private and public sphere [7, p. 20], "coming into contact" with the latter, which is why they can be called the semi-public, or semi-common sphere.

The layout of buildings themselves can encourage spontaneous participation of residents in the social life of the group. The subject of the proper placement of buildings within the interior of a housing complex so that it will facilitate the formation of NST, while their schemes were featured in Durrett's and McCamant's book [2]. Based on these examples, the following layouts can be distinguished:

a) Pedestrian street (Fig. 1.1)
   It is a small walking street or streets inside the housing complex, usually with a prohibition on vehicular traffic, and which features houses on both sides.
b) Courtyard (Fig. 1.2)
   This is a space that features a centrally-placed square, surrounded by houses, forming a courtyard.
c) Combination of street and courtyard (Fig. 1.3)
   This is a combination of the scheme with the street/streets and the courtyard, where, as in the case of the first scheme, houses are located along main streets that come together at a centrally-placed courtyard/square.

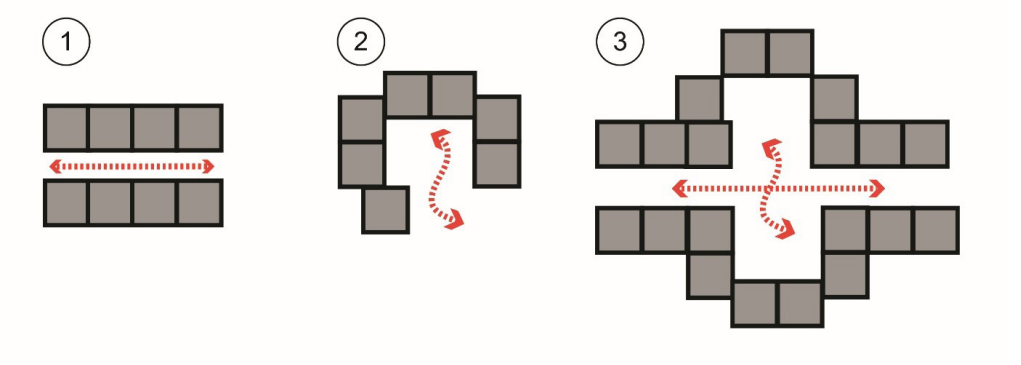


Fig. 1. 1 – pedestrian street, 2 – courtyard, 3 – combination of a street and courtyard (work based on Durrett and McCammant, author: M. Bednarz)

In the case of Tinggarden, we can observe a mixed layout, where from a pedestrian path in the form of a main street we can reach squares surrounded by houses. Six groups composed of 12–15 houses were placed in the area. A Common House (Fig. 3) was placed at the centre of each group, forming a place meant to integrate residents in co-housing complexes, and is also meant for use by residents of neighbouring areas. When discussing Tinggarden, it should be noted that it is the first co-housing complex subsidised by the Danish government. Thanks to government aid, the dwellings could be either bought or rented, which enabled adaptation to the financial capabilities of residents. It is one of the model examples of a co-housing complex, where vehicular traffic was "banished" outside, although there is a possibility of getting in the vicinity of one's apartment if there is a need to do so. Parking spaces are located all over the complex-; however, they were planned in areas that do not break up the continuity of internal pedestrian paths.

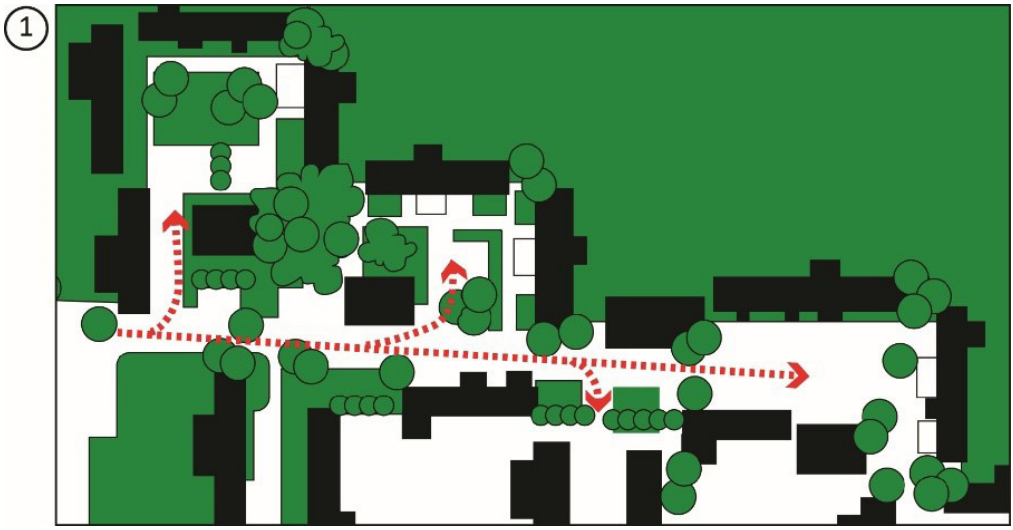


Fig. 2. Spatial structure – combination of street and courtyard, Tinngarden – Herfloge (by M. Bednarz)

Fig. 3. Tinggarden, Herfloge; Common House area (by M. Bednarz)

## 2.2. Ecolonia, Alphen aan den Rijn in the Netherlands.

Lucien Kroll is a Belgian architect who favoured the idea of promoting design along with residents. He was one of the pioneers of the social participation movement. The most well-known and controversial of Kroll's projects is the student dormitory of the Louvain University [5]. Prior to drawing the building's floor plans and cross-sections, the architect conducted discussions and workshops with future users – students. The building was designed by the students themselves while he was the animator of their actions. In his projects, Kroll referred to the model of open architecture[1] that adapted itself to society. He strongly emphasised that the architect's role is to be the "tool" in the creation of architecture by its users themselves.

Ecolonia was built in 1991 in Alphen aan den Rijn, a Dutch town located between larger urban centres like Amsterdam, the Hague, Rotterdam and Utrecht, and is an area called the "green heart of the Netherlands". The project was supported by the Dutch Housing Ministry, the Ministry of the Economy and the Ministry of Spatial Planning. It featured over a hundred semi-collective housing units. Their construction took place as a part of city development plans to expand housing units.

Fig. 4. Ecolonia, Alphen ann den Rijn; Bridges above mini channels in front of the houses (by M. Bednarz)

[1] "open architecture" – designing in a manner so as to fluidly connect what is outside the building with what is inside, while maintaining contact with nature and greenery. F.K. Wright was the pioneer of this type of design, and who developed his ideas while drawing inspiration from Japanese art, architecture and construction (author's note).

Kroll, in cooperation with nine other architects, obtained an effect of architectural diversity, distinct for urban tissue that forms over a longer period of time. The architects designed the first buildings and later subjected them to evaluation by future users. The compact style of the semi-collective development features smaller housing units: either terraced or semi-detached houses. They initiated a change in the manner of thinking about housing areas as a social structure. The scheme was repeated in designs of other housing complexes in the Netherlands [6].

The small scale of the buildings is beneficial for residents. Every house has a semi-private space in the form of a front yard, which is a belt of space near the entrance zone, developed as to make it possible to form contact between neighbours. This space is the previously mentioned *soft edge*, a comfortable space for rest, placed on the public side of the building and in direct connection with it. In the case discussed, this zone takes on the form of, among other things, bridges above mini channels (Fig. 4), referring to the location of the area and its naturally occurring waterways. Benches and garden chairs with tables appear here, initiating the formation of social ties, while simultaneously facing the public sphere of the street. There is a lot of greenery – primarily private greenery – in front of the houses, which is maintained by residents.

The private zone, of course, includes the interiors of apartments and the gardens located at the backs of houses, which remain hidden from the area's users who are not owners. One interesting solution is the arrangement of the private sphere in the houses that are located in the immediate vicinity of water. From the side facing the water there are gardens that are "drowned" in greenery, while the residents of the houses have access to the pond from the level of their private space. Greenery is a natural soft barrier here – providing separation from the neighbourly space located on the opposite side – in the form of a square with a fountain and seating. Zoning in terms of accessibility is legible. The complex appears to be very open to users who are not residents.

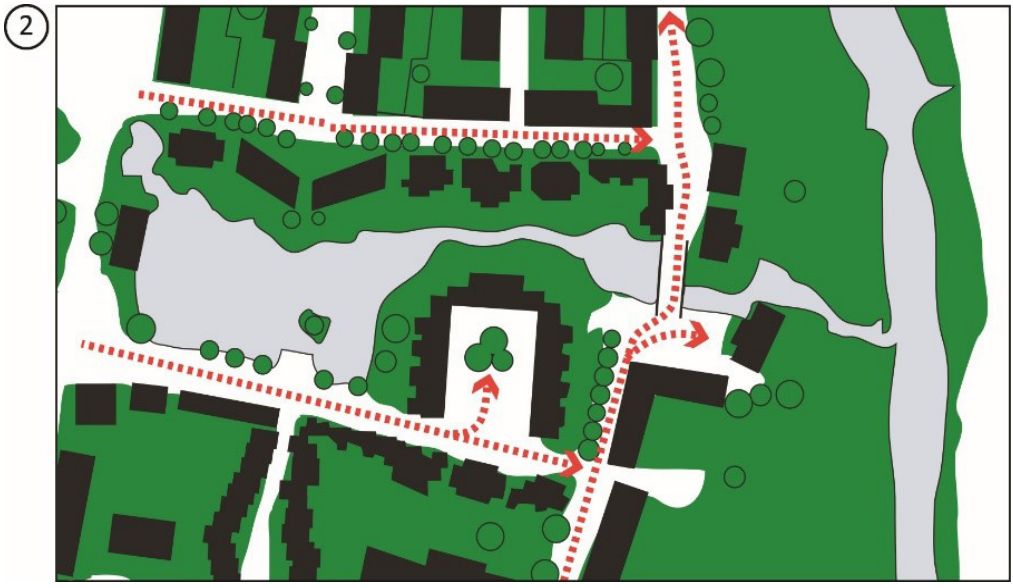


Fig. 5. Spatial structure – combination of street and courtyard, Ecolonia – Alphen ann den Rijn (by M. Bednarz).

The spatial structure (Fig. 5) of the area reflects the assumptions of co-housing complexes. The urban planning solutions used here favour pedestrians and green areas, while simultaneously providing space for vehicular traffic. This traffic is, however, subjected to self-regulation, as users have the option of using parking spaces located outside of the complex, while residents – those near their homes. We can see a mixed layout here, which (as previously mentioned), is a combination of the street and courtyard scheme, where houses are located along main paths that connect at a centrally-placed square, which in this case is located near a lake.

### 2.3. Bo01 Malmö in Sweden

The Bo01 project is a high-density urban structure that was built on the basis of innovative procedures of sustainable development. The complex definition of sustainable urban planning necessitated the formulation of a new model of cooperation with the city, developers, planners and designers. As a result, a project with high aesthetic qualities in terms of both architecture and urban layout was developed, featuring attractive public spaces and neighbourhood spaces facilitating the formation of local social ties. The city employed the well-known architect and urban planner Klas Tham to execute the project, who not only developed a design of an area that is sustainable in terms of energy, but also took measures to take into consideration the aspect of the social environment and the high aesthetic quality of the entire project.

The architect's holistic approach facilitated dialogue between city officials from different departments, developers, as well as future residents during a series of "Creative dialogue" meetings. This made it possible to formulate a set of criteria that the planned district was to meet, and which were written down in the "Quality Program". The decisions concerning programmatic elements were changed several times, but the main success of the project was mutual cooperation and the opportunity to gain interdisciplinary experience over the course of the entire process.

Public spaces in the area are composed of several squares that have a downtown-like character (Scania Plaza, Scania Portal or Citizens' Square), comfortable sequences of pedestrian paths and a large amount of generally accessible greenery (a promenade, Dania Park, Scania Park). Neighbourhood spaces primarily featured numerous courtyards and the Anchor Park area [1]. Open areas were designed by several different landscape architects, which resulted in their variety.

Fig. 6, 7. BO01, Malmo; Various forms of soft edges (by M. Bednarz)

One of the main assumptions of Bo01, apart from energy-efficiency, was the creation of aesthetic spaces while taking into account the needs of residents concerning the forming of social bonds. Sustainable development in terms of energy or resource and water use, according to Tham, could not negatively affect the quality of life of residents themselves. This is why he promoted an approach to planning the neighbourhood structure so that it would be highly diverse in terms of architecture and the landscape. He wanted residents to identify themselves with their place of residence and the manner of the functioning and design of the district.

The spatial structure (Fig. 8) favours pedestrians in the entire area, featuring a legible gradation of space into public, neighbourhood and private space, including soft edges (which in this case takes on various different forms, Fig. 6,7), while using the area's energy efficiency by using a surface runoff management system with reservoirs becoming interesting natural features of urban interiors.

One of the key elements here is the balance between fixed and changing elements in a sustainable housing environment. Fixed elements include: the spatial structure, the relationships with the city and the continuity of the system of public spaces (along with parks, streets and squares), while maintaining a hierarchy of space – from public to neighbourhood and private spaces (including *edge spaces* – semi-public or semi-private spaces) [10, pp. 92–93]. The spatial structure remains unchanged, but is balanced by the changing structure, which is the capacity for transforming ground floors and various forms of changing detail that can follow changes in social structure, which is aging, and its constantly shifting needs.

The principle of freeing up public spaces from vehicular traffic, prioritising pedestrians, has remained in effect in the construction of this housing area. In Bo01 we can also observe the mixed scheme of the layout of buildings. Of course, the scale of the architecture is much greater

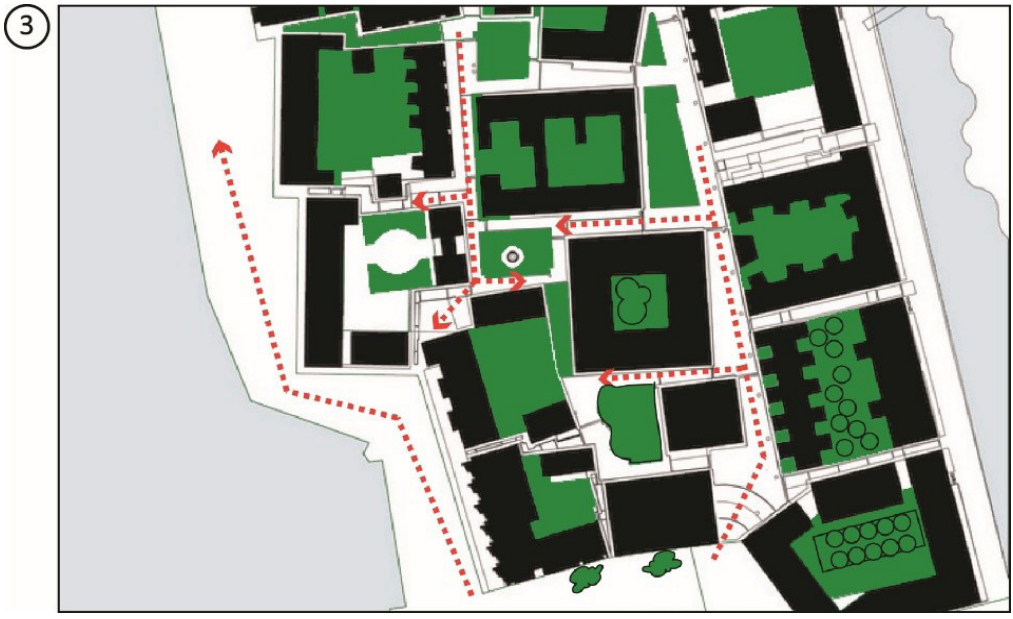


Fig. 8. Spatial structure – combination of street and courtyard, BO01 – Malmo (by M. Bednarz)

than in the case of previously discussed examples, but the same spatial structure of streets and courtyards, as well as pedestrian paths that intersect in public spaces – in this case parks or the promenade – remains in line with assumptions that can be seen in co-housing complexes.

## 3. Conclusion

The possibility of random meetings taking place has an impact on the development of the culture of resident groups. The ease of going from one's private home, through a semi-private terrace or veranda placed near one's house to a public zone of paths and small squares running between houses is a deciding factor in strengthening the bonds between neighbours and deepening their mutual relations [12, p. 15]. Borders that are delineated in an improper manner or an excessively large space between individual points can limit opportunities for residents to spontaneously participate in the life of the public space of the entire housing area or the one in the common areas of an individual block.

Elements that positively affect the shaping of common spaces include, the spatial structure, which is the fundamental programmatic function of creating the layouts of co-housing areas. Distinguishing courtyards within the space of the housing area, prioritising pedestrian traffic or the use of varied changing elements, results in a greater chance for residents to identify with their place of residence. Handing over the space inside a complex to the people and limiting (or prohibiting) vehicular traffic provides not only the possibility of forming and tightening neighbourly ties, but also ensures the safety of children.

Another essential factor in the creation of common spaces in housing areas is the lack of fences and "hard edges". The gradation of space is performed "softly", however, with respect for that which is private. The soft edge zone makes it possible to regulate contact by residents themselves, simultaneously resulting in their participation in the shaping of neighbourhood areas.

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TECHNICAL TRANSACTIONS 6/2019
ARCHITECTURE AND URBAN PLANNING
DOI: 10.4467/2353737XCT.19.058.10611
SUBMISSION OF THE FINAL VERSION: 29/05/2019

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# Does colour planning matter? Reflection on the impact and coordination of colour planning in Poland and Slovakia

## Po co planować kolor? Refleksja na temat koordynowania koloru w architekturze w Polsce i na Słowacji

**Abstract**

Research was undertaken in order to examine the ways colour has been coordinated in urban design in Poland and Slovakia – especially reasons and conditions under which colour planning started and thereafter operated. The methodology employed included an analysis of archival materials, interviews with designers and public officials as well as field studies. Five colour plans were analysed from the following points of view: the circumstances of their initiation, the methodology and process of their elaboration, the method and degree of implementation and their 'life' over the following years. The aim of this study is to compare and analyse the impact of individual colour plans in order to get an input for strengthening the professional and scientific approach to colour planning through lessons learnt from these examples.
**Keywords:** colour, colour planning, architecture, urban design, design methodology

**Streszczenie**

Artykuł przedstawia wyniki analizy sposobów koordynowania koloru w architekturze i urbanistyce w Polsce i na Słowacji, w tym badania powodów i warunków, w jakich podjęto się planowania koloru w architekturze w tych krajach. Metodologia badań objęła szczegółowe zapoznanie się z materiałami źródłowymi i wywiadami z projektantami i urzędnikami oraz badania terenowe. Pięć przykładów planowania koloru przeanalizowano pod kątem okoliczności ich powstania, metod projektowania, sposobu i stopnia zastosowania. Porównanie i analiza wpływu poszczególnych planów kolorystycznych pomogły wyciągnąć wnioski, które powinny przyczynić się do rozwoju planowania i koordynowania koloru w przestrzeni publicznej.
**Słowa kluczowe:** kolor, planowanie koloru, architektura, urbanistyka, metodologia

## 1. Introduction

Over the centuries colour has been recognised as one of the tools that visually forms the built environment; but on the other hand colour has rarely been regulated in the way other building components have been. Thus, research was undertaken to investigate selected examples of colour planning in Poland and in Slovakia in order to evaluate the existing experiences, and to develop the methodology of colour planning.

In regard to literature on colour planning in these two countries, so far few attempts to coordinate colour in Poland have been presented at a conference in Warsaw in 2015 and published in conference literature, including colour proposals for Warsaw, Lublin and Gdansk old towns [9]. A co-author of this article, Karolina Białobłocka, discussed the colour design for Blücherplatz (now Plac Solny) and the standard colours for Silesia proposed by the Association *Die Farbige Stadt*, both created in the 1930s [1, 2]. In a paper on the conservation of Wroclaw main square, Olgierd Czerner mentioned two colour proposals for the Market Square and prepared a report that included suggestions on colours for the square [5][1]. Colour planning in Slovakia has been partially discussed in a few publications. Mária Grigerová and Pavol Bauer provided an overview of research on historical colours and the colour plan prepared for the Old Town of Bratislava in 1981 [6]. A co-author of this article, Andrea Urland, included her design of colour proposals for Banská Štiavnica and Dolný Kubín in a monograph on the power of colour [11]. Beáta Breitkopf Lososvy and György Breitkopf published drawings of their colour proposal for the square in Šahy [3].

In order to deepen our knowledge of colour planning and to explore the potential that colour planning may bring to a place and the key points that help with successful implementation and maintenance, the mechanism for the whole procedure was analysed focusing on the following three aspects: reasons for the formulation of specific colour proposals, design principles, and issues related to the implementation process. Furthermore, the current situation and state of the matter were investigated and compared with the initial intentions and proposed designs or guidelines. Those issues were explored using five examples of colour coordination that took place in Wroclaw, Poland and in Bratislava, Banská Štiavnica, Dolný Kubín and Šahy in Slovakia as a basis.

## 2. Sources and Methods

Three types of data sources were identified in order to explore the phenomenon of colour planning: archival sources, interviews, and formal analysis of colour designs.

Archival research was conducted in Poland in July 2018 and in Slovakia from October–December 2018 in the following archives: the Museum of Architecture, Wroclaw; Mestský ústav ochrany pamiatok v Bratislave, Pamiatkový úrad Slovenskej republiky Bratislava, Krajský pamiatkový úrad Bratislava, Krajský pamiatkový úrad Banská Štiavnica, Krajský pamiatkový úrad Nitra. Relevant documents were also found in the municipality offices of Dolný Kubín and Šahy.

[1] The colours suggested were linked with historical colours, typical for each architectural style [4].

Interviews were conducted with designers and public officials, the former were responsible for the design of the examined examples of colour planning and the latter, for their implementation. Questionnaires were sent by electronic post or face-to-face interviews took place. During the interviews, the following issues were tackled: reasons for the introduction of colour strategy, ways of defining palettes of colours, issues related to the implementation of colour planning like planned and achieved goals, duration, maintenance methods, cooperation with inhabitants and, profits[2].

Finally, field studies took place under different weather and light conditions, in late autumn and early winter mornings and afternoon light, on both sunny and cloudy days.

## 3. Colour Planning in Poland and Slovakia: an overview

In Poland, colour planning in urban design has been generally linked with post-war reconstruction and refurbishment of historical town centres that took place in major cities in the 1950s and 1960s. At that time colour was included in the complex designs of the main squares of Warsaw, Lublin, Gdansk, and Wroclaw[3]. In regard to Wroclaw, there were also colour proposals made in the 1930s that aimed to promote colourful architecture and to create a more exuberant image of the then German city [2], whereas the post-war proposals were part of the refurbishment of the city after the damages of World War II.

The research indicated that in Slovakia, the interest in coordination of colour in the built environment started in the early 1980s in Bratislava, and has reappeared irregularly in different parts of the country and that attempts were made to coordinate colour in both listed areas of historical significance (Banská Štiavnica, Dolný Kubín, Šahy) and in residential districts of prefabricated concrete blocks of flats erected in the second half of the 20th century (e.g. Levice).

## 4. Case studies

### 4.1. Wroclaw - colour planning for the Market Square and Plac Solny

#### 4.1.1. Reason

There have been a few attempts to coordinate colour in the Market Square and the adjacent square Plac Solny in the Wroclaw Old Town including colour proposals made in 1928 and in 1959.

The 1928 colour proposal for Plac Solny (Blücherplatz at that time) was the subject of an architectural competition that took place at the peak of the 'call for colour' movement in the early 1930s; typical colours were also recommended for the Silesia region in the late 1930s [1].

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2 All the interviews included questions from the questionnaire prepared by Karolina Białobłocka in 2016.

3 For further details refer to [9].

In 1959 the state office *Pracownia Sztuk Plastycznych* ordered a colour design for the two main squares in the Old Town: Market Square and Plac Solny. The complex colour design was related to the refurbishment of the Market Square undertaken as the main part of commemorating the 15th anniversary of the so-called return of the retrieved lands to the motherland, which took place in Wroclaw in 1960[4]. Because of this event, the decision was made to plaster and paint the whole square for the first time after the end of World War II in accordance with the colour proposal prepared by three artists: the stenograph Aleksander Jędrzejewski, painter Stanisław Pękalski and furniture designer Władysław Wińcze.

### 4.1.2. Design

The 1928 colour proposals for Blücherplatz (present day Plac Solny) in Breslau (present day Wroclaw) were the competition entries from 1928. The limited available data on the competition informs us that both entries were award-winning, the first entry characterised a reduced palette of colours to shades of yellow and brown, whereas the other entry was composed on contrasts of hues, saturation and light [2][5].

The colour proposal made for the Market Square around 1959 was the consensus of ideas and approaches towards colour undertaken by the three artists. The idea was to paint each side of the square with a slightly different set of hues because of the authors' awareness of the power of sunlight depending on the direction the buildings faced. Cold hues dominated on the sides that received less direct sunlight and warm hues were applied to the sides with direct sunlight[6]. Additionally, the corner buildings were to be painted stronger colours in order to 'keep the side together' (similarly to the imitations of stone blocks painted on the corners of medieval buildings that aimed to provide a feeling of stability to the whole structure). Another feature of the colour proposal was the special treatment of the window frames of the stone facades. In order to harmonise and link the stone facades with the plaster facades, the artists proposed to paint those window frames with the colours of the neighbouring facades. In regard to the colours suggested, the range of colours varied but colours applied to a single side were more uniform. The interviewed artist recalled that colours were saturated, intense darker shades obtained by mixing with black or grey and pastel hues were omitted. Darker shades were applied on elevations with direct sunlight and lighter – on elevations that lacked direct sunlight.

The design had to be adjusted as the original idea was not highly regarded by the local conservation office. The colours proposed did not respect the original historical colours and for this reason the city conservator opposed the project by indicating the lack of experience of the artists regarding issues related to the monument conservation process. The city conservator

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4 Information on this colour plan comes from a private communication between Olgierd Czerner and Michał Jędrzejewski. Interviews took place in March 2015 and July 2018.

5 For details refer to [2].

6 The conservator pointed out that the same rule was applied by one of the artists of the colour proposal on the stained glass located in the octagonal chancel of the Dominican Church in Wroclaw. The medieval church is orientated to the east, therefore the right side of the stained glass receives more direct sunlight and is composed of warm hues, whereas the left side receives less direct sunlight and cold hues dominate on this side.

intervened, even personally removing part of the plaster and paint layers to expose older colours. Original colours had been suggested and as a result of those discussions, some of the colours proposed were changed in accordance to the city conservator's indications of which colours would be accepted by both parties[7]. The other interviewed artist mentioned that the original design was also planned to be richer in terms of ornamentation including wall painting, similar to the colour scheme applied in Warsaw in the 1950s; however, the limitation of founds prevented implementation of such an ornamented colour scheme in Wroclaw (Fig. 1).

Fig. 1. The 1959 colour proposal for the Market Square, Wroclaw by A. Jędrzejewski, S. Pękalski and W. Wińcze (source: the collection of the Museum of Architecture, Wroclaw)

### 4.1.3. Implementation

It is not known if the 1928 colour proposal was implemented. The 1959 colour proposal was implemented only once for a celebration in 1960 and only partially. According to the interviewed former head of the city conservation office, this implementation was possible due to practically absence of private ownership; state ownership of the buildings around the square prevailed. However, the colour proposal did not last for long as there were too many users and it was difficult to execute the colour scheme during subsequent refurbishments. With the lapse of time, the political system and ownership have changed and private owners did not

[7] The Conservator's suggestions on colours for the market square that would follow historical hues, typical for each architectural style can be found in the unpublished report stored in the archive of the City Conservator [5]. Additionally, art historians' comments on the same issue can be found in [7].

show any interest in the designers' postulates. The city conservator mentioned, that some of the designers reacted to the changes in their colour proposal with resentment; however, in the conservator's opinion, the situation has come back to a normal state, as in the past this was the way to paint facades – everyone painted his or her house in accordance with their own wishes[8].

The former city conservator also admitted that colour had not been of any special importance, there was no consistent approach towards the city as a whole in terms of colour, and regulations on colour were never introduced during his work as a city conservator in the years of 1955–1965, as the public official did not see any sense in it, adding that all the available financial support was used on refurbishing monument structures and not on painting elevations.

At the present time, colourfulness of both squares is the first feature to be noticed as, in regard to care of colour, the monument office in Wroclaw has been concentrating on the return of historical colours of individual buildings but has not provided consistent policy on colour that would help to provide harmony within the square[9] (Fig. 2).


Fig. 2. Colourfulness characterises the Market Square (selected facades) and the adjacent Plac Solny (lower row), Wroclaw in the present day (photo by K. Białobłocka, 2019)

[8] Yet at the same time, Olgierd Czerner indicated the possibility of a common initiative to repaint prior to the visit of a monarch, etc [5, p. 226].

[9] For details on historical colours of Wroclaw, refer to [1].

## 4.2. Bratislava – colour planning for the Old Town

### 4.2.1. Reason

Attemps to coordinate colour in the Old Town of Bratislava took place in the early 1980s. The colour proposal was prepared as a part of a bigger study consisting of historical and architectural analyses including new functions, public spaces, greenery, etc. The study was prepared in the Regional Monument Board in Bratislava SMPR (*Statna mestska pamiatkova rezervacia*) in 1981 by a team consisting of architects and art historians: Anna Schwarczova, Pavol Bauer, Maria Grigerová, Viktor Ferus and Martin Melichercik. The study was initiated by the architect Anna Schwarczova and aimed to conduct a renovation of the whole old town at a highly professional level. The reason for undertaking the study was described by the interviewed architect as a wish to restore Bratislava, the capital and one-time coronation city, to the grand character the city used to have in the past.

### 4.2.2. Design

Apart from other goals, the study aimed to provide a complex colour scheme for the whole area. The methodology applied included paint research and alterations of findings.

The study started with paint research undertaken across the whole Old Town, and it covered most of the buildings apart from the contemporary buildings coated with stone[10]. At that time the methodology of paint research was limited to a few on-site scratches on the facades where the number of samples taken by art historians varied from five to fifteen on each dwelling. Findings were documented and colours were described in comparison to the colour chart of the paint company SYNTHESA. Colours for walls and architectural details were provided but colours of doors, window frames and roofs were not considered in the colour proposal[11].

In regard to the alterations provided, the interviewed architect explained that the study aimed to emphasise the character of the area that consists of buildings representing different architectural styles. Provided modifications were minor and limited to the changing of nuances. Each street and square was treated individually and colour was used to differentiate the space, yet in different ways. As a rule, the grander and wider streets like Michalská and Panská were emphasised by lighter colours, whereas narrower streets of lesser importance were to be more colourful. In some areas a graduation of shades was provided, whereas in other places darker shades were suggested to make the area more visible (Fig. 3).

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[10] Archival research in the two Bratislava archives that store documents regarding the conservation of the Old Town: Krajski Pamiatkovy Urad (KPU) and Mestsky Pamiatkovy Urad (MPU) revealed very limited archival sources. Report 'Vyhodnotenie stavu fasad v CMO Bratislavy', Bratislava 1988, MPU archive, call number 3316, consists of black and white pictures that depict the condition of buildings in the old town. Only a few pictures include written information on the colours of walls and architectural details.

[11] Documentation of the 1981 research is stored in Mestský **ústav** ochrany pamiatok v Bratislave in four volumes under the name 'Farebnost fasad', There is no call number provided. Documentation is not completed as it lacks information on several elevations. Additionally, the maps that presented the colour proposal in the scale 1:1000 are missing.

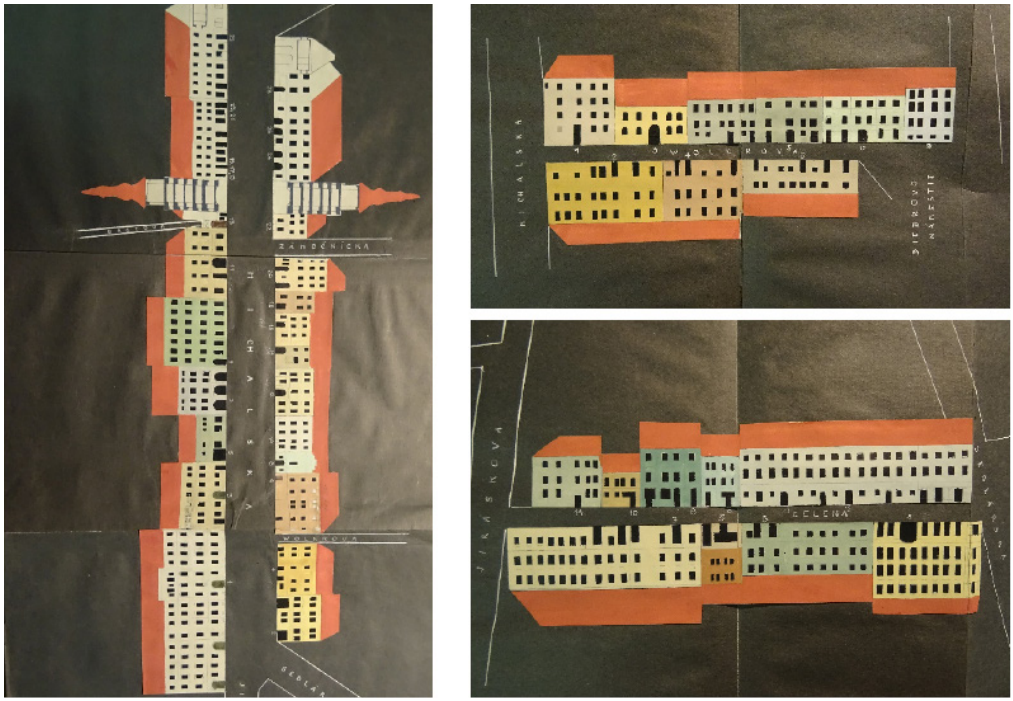


Fig. 3. Selected details of the Colour Proposal for the Old Town of Bratislava from 1981 – one of the main boulevards: Michalská ulica, and two narrow back streets (source: Archive of Mestský ústav ochrany pamiatok v Bratislave)

### 4.2.3. Implementation

The colour proposal has never been implemented as a whole. Thus far, only selected buildings were renovated in the years 1981–1989 using as the principles of colour planning as a basis, including restoration of part of the so-called coronation street – Michalská, Sedlárska and Rybárska brána.

The political transformation in 1989 brought changes related to the law and the ownership of buildings; transforming from state ownership to private ownership; the closure of state architectural offices and the employment of new staff in conservation offices took place. As a result of changes in ownership, the restoration of the Old Town was not continued and with time the attitude towards colour planning has also changed. According the interviewed public official, after 1989 the colour proposal was still in use, but public officials have started to concentrate much more on original colours that would match the styles of facades instead of considering the harmony of the whole area. Additionally, the colour proposal was not favourable any more since the conservation office could only demand paint research of privately owned house and was not able execute an examination of a bigger area, e.g. a whole street. However, paint research has continued and its quality has increased especially as a special conservation office was established in 2002 to provide paint research and owners

themselves had to pay for the examinations. Since then, there has been no more consideration given to the area as a whole or to matching colours.

Nowadays, the Regional Monument Board in Bratislava continues to examine historical colours[12]. The discoveries serve as a base for decisions made by public officials who as a rule, seek to restore the original colour schemes. Sometimes compromises have to be made due to differences between historical and modern technologies and also due to requests made by the owners – in both cases compromises are limited to the choice of a similar shade. In case the paint research was not successful and did not provide any information on the original colours, the public officials base their decisions on historical analogies instead (Fig. 4).

Fig. 4. Selected streets in the Old Town of Bratislava in the present day: Michalská ulica and two back streets. With focusing on historical colours, some areas are still painted limited colours, whereas other areas became much more colourful (photo by K. Białobłocka, 2018)

The idea of colour planning in the form of guidelines sounds positive to the public officials. According to them, such guidelines may be especially useful in case there is no information on the original colours, but lack of time and limited workforce prevent any initiative from their side to prepare such a document.

[12] From private communication with the public officials, KPU in Bratislava.

### 4.3. Banská Štiavnica - colour planning for the town centre

#### 4.3.1. Reason

This colour plan was initiated as a response to an urgent practical need and it was elaborated in the framework of two concurrent research projects: Colour in Architecture and the Cultural Historical Topography of historic urban structures. The preparation of the plan was financed by grants and the client was the Union GRADUS of Banská Štiavnica[13]. The material was intended to be used by the Monuments Board officials in their day-to-day practical work with the owners of buildings. The interdisciplinary team consisted of architects A. Schwarczova and A. Urland, and art historians H. Haberlandova, Z. Sevcikova and Z. Zvarova. It was conceived as the first phase which was to be elaborated further to a more detailed level (from the level of an urban zone through to streets and squares, visual units, individual buildings, details).

The group of young architects from the GRADUS association aimed to recognise the merits of Banská Štiavnica and to preserve and maintain them in the most appropriate way. The document included a colour proposal outlining how to manage the colouring of the central, protected area of the town[14]. The interviewed architects explained that, first of all, there was a wish to improve the place. The other reason was the need for some guidelines that would help public officials; such as a document based on scientific research and not on public officials' personal preferences, which would be much more convincing for owners.

#### 4.3.2. Design

The aim of the work was to obtain objective information on the colours of the facades in relation to their stylistic expression, propose colours for the restoration of the facades with regard to the listed historic environment and to verify the newly developed methodology. The working methodology of colour design in historic environments consisted of surveys, analyses, synthesis and colour proposal with regard to:

- the character of the historical environment, its cultural and social significance and cultural and historical values,
- the existing knowledge of the historical environment, buildings and facades,
- the character of the task and the possibilities of making use of existing experiences,
- the available information input at that time,
- choice of buildings by the partner institutions (incomplete streetscapes),
- the requirement that the document should be used as a basis for methodical and administrative practice in safeguarding the built heritage of the town.

In the period between January to September 1992, facades of one hundred and thirty buildings in nineteen streets in the centre of Banská Štiavnica were subject to the colour

[13] Now *Spolok Banskej* Štiavnice

[14] Three people who worked in the conservation office in Banská Štiavnica at the time the colour proposal was created were interviewed in October 2018. They provided information on the colour proposal in the 1990s presented in this article.

plan as selected by the Monument Board. The colour plan focused on the present state of the facades, e.g. their prevailing architectural expression, for the immediate needs of the methodical practice.

On site surveys on the colours of the facade are studied in relationship to the colour of their stylistic architectural expression. Stratigraphic surveys were carried out at various heights of the facades according to their complexity, ranging from five to fifteen. Classical scratching techniques were employed. The process was recorded and the colour findings were documented by visual measurement using the ACC system. As a result of a thorough analysis, each facade was characterised from an architectural stylistic and technical point of view, a record was made of its re-buildings and restorations and the sequence of colour layers. The recommended colours were described in words and also by notions used prevailingly the ACC. The team obtained information on the state of the current knowledge of the facades (Fig. 5).

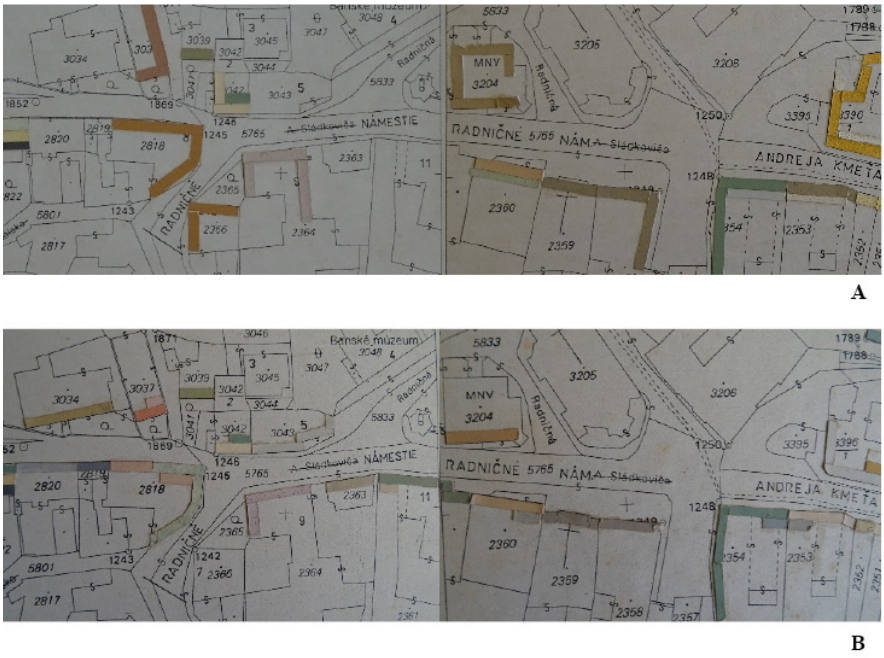


Fig. 5. Detail of the 1992 colour proposal for Radnicne Namestie – one of the two main squares in Banská Štiavnica: results of the paint research (upper row) and the colour proposal (lower row) (source: KPU Archive, Banská Štiavnica)

### 4.3.3. Implementation

The colour proposal was implemented by the local Monument Board and has been in use since 1992. The interviewed architects recalled that the proposal was fairly easy to implement as it was logical; scientific-based material was helpful to convince the owners and most of the owners liked it and approved of the scientific-based colour proposal, only very few people were opposed.

The document was used in the following way: in case the owner wanted to refurbish his/her house, he or she was informed to use a certain colour from the colour proposal. In case of a disagreement only a small compromise was possible and was limited to the same hue but of a lighter/darker or warmer/colder, etc, shade.

In regard to the profits colour planning has brought in the 1990s, the advantages were described in the following way – saving the authentic feeling of the town; general improvement of the place, the town has a more historical atmosphere because of the lack of artificial colours and because of the use of traditional materials. However, there was also an opposing voice. One of the interviewed architects indicated that the study tried to create a sort of ideal situation since the dominating colours in the proposal were the colours typical for the 19th century but the buildings were erected in different architectural styles, so the interviewed architect argued that in reality there has been never an ideal situation[15].

Nowadays, the responsibility of colour within the protected area lies with the local branch of the Monument Board in Banská Štiavnica. The interviewed public officials draw attention to the fact that despite the 1992 research begin an old research, it has never stopped being used; but only to some extent – as a sort of a consultation document. In fact, the current


Fig. 6. The Radnicne Namestie square in the centre of Banská Štiavnica in the present day with renovated facades in accordance to the current approach remains fairly uniform (photo by K. Białobłocka, 2018)

[15] The colour designer of the colour proposal explained that in the proposal the present style and character of the facades was respected (many of the buildings were older, but facades had been remodelled in the 19th or early 20th century).

approach differs as the main aim is to re-establish original colours. For this reason, in the case that a certificated conservator would find new information, the public officials would decide in favour of the updated findings, but only if there are no findings in the 1992 colour proposal when consulted or if the decision is made to use light colours that have been already applied somewhere within the vicinity. The public officials consider owners' opinions and wishes only in cases there is a lack of information on the exact historical colours, but the choice is limited to light hues.

The conducted interviews revealed that the colour proposal is perceived as useful since the public officials find it difficult to decide on colours on their own. However, at the same time they stress that it is important to have information on the original colours, and that they concentrate on single buildings, not on the whole streets (Fig. 6).

### 4.4. Šahy - colour planning for the main square

#### 4.4.1. Reason

Colour planning for the main Hlavné námestie square in Šahy was initiated by the local municipality office and the design was made by the architects Beáta Breitkopf Lososvy and György Breitkopf in 2005. In accordance to the interviewed public officials, the colour proposal aimed to help to improve the image of the main square of the town. The idea appeared that a complex colour design would serve as a guide supporting the municipality office in assessing restorations and in this way would help to prevent messy restorations on the square. The need for such a document became crucial especially after 1989 when the number of restorations conducted according to the owners' own ideas significantly increased, which resulted in repainting houses in various different colours and shades bringing a chaotic result to the whole square.

#### 4.4.2. Design[16]

The available document consists of part drawing and part text, which is in fact the list of colours described by comparison to the NCS colour chart. The colour proposal was provided in three variants and colours were estimated for the walls, architectural details and plinths for all buildings. Colours of the entrance doors, window frames and roofs were not provided. The design was elaborated using the layout of the square as a base and was consulted with the owners of the buildings. Three variants aimed to provide more freedom to the owners while choosing colours. The design was presented at the exhibition in a local museum and the interviewed public official recalled that the feedback was generally positive (Fig. 7).

[16] Information on the design for Šahy main square comes from analyses of available sources and interviews with public officials as the authors of the colour proposal refused to take part in the interview.

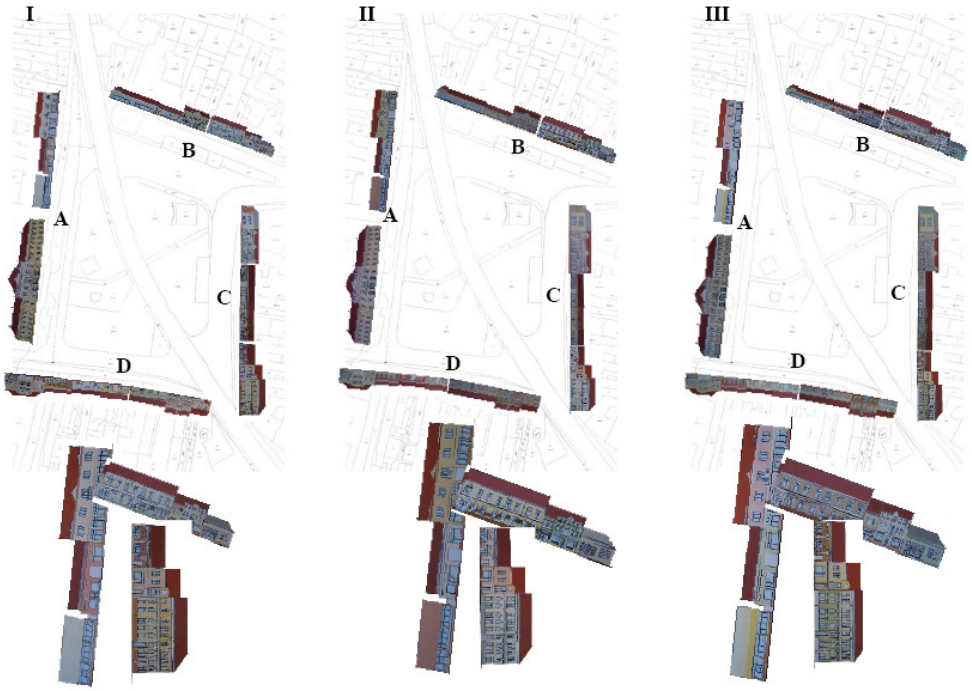


Fig. 7. The colour proposal in three variants for the Hlavné námestie in Šahy by Beáta Breitkopf Lososvy and György Breitkopf (source: https://www.sahy.sk/navrh-farebneho-riesenia-hlavneho-namestia.phtml?id3=33467)

### 4.4.3. Implementation

In regard to the implementation process, on one side the private ownership prevented the use of the colour proposal, as the municipality office had no legal right to execute the document[17], and from the other side, as the square lies within the protected zone and under the law, Act No. 49/2002, the conservation office has to approve colours of buildings protected by this rule, so the town hall had to seek the opinion of the conservation office. The public officials from the conservation office in Nitra confirmed that the office issued an opinion of the document on the request of the municipality office in 2006. They stated that the document *Návrh farieb budov Hlavného námestia* Šahy was not relevant for them and that they were not going to use it. In fact, the Regional Monument Board in Nitra rejected this document in 2006 because of the methodology used in the colour proposal. The public officials explained that the colours of all the buildings were invented and they were not based on paint research that would reveal the original colours of individual buildings. The theory is

[17] At the same time, the interviewed public officials from the municipality office did not mention any attempts to make the document compulsory by local law.

Fig. 8. At present, Hlavné námestie in Šahy remains multi-coloured and without any feeling of harmony in terms of colour (photo by K. Białobłocka, 2018)

that the office decides on colours using paint research that seeks historical colours as a basis. For this reason, this colour proposal has been never implemented in Šahy.

After the rejection of the colour proposal, the municipality office neither continued their interest in a colour plan by trying to adjust it to the law, nor got directly involved in paint research. The public officials did not see the point in such actions as that would mean the financial involvement in paint research and according to the public officials, the municipality office has no right to comment on colours – that responsibility lies with the conservation office. At this moment, the municipality office presents the colour proposal on their website for information only and interviewed public officials were not aware of any future plans regarding the 2005 colour proposal prepared for the main square in Šahy (Fig. 8).

### 4.5. Dolný Kubín - colour planning for the main square

#### 4.5.1. Reason

A colour plan for the Námestie P.O. Hviezdoslava square in Dolný Kubín was elaborated in 2006 by the architect Andrea Urland on the basis of the request made by the Dolný Kubín Municipal office which felt the need to have a conceptual material at hand when responding to the desires of the owners of buildings to restore or repaint facades. It was a response to the

rapid and rather dramatic visual changes of the square – the aim was to set an end to such arbitrary use of colour in the square of major importance to the town.

The colour plan was initiated by the public official from the municipality office who perceived the colour proposal as a tool that would provide improved aesthetics within the main square of the town, an area of huge importance for the town but not listed with the exception of two buildings; for this reason there is no necessity to consult the local monument board prior to the refurbishment of the buildings. The interviewed public official mentioned that it was difficult to convince the owners to use certain colours in order to provide spatial harmony. For this reason, the office requested colour planning that would serve as an official document and as a basis for discussions on colour.

### 4.5.2. Design

The colour proposal [10] was prepared for the Námestie P.O. Hviezdoslava square and for part of the adjacent street 'Matúškova ulica' that encloses the rectangular square from the east. Information on colours was provided for thirty four buildings on the square and seven on the adjacent street. The document provides information on colours for the walls and architectural details, whereas colours for roofs, window frames and the entrance doors were not included in the colour proposal. Colours were specified using the NCS colour chart; in most cases one

Fig. 9. Colour proposal for the Námestie P.O. Hviezdoslava square in Dolný Kubín by Andrea Urland (source: courtesy of the author of the plan)

colour or a combination of two colours were provided, in some cases alternatives were also offered in order to give some liberty to the owners or users of the buildings for their own taste.

The plan focused on the P.O. Hviezdoslav square, i.e. the main town square – a historical urban space with two listed buildings. A total of thirty four buildings of various styles and values were studied as the subject of the colour plan. Many of the facades had been modified several times in the past and in the majority of cases their original or previous colour appearance is not known. In several cases it was possible to find historical surface layers with colour on the facades that allowed the history of their colour appearance to be traced down. Most of the buildings serve as commercial functions and part of them for living, but there are also some important buildings such as the Municipal office, the church, Orava museum and gallery as well as, the former synagogue.

The colour plan had been worked out for the present state of the buildings, e.g. their current expression and artistic and historical meaning which had been evaluated by the collaborating art historian Dr Magda Kvasnicova. The analyses of the square and the individual buildings, including a spatial one, showed several problems and needs (Fig. 9).

### 4.5.3. Implementation

The colour proposal has been in use since 2006 in the following way: whenever an owner comes to the department of planning and building regulations (*Referát územného plánovania a stavebného poriadku*) in the local municipality office in order to discuss his or her plans for future refurbishment, the public officials inform them that there is a colour document and those colours should be used. In case an owner opposes, at compromise is sought and a similar shade is proposed; however, in the case of disagreement, the most helpful argument is that the colour proposal was made by a colour designer so the colours suggested are not the personal preference of public officials. When asked about the profits the colour proposal has brought, the interviewed public official briefly indicated some improved aesthetics.

The interviews and fieldwork conducted in December 2018 allowed us to assume that the colour schemes as provided in the colour proposal are suggested by the municipality office whenever the façade refurbishment is performed. However, the analyses of the colours of the facades in late 2018 revealed that only some of the buildings have been renovated since 2006 and only some of the renovated facades were repainted using colours indicated by public officials from the municipality office[18]. While asked about this issue, the public official explained that there has been no town architect office in Dolný Kubín for years and that they do not have enough authority to execute the colours proposed in the colour proposal[19] (Fig. 10).

[18] Limited access to the document did not allow us to estimate the exact number of renovations.

[19] The public official did not reveal any plans to make the document compulsory by the town council.


Fig. 10. West part of the main square Námestie P.O. Hviezdoslava in Dolný Kubín in the present day partially renovated in accordance to the 2006 colour proposal (photo by K. Białobłocka, 2018)

## 5. Conclusions

Investigations of attempts of colour coordination in architecture and urban planning in Poland and in Slovakia revealed four examples of such actions undertaken in representative historical areas in Slovakia : two examples of colour planning for the old towns of Bratislava and Banská Štiavnica, and two examples of colour planning for small-scale locations: the main squares in Dolný Kubín and Šahy. Those case studies were analysed and compared with one case from Poland – colour planning for the Market Square in Wroclaw[20].

All of the examined cases were structured in a similar way – they were not meant to act as more or less flexible guidelines that would provide a choice from the established range of colours, but they were prepared as complex designs that provided exact information on colours to be executed on each building. In this matter, no significant differences were spotted in the approach towards colour planning in Poland and Slovakia.

In regard to the reasons for the introduction of colour proposals, the following reasons were indicated by the interviewed public officials and designers: a feeling of overwhelming colourfulness, lack of connections between the colours used and local traditions, lack of

[20] Colour planning for other historical centres in Poland are under examination.

respect towards cultural heritage (traditional colours), the wish to improve the area, the wish to emphasise the significance of the area, the need to provide spatial harmony within the area.

In regard to the design methodology, the conducted interviews indicated that in some cases the examined designs were a result of the designers own research experience and ideas (Wroclaw, Šahy, Dolný Kubín), whereas in other cases, paint research served as a base for a choice of colours (Bratislava, Banská Štiavnica)[21].

Regarding the implementation process, four colour proposals were implemented to some extent at the time of creation (Wroclaw, Bratislava, Banská Štiavnica, Dolný Kubín); two colour proposals are still being consulted (Banská Štiavnica, Dolný Kubín); and only one colour proposal has never been implemented (Šahy). In regard to the profits the colour plans have brought, the interviewed designers and public officials indicated the following: better aesthetics within the area, general improvement of the place and, salvation of the traditional image of the place. During interviews, only one opposing voice appeared indicating that some sort of artificiality in the colour proposal had been created.

The interviews indicated that the public officials' strong belief in profits that colour planning may bring, resulted in creating colour proposals (Bratislava, Banská Štiavnica, Dolný Kubín, Šahy), whereas a lack of conviction towards colour planning among public officials prevented either their implementation or keeping them in use (Wroclaw, Bratislava). Generally speaking, it appears that the existence of colour planning is strongly related to the awareness of the power and importance of colour and depends on the presence of such awareness at the local municipality and conservation offices. Again, in this matter, no difference was seen between Poland and in Slovakia.

Additionally, the interviews also revealed that in two cases the implementation process was easier to proceed with due to the then political system and state ownership, but it was not in position to allow the implementation of the whole colour proposal – the financial constraints and lack of interest from both the public officials and the owners' side prevented the implementation of the whole colour plan (Wroclaw, Bratislava). The other problem was that unsuccessful implementation could also be the result of the lack of coordination among various offices that participate in renovations – from one side public officials indicated a lack of authority on executing a certain colour change, at the same time no public official interviewed indicated the need or plan to make the colour plan compulsory by the municipal office's decision (Dolný Kubín, Šahy)[22].

Currently, instead of colour proposals that would not only keep local traditions, but also unify the space, efforts are instead concentrated on reconstructing historical colours. This is the approach taken in all the examined cases in Poland and Slovakia that are protected areas (Wroclaw, Bratislava, Banská Štiavnica and Šahy). Some of the interviewed public officials admitted that the guidelines on colour would help them in their every day work with protected areas but no specific plans to achieve this goal were indicated, or even suggested.

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[21] The available colour designs only allow us to increase our knowledge of colours used but the limited access to the designers prevented us from detecting what ideas and inspirations lay behind each colour plan.

[22] Especially the case of Bratislava allow to assume that both the strong leadership and the awareness of colour and its influence on human beings may help to provide guidelines on colour in the built environment.

*This research was supported by the scholarship of the Government of the Slovakian Republic for University Teachers, Researchers and Artists. It was conducted at the Slovakian University of Technology, Faculty of Architecture, Colour Laboratory in 2018.*

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If you want to quote this article, its proper bibliographic entry is as follow: Białobłocka K., Urland A., *Does colour planning matter? Reflection on the impact and coordination of colour planning in Poland and Slovakia*, Technical Transactions, Vol. 6/2019, pp. 17–36.

TECHNICAL TRANSACTIONS 6/2019
ARCHITECTURE AND URBAN PLANNING
DOI: 10.4467/2353737XCT.19.059.10612
SUBMISSION OF THE FINAL VERSION: 28/05/2019

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# The role of parish churches and adjacent parish facilities in a city's spatial structure

# Rola kościołów i zespołów parafialnych w strukturze przestrzennej miasta

**Abstract**

The aim of the study is to determine the role of parish churches and adjacent parish facilities in a city's spatial structure on the example of southern districts of Warsaw. The research includes a description of the parish structure development and characterisation of urban elements surrounding existing parish churches and architectonic elements of the ecclesial buildings which link them to the exterior space. Within the area analysed, initially rural settlements developed surrounding churches founded by Catholic religious orders or landowners and later have been included within the city limits. New ecclesial buildings were erected in parallel to the new residential area. The churches have an important influence on their urban surrounding form. Their influence often extends beyond their nearest surroundings due to the vertical elements of symbolical character, which are a clear reference point in the urban landscape.

**Keywords:** church, city, ecclesial building, sacral architecture, urban development

**Streszczenie**

Celem badań było określenie roli kościołów i towarzyszących im zespołów parafialnych w strukturze przestrzennej miasta na przykładzie dzielnic południowej Warszawy. Przedstawiono rozwój południowej Warszawy na bazie rozwoju struktury parafialnej. Scharakteryzowano elementy struktury miejskiej towarzyszące kościołom oraz elementy budowli sakralnych łączące je z przestrzenią zewnętrzną. Na badanym obszarze początkowo struktura osadnicza o charakterze wiejskim rozwijała się wokół kościołów fundowanych przez klasztory i właścicieli ziemskich, a później włączona została w granice miasta. Nowe kościoły wznoszono wraz z budową osiedli mieszkaniowych. Kościoły mają istotny wpływ na formę ich urbanistycznego otoczenia. Ich obszar oddziaływania sięga często dalej niż przestrzeń miejska przylegająca do świątyni dzięki elementom symbolicznym o charakterze wertykalnym, które są czytelnymi punktami odniesienia.

**Słowa kluczowe:** kościół, miasto, architektura sakralna, rozwój miasta, ogród kościelny

## 1. Introduction

In literature there are two terms characterizing the type of cultural landscape where sacred and religious values are important. The first one is the sacred landscape, which is related to material manifestation of the sacred, such as the presence of places of worship. M. Lehmann considers the sacred landscape as the spiritual and cultural heritage, expressed in religious buildings in landscape [8, 11]. The other term is the religious landscape. According to C.C. Park, the range of research on the religious landscape includes such issues as: sacred architecture and churches' spatial distribution and dynamics of changes [8, 16].

Sinha claims that the religious past of most societies is alive in religious buildings and sacred sites [17]. Parish churches in countries with a Catholic tradition are deeply-rooted in the urban landscape and in societies' culture. Sacred places together with places of power and places of commercial trade were always characteristic elements of urban configuration [14]. Norberg-Schulz pointed out that for centuries European architecture was mostly sacral architecture. Still today, the majority of European cities are dominated by a centrally situated church which shapes urban landscape and its meaning. The church explicitly determined the silhouette of Christian cities. It constituted a clear physical and meaningful centre. It was easily recognisable both in the spatial and symbolical aspects [15]. The influence of religious architecture on the landscape has attracted few researchers, especially within architectural and urban fields of studies. The role of churches in the urban landscape has been a subject of interest for Marek Grymin, Claudia Manenti, E. Klima, Alba Arboix Alió and Joanna Gil-Mastalerczyk [1–5, 9, 10, 12–14]. Grymin emphasises that to understand the present role of parish churches in the city landscape it is important to analyse the historical context. Contemporary cities were influenced by previous generations and the sacred architecture which they erected and which often still exists [5]. As pointed out by Arboix Alió, parish churches are significant buildings for understanding a city's development. The identification of the parish churches' structural evolution is crucial for understanding the urban layout and conditions of its spatial development, and also for understanding the ecclesial buildings nearest surrounding composition. These types of building combine the architectonic form, and political and economic conditions, which were the impetus for their establishment, as well as the mentality of the society and the culture of architects who designed them [1]. According to Marek Grymin, the range of research concerning the churches' role in the city landscape should include the space related to the sacral buildings, such as the surrounding parish facilities complex [5]. Alba Arboix Alió emphasises that sacred architecture influences the composition of the surrounding area. The urban space surrounding the church is a kind of open-air interior destined for the everyday use of the local community [1]. According to Marek Grymin and Alba Arboix Alió, there are diverse types of parish complexes' relation to their urban surroundings. Marek Grymin identifies: churches located next to a square, new sacral buildings within the inner city, "islands", temporary ecclesial buildings, "roadside" churches, temples within housing estates and churches "incorporated into green areas" [5]. Alba Arboix Alió identifies churches linked to a square, a passage or other public spaces,

those located directly along a street and churches with no visible relations to their urban surrounding. The author also claims that there are some sacral buildings whose relations with their surrounding are more extended because of their vertical architectonic elements visible from distant perspectives [1].

Manenti emphasises that since the 20th century, places of worship have become marginalised, and driving them into the private sphere causes the loss of their social and urban roles, which they performed until the end of the 19th century [14]. According to Marek Grymin, currently, due to the intensive and spontaneous urban areas development, buildings which created landscape identity and which were perceived as landmarks, such as churches, lost their historical role. More often, their location in the city landscape is random [5]. Because of their location and form, churches are now rarely considered as reference points in the city landscape. Often an initiative for a new sacral building establishment arises late, when urban development is already dense and there is no representative location. Sometimes, during parish structure formation and identification of the main centres of the Church organization, the complex urban system has not been taken into consideration [13]. Szymski and Długopolski indicate four types of main problems concerning new churches: 'peripheral location', misunderstanding of the idea of the 'ecumenical simplicity', misinterpretation of the 'return to the roots of Christianity' and focus only on utilitarianism and pragmatism [18].

In the European Christian tradition, the church was a characteristic element of urban structure, a visible dominant, a strong form which served the local community as a centre of physical space of their environment. For ages, the church presence gave people a sense of safety, of belonging to the community of faith, thoughts, actions and hope [6]. The necessity to continue this tradition resulted not only from the spiritual need of local communities; it is also related to the need of symbolical emphasizing their identity [7]. The location of religious buildings should be linked to urban context. Worship places shouldn't be hidden or isolated. They should be placed within the space which concentrates the city's life, which performs social, recreational and commercial functions. Religious buildings should be visible and their form shouldn't be excessively monumental, but must be sufficiently representative [14].

The aim of this research is to determine the role of parish churches and adjacent parish facilities in a city's spatial structure based on the example of the southern districts of Warsaw. The study includes 28 parish churches currently existing there. The southern Warsaw urban landscape was mostly shaped from the 1970s to the 1990s and at the start of the 21st century. Its spatial composition is based on the historical road system of the previously existing rural area. Although the great part of the landscape is occupied by relatively new housing estates, the spatial complexes of the former villages with their internal road system are still preserved. The analysed area reflects a process of city development through incorporation of the rural area with the existing historical parish churches into the city boundaries and the establishment of new urban housing estates with new parish churches meeting the needs of new communities.

## 2. Materials and methods

The role of parish churches and adjacent parish facilities in the city's spatial structure has been considered in three aspects proposed by Alba Arboix Alió [1]:

- parish churches as objects which contribute to the form and process of urban development;
- spatial relations between parish churches and their urban surroundings – the church as strong architectonic form which agglutinates a certain type of urban element (e.g. churches linked to a square, a passage or other public spaces);
- architectonic form of the sacral buildings and especially those elements which link them with the exterior space, such as a cloister garden, churchyard garden, portico, arcaded galleries, stairs, towers, campaniles and domes. These last elements do not organize the space around a church but are important elements of the city's skyline; they are visible from a distance and perform the role of reference point and facilitate orientation in the city. In this approach, the church's topographical situation in relation to its surrounding is also analysed.

The main research method has been terrain observation, which allows the spatial relations between the parish churches and their surrounding to be identified and to recognize elements which link them to the urban surroundings. Simultaneously, historical written and cartographical sources have been analysed. This allowed the time and circumstances of the parishes establishment and churches construction to be determined, their location selection, their architectonic form, their surrounding composition, its transformations and the church's influence on city development.

## 3. Parish structure development

Four of the analysed parish churches initiated development process of new settlements which have grown around the place of worship and were later incorporated into the city of Warsaw. These churches are: the Immaculate Conception of the Virgin Mary church (St. Catherine's parish) in Służew, erected in 1238, the St. Anna church in Milanów (later Wilanów), erected in the middle of the 13$^{th}$ century to the east of Służew, the St. Elizabeth church in Powsin erected in 1410 and the St. Anthony of Padua church with the Bernardines' cloister built in 1690–1693.

The historical churches were usually located in the centre of the settlement, often in the highest place (e.g. the church in Służew) or close to the residence of the landowner who founded the place of worship (e.g. the church in Wilanów). Some churches (e.g. the churches in Wilanów and Służew) were visually connected with and constituted an important element of the composition of the landowners' residential gardens. Churches were located along the main roads, which were parallel to the lineal elements of the terrain topography – the terraces of the Vistula river valley and the postglacial plain edge, the so-called "Warsaw escarpment". The historical roads became part of the street system of the present urban landscape.

The majority of the parish churches (twenty-one cases) and their urban surroundings were established almost at the same time. The ecclesial buildings were erected within newly built housing estates. The first new parishes were established after the Second World War. Other parishes were erected in the 1980s.

During the Polish People's Republic period, churches were built in less prestigious places which did not allow them to have a visual impact on the surrounding landscape. New churches, often surrounded by high blocks of flats, seemed to be 'pushed into' residential areas and were not perceived as landscape dominants [10]. An example of this kind of location is the church of Our Lady the Mother of Mercy in Stegny. An exception is the Lord's Ascension church in Stokłosy built in the centre of the housing estate, on the large square previously occupied by the marketplace, which was transformed into a representative public space. The church has unexpectedly become the dominant of the whole residential area [10] and the local centre which consolidates the surrounding housing estates. The last parishes were established after the decline of the Polish People's Republic in the 1990s and at the beginning of the 21st century. After the political transformation in 1989, because of the necessity for increasing the number of worship places, sacral buildings were often located in areas originally destined for other purposes. For example, the church of Blessed Edmund Bojanowski in Wolica was built on the edge of the escarpment, next to the natural reserve area because the local authorities could not find another location for the sacral building in this neighbourhood.

Table 1. List of the analysed parish churches and adjacent parish facilities within the southern Warsaw districts

| No. | Name of the church and parish | |
|---|---|---|
| 1. | St. Madeleine Sophie Barat church, the Sacred Heart of Jesus convent in Grabów | Church erected in parallel to housing estates |
| 2. | St. Thomas the Apostle church in Imielin | Church erected in parallel to surrounding housing estates |
| 3. | St. Pio of Pietrelcina church in Moczydło | Church erected in parallel to surrounding housing estates |
| 4. | Ladislas of Gielniow church in Natolin | Church erected in parallel to surrounding housing estates |
| 5. | Sts. Peter and Paul the Apostles church in Pyry | Church erected in parallel to surrounding housing estates |
| 6. | St. Dominique church and Dominicans cloister in Służew | Church erected in parallel to surrounding housing estates |
| 7. | Immaculate Conception of the Virgin Mary church (St. Catherine parish) in Służew | Church erected before surrounding housing estates |
| 8. | Lord's Ascension church in Stokłosy | Church erected in parallel to surrounding housing estates |
| 9. | Blessed Edmund Bojanowski church in Wolica | Church erected after surrounding housing estates |

| | | |
|---|---|---|
| 10. | Lord's Offertory church in Wyżyny | Church erected in parallel to surrounding housing estates |
| 11. | St. Antonio of Padua and St. John of Dukla churches (St. Boniface in Czerniaków parish) the Bernadine's cloister | Church erected before surrounding housing estates |
| 12. | Church dedicated to Mission of the Lord's Disciples in Kępa Zawadowska | Church erected in parallel to surrounding housing estates |
| 13. | Sanctuary of Our Lady Longing (St. Elisabeth parish) in Powsin | Church erected before surrounding housing estates |
| 14. | St. Thaddeus the Apostle church in Sadyba | Church erected in parallel to surrounding housing estates |
| 15. | Sanctuary of Our Lady Teacher of the Youths (Our Lady Queen of the Believers parish) in Siekierki | Church erected in parallel to surrounding housing estates |
| 16. | St. Antonio Maria Zaccaria church (Barnabite Fathers parish) in Stegny | Church erected after surrounding housing estates |
| 17. | Our Lady the Mother of Mercy church (congregation of Marianist Brothers and Priests parish) in Stegny | Church erected in parallel to surrounding housing estates |
| 18. | St. Anna church in Wilanów | Church erected before surrounding housing estates |
| 19. | Temple of the Divine Providence in Wilanów | Church erected in parallel to surrounding housing estates |
| 20. | Our Lady the Mother of the Church church in Ksawerów | Church erected in parallel to surrounding housing estates |
| 21. | St. Casmir the Prince church in Sielce (Resurrectionist Congregation) | Church erected in parallel to surrounding housing estates |
| 22. | St. Joseph the Betrothed to the Virgin Mary church (St. Stephan the King in Sielce parish) Sisters of Nazareth convent | Church erected in parallel to surrounding housing estates |
| 23. | St. Maximilian Kolbe church in Służewiec | Church erected in parallel to surrounding housing estates |
| 24. | St. Andrzej Bobola church in Mokotów | Church erected in parallel to surrounding housing estates |
| 25. | St. Michael Archangel church in Mokotów | Church erected in parallel to surrounding housing estates |
| 26. | St. Stephen church in Mokotów | Church erected in parallel to surrounding housing estates |
| 27. | Mary, Mother of God church in Wierzbno | Church erected in parallel to surrounding housing estates |
| 28. | Most Holy Mary the Mother of Saviour church in Wyględów | Church erected after surrounding housing estates |

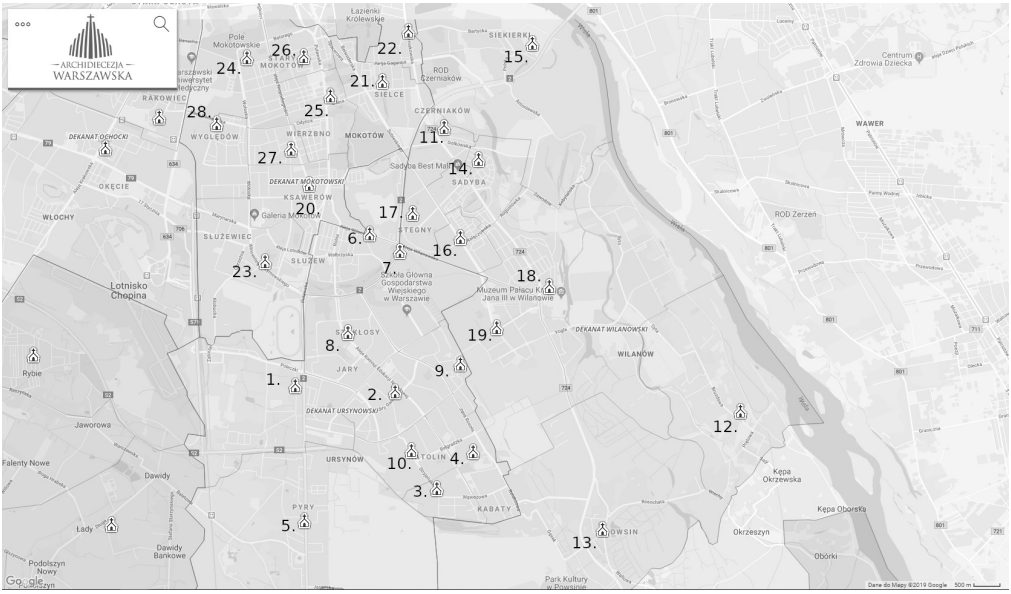


Fig. 1. Location of the analysed parish churches and adjacent parish facilities within the southern Warsaw districts. Church numbers according to the Table 1 (Own elaboration based on Warsaw parishes map retrieved from https://mapa.archwwa.pl)

## 4. The parish church and its surrounding urban elements

There are two types of relations between parish church and the urban elements which surround it. The first situation (represented by eight sacral buildings) is a church linked to a square (the Immaculate Conception of the Virgin Mary church, St. Catherine parish and St. Anthony of Padua church), a passage, or other public spaces such as gardens or passages. Particularly interesting are the Church of St. Anna in Wilanów, compositionally connected with the palace and garden complex of the former royal residence and the Lord's Ascension church in Stokłosy whose façade is the visual closure of the large square situated on the main compositional axis of the Pope John Paul II park.

The second situation is a church located directly along a street (twenty one churches). The majority of them (sixteen churches) are preceded by at least a small-sized open space created by the pullback of the church façade in parallel to the street or diagonally to the street.

Among churches of both types of spatial situation, there are sacral buildings whose relations with their surroundings are more extended. They are visible from many perspectives, both on the smaller and larger scales; they are distinctive architectonic forms, and actively create the image of the residential area. Two of them – the Immaculate Conception of the Virgin Mary church, St. Catherine parish and the St. Dominic church are located on the highest places. The third sacral building, the Temple of the God's Providence in Wilanów, because of the large-sized dome which crowns the building, constitutes a characteristic landscape element, a point of reference which can be identified from many distant perspectives.

Five parish churches have been situated on building plots located at the end of a street. They constitute the closure of the perspective view which strengthen their role in the urban landscape and visual impact. A good example of this is the Avenue of the Polish Republic leading to the Temple of Divine Providence in Wilanów, which has a particularly representative character.


Fig. 2. a). St. Madeleine Sophie Barat church in Grabów located directly along a street.
b). The Avenue of the Polish Republic leading to the Temple of the Divine Providence in Wilanów.
c). The Immaculate Conception of the Virgin Mary church, St. Catherine parish.
d). St. Anthony of Padua church. Both churches are preceded by intentionally designed squares compositionally related to the sacral buildings.

Fig. 3. The Lord's Ascension church in Stokłosy is the visual closure of the large square, situated on the main compositional axis of the Pope John Paul II park, which serves both liturgical and social activities

## 5. Compositional elements of sacral buildings which link them with exterior space

The most frequent compositional elements of the sacral buildings which link them with exterior space are stairs leading to the main church entrance. They are present in twenty-three churches analysed. In ten cases, the stairs consist of only a few steps and in thirteen churches they have a monumental character and they constitute the extension of the open space or the public square which precede the temple. In eleven churches, the entrance leads through the portico which symbolizes transition from the profane to the sacred sphere.

Three sacral complexes include a traditional cloister garden; however, they are isolated from the urban space and are not accessible to secular users. A large number of sacral complexes (fifteen) include at least a small garden surrounding the church and parish facilities. These gardens are open to the public during the whole week. They serve not only a liturgical function (e.g. processions), parish fairs and festivities, but are also used by local residents as a place for walking and recreation.

Half of the analysed ecclesial buildings have symbolical vertical elements (a tower or a dome) which are a visible reference point in urban landscape.

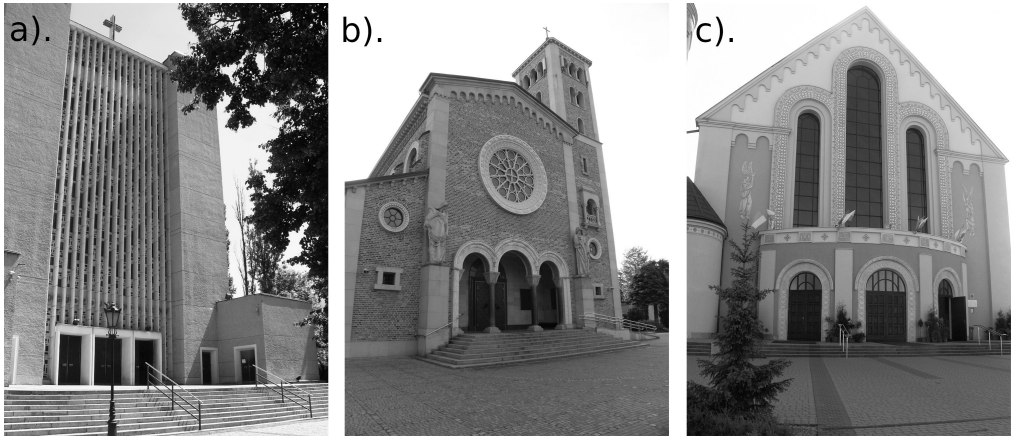


Fig. 4. Church entrances: a). the St. Michael Archangel church in Mokotów, b). the Sts. Peter and Paul the Apostles church in Pyry, c). the Lord's Offertory church in Wyżyny

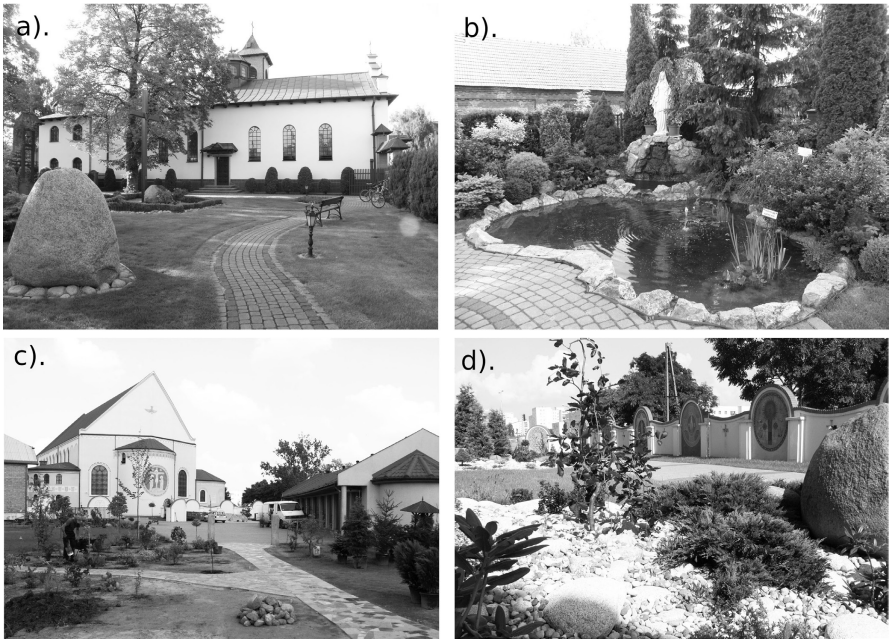


Fig. 5. a). and b).Garden surrounding the St. Madeleine Sophie Barat church and the Sacred Heart of Jesus convent in Grabów. c). and d). Garden surrounding the Lord's Offertory church in Wyżyny


Fig. 6. Fig. 6. a). The St. Anna church in Wilanów. b). The Lord's Offertory church in Wyżyny. Ecclesial buildings with symbolical vertical elements which are a visible reference point in the urban landscape. c). and d). Bell-tower building of the Our Lady the Mother of Mercy church in Stegny seen from different perspectives

## 6. Conclusions

The analysis of the parish churches' structural development is useful for understanding the process of urban landscape shaping. Within the analysed southern Warsaw area, initially rural settlements developed surrounding churches founded by Catholic religious orders or landowners and were later included within the city limits. Despite further urban development and changes in the buildings character, the layout of the historical roads leading to the churches and their originally formed surrounding (e.g. a square) have been preserved in the structure of Warsaw. New ecclesial buildings were erected in parallel to the new residential area. Unfortunately, because of the political conditions, new churches, erected during the Polish People's Republic, were not taken into consideration in the planning process for the new housing estates. This situation was common for Polish cities. The greater part of churches erected between 1945–1988 were 'pushed into' residential areas consisting of blocks of flats [10].

The parish churches have an important impact on their surrounding urban form. The ecclesial building often is set deeper back from the street than the other buildings or is preceded by a square. For this reason, it stands out from its background and its façade is clearly visible. The impact of the sacral buildings is bigger if the church nave's main axis is continued in the composition of surrounding urban space (e.g. in pavement layout, vegetation composition or representative avenue). The sacral buildings also possess elements such as stairs, entrance porticos or are surrounded by garden areas. They are transitional spaces between the sacred space of the church interior and the surrounding public space.

The area of the parish churches' influence often extends beyond their nearest surroundings (e.g. street, square). The majority of parish complexes includes vertical elements of symbolical character which are a clear reference point in the urban landscape.

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If you want to quote this article, its proper bibliographic entry is as follow: Kaczyńska M., *The role of parish churches and adjacent parish facilities in a city's spatial structure*, Technical Transactions, Vol. 6/2019, pp. 37–48.

TECHNICAL TRANSACTIONS 6/2019
ARCHITECTURE AND URBAN PLANNING
DOI: 10.4467/2353737XCT.19.060.10613
SUBMISSION OF THE FINAL VERSION: 3/06/2019

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# Fifty shades of Las Vegas

## Pięćdziesiąt twarzy Las Vegas

**Abstract**

A glass pyramid, a sphinx and a Medieval Excalibur, an Eiffel tower, a Statue of Liberty, a Ponte Rialto with an escalator and a canal sailed by gondolas with Mickey Mouse – these are the faces of Las Vegas. Kitsch, excess and chaos are concepts that form the universe of the semantics of Las Vegas. We can also attempt to understand this identity, distinct both in its unbridled form and the ideas represented by the city, by referring to Bakhtin's concept of the carnival.

**Keywords:** Las Vegas, kitsch, camp, art, architecture, city

**Streszczenie**

Szklana piramida, sfinks i średniowieczny Excalibur, wieża Eiffla, Statua Wolności, Ponte Rialto z ruchomymi schodami i kanał, po którym pływają gondole wraz z myszką Miki – oto oblicza Las Vegas. Kicz, nadmiar i chaos to pojęcia tworzące uniwersum znaczeń Las Vegas. Tę tożsamość, charakterystyczną zarówno w nieokiełznanej formie, jak i ideach reprezentowanych przez miasto, można próbować zrozumieć, odwołując się także do bachtinowskiej koncepcji karnawału.

**Słowa kluczowe:** Las Vegas, kicz, kamp, sztuka, architektura, miasto, karnawał

## 1. Introduction

2019 marks the fiftieth anniversary of Elvis Presley's first concert in Las Vegas. We can almost still believe that Elvis lives when walking down the neon streets of this brightly lit city, in which Elvis lookalikes not only sing or encourage us to buy hot dogs, but also preside over speed weddings. And, although it is sometimes said that it is Berlin, Paris or New York that never sleep, it is Las Vegas that truly never sleeps. It does not sleep, because the artificial horizon, the artificial sky and the artificial sun look much better than the genuine ones.

As Hermann Broch claimed, kitsch is created when truth is abandoned in favour of beauty [4, p. 114]. According to Broch the aims of kitsch are meant to be beauty and decoration, instead of *truth*, which should be the guiding principle of every active artist and the art that they create. It is difficult not to acknowledge that in Broch's already historical concept that features a highly averse attitude towards kitsch, which – as "the art of happiness" [11] – is a form that continuously escapes definitive assessment. Even though, after the pop-art revolution and the later concept of camp by Sontag, even the average audience of kitsch culture does not need to be ashamed of satisfying their aesthetic tastes and yearnings.

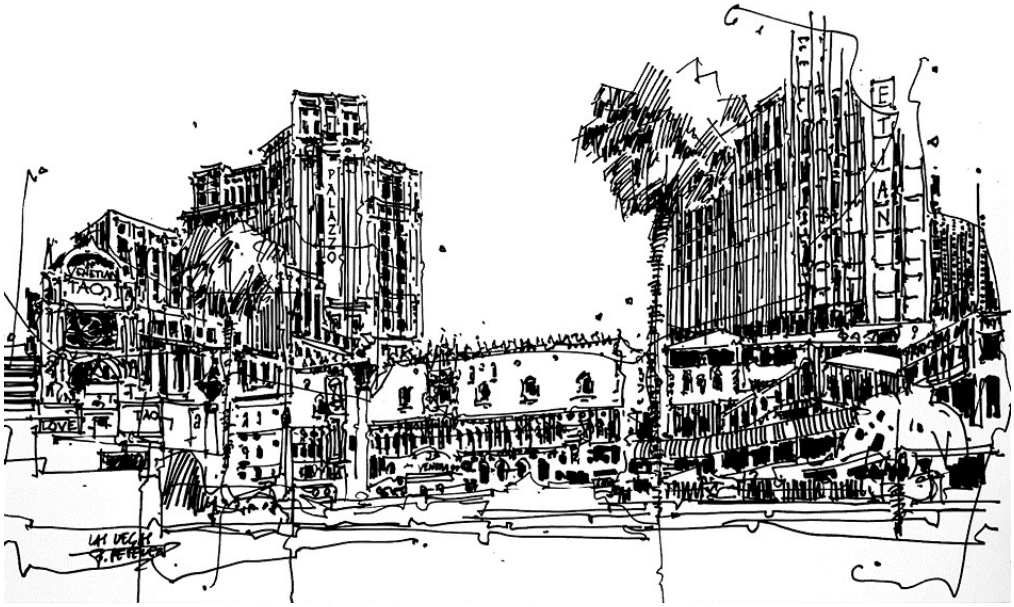


Fig. 1. "The Venetian" hotel and shopping mall complex, Las Vegas Strip, Las Vegas, Nevada; drawing by B. Malinowska-Petelenz

Susan Sontag, in her "Notes on 'Camp'" [16] made an attempt not only to redefine kitsch, but also to develop this aesthetic discourse. She described and placed within culture the aesthetic of excess called camp, in which kitsch takes on a new meaning, gaining an ironic context. According to Sontag, the fundamental criterion that defines camp is its intended artificiality, but also – from the historical notion of the intention truth of the artist – it relocates the axis of

significance onto the audience and its conscious. Camp is therefore not read in the categories of the artist, but the degree of stylisation; it is also a dependency between the observed object and the audience's cultural experience and sophistication. Sontag lists examples such as Art Nouveau, the gothic novel, the extreme hyperbole of femininity in Fellini's work, as well as the works of Gaudi. Camp, as an aesthetic of post-modernity, has the character of a collage, being full of analogies and references, irony and distance. Camp can also appear over time. That which was deliberately serious during its deliberate creation can become camp years later. This is clearly visible in Sergio Leone's spaghetti westerns, as today the famous "looks" have become cultural gestures and signs transformed by successive generations[1].

The transformation of meanings, their exploitation, modification and recycling are some of the permanent elements of the popular culture of the twentieth and the twenty-first century. Postmodernism, which made collage, quoting and references its modus operandi, has left us with a set of formal solutions that create an essential part of the visual heritage of the past decades. In the case of Las Vegas, continued postmodernism, transforming iconic cultural meanings into their pop and kitsch versions, create an entire universe of notions that form this extraordinary American city.

## 2. The essence of the American Dream

A glass pyramid, a sphinx and a Medieval Excalibur, an Eiffel tower, a Garnier's opera, a Statue of Liberty and a Brooklyn Bridge, towers of Manhattan, the MGM Grand and a di Trevi fountain, a Ponte Rialto with escalators and a canal, sailed on by gondolas with Mickey Mouse – these are the faces of kitsch that form Las Vegas – a striking and "hideous phenomenon of culture" [2, p. 83], as well as the "urban essence of American roadside architecture". In this case the city is formed by a desert highway surrounded by gilded sheds that glimmer with neon lights. The postmodernist opposition to big business and technocracy, which came to be symbolised by the tower buildings designed by Gropius and Mies van der Rohe, reached its peak in the growth of popular culture that Las Vegas turned out to be.

As Bogdan Paczkowski wrote, pop-art initially had no particular connection with architecture. However, who knows if the American Robert Venturi, considered to be the main inspirator of post-modern architecture, would have devoted so much attention to neon signs and advertising facades that decorate the hotels and casinos of Las Vegas if it had not been for Andy Warhol. In his book "Learning from Las Vegas" he suggested that we learn from the image of this city, contrasting the sterility and emptiness of modern architecture with the spontaneity and liveliness of the commercial street, full of signs, symbols and codes [13].

Both Reyner Bahnam and Charles W. Moore were precursors of an analytical perspective on America's commercial architecture. Its continuator was Venturi himself, the apologist of camp, who, along with Denise Scott Brown and Steven Izenour, in the "Learning from Las Vegas" [20] manifesto, performed an analysis of this city, which causes aversion in

[1] E.g. Quentin Tarantino, more [in:] [10].


Fig. 2. The legendary sign „Welcome to Fabulous Las Vegas" near the entryway to the city, Las Vegas Boulevard; phot. B. Malinowska-Petelenz


Fig. 3. The Strip, Las Vegas, Nevada; phot. by B. Malinowska-Petelenz

architects and aestheticians. The authors deconstructed modernist thought, or rather the vision of modernism that breaks away from romantic eclecticism, introducing sterilised and functional architecture that abolishes the dissonance between function and form, between massing and ornament. Venturi ennobled Disneyland, casinos and highways, and even the

ugly architecture of plastic roadside diners. He proved that it was Las Vegas that was the embodiment of the modernist dogma that form follows function[2], which is most fully realised in the hamburger stand, much more so than in the meticulous and abstract icon buildings following Le Corbusier.

The authors therefore weaved their narrative from the perspective of the car driver. In this story, the reader becomes a passenger of this trip [17, p. 84], a sort of partner in crime, in pursuit of a fresh perspective. The city, and especially its primary circulation axis – The Strip – is viewed from the window of a moving car. It attacks the observer with intrusive logos and billboards, banners, advertisements and neon signs creating an eclectic and loud architecture that is full of hyperrealist references, quotes and popular, poor symbolism. Venturi, thanks to this modernist simplification, clashes complexity with simplicity, clarity – with contradiction and ambiguousness. He simultaneously wrote of urban space as a circulation system [19]. From the pages of "Learning from Las Vegas" there emerges a portrait of a "frenetic prototype of one of the most fascinating metaphors of contemporaneity – the theme park"[3]. Venturi ennobled that which is ordinary and ugly, comparing The Strip with the Roman piazza, he elevated the streets of Las Vegas, teeming with life and lit with the light of neon signs, with their billboards and pop-culture symbolism that is understandable to all. America has, after all, drawn heavily on Europe, while also having given back quite a lot – in a manner that is distorted and covered with Disney gold.

The hallucinogenic image of Las Vegas functions in a landscape shaped primarily in the eye of the beholder sitting in a moving car, another myth of the American identity. The Las Vegas Strip is a contemporary parallel to Benjamin's passage, modified through the difference in speed. The speed of the motorised user of Las Vegas and the nineteenth-century flaneur, however, create two different social realities. This is why architecture in Las Vegas forgoes the facade ("first the symbol within the space, then the form within the space" [20, p. 24]), it is the advertisement signs that are the most important. Signs created with an audience in motion in mind, with a precisely calculated amount of information that a passerby is capable of registering over the course of two seconds.

Today's Las Vegas, even more different than the one described on the pages of Robert Venturi's book, is an effusion of an unending Bakhtin's carnival [21], a house of joy and Disneyland. The cultural carnival is "a world upside down", a world of inverted values and perverted meanings, a world in which more is allowed, and that which is not is almost beyond the boundaries of language and cognition. The carnival is a time of the death of a specific order, hierarchy and rules, a place in which Huizing's *homo ludens* finds their fulfilment and relief, and at the same time an unending encouragement for further entertainment. Las Vegas is, after all, the city of the artificial horizon and unending fun, of dizzying gambling and one night stands. A city that forgives, because *what happens in Vegas, stays in Vegas*, and it is therefore an almost perfect embodiment of Mikhail Bakhtin's concept.

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2 Form follows function.

3 Quote from the afterword by Anna Porębska, p. 222.

Fig. 4. The Lou Ruvo Center for Brain Health of the Cleveland Clinic, design by Frank Gehry, Las Vegas, Nevada, 2010; phot. by B. Malinowska-Petelenz

Ewa Rewers wrote that fantasy supported by electronics stimulates and multiplies its internal worlds in the self-sufficient spaces of casinos that gradually transform into environments of virtual and unending consumption [15, p. 137]. In Vegas, the real world disappears, replaced by a virtual version of the nightly world and images that appear truer than reality. The culture of old Europe plays the role of a point of reference here. It is neither imitation nor copying, or even a parody of semantics – wrote Jean Boudrillard in her concept of simulacra. It is rather an abandonment of reality in favour of its signs, the stopping of real processes using their operational copies, using a meta-stable, programmable and infallible machine, which provides all the possible signs of reality [3, p. 7]. The Venetian hotel complex, featuring a shopping mall and casinos, is such a hyperreality[4], in which imitations and technology reproduce reality, producing an entity that even better. It is a finished space, filled to the brim with icons collected from the most popular European postcards. We can find replicas of the most important elements that make up Venice there – along with the azure sky above the Canale Grande, the gondolas, the Ponte dei Sospiri, the Ponte Rialto and the bell tower of Saint Mark. There are also frescoes on the walls and ceilings of the Palazzo Ducale. Here, reconstructed objects – as Umberto Eco wrote – are marred by the original sin of "neutralising the past and identifying the copy with the original" [5, pp. 11–73]. By creating copies of reality and fabricating realistic originals of the models of Apollo Belvedere, the di Trevi Fountain and Augustus Caesar, we perform an act of forgery and manipulation[5]; This kitsch is therefore a replacement experience, yet one that is striking nonetheless. Kitsch does not require anything but money from its consumers – not even their time [7, pp. 34–49].

[4] More [in:] [6].

[5] Eco wrote of the Palace of Living Arts in Buena Park, Los Angeles: *Filozofia właściwa dla Palace nie głosi: „We are giving you the reproduction so you will no longer feel any need for the original. But for the reproduction to be desired, the original has to be idolized, and hence the kitsch function of the inscriptions and the taped voices, which remind you of the greatness of the art of the past"*; quoted [from:] [6, p. 19].


Fig. 5. Las Vegas Library and Discovery Museum, design by Antoine Predock, Las Vegas, Nevada, 1990; phot. by B. Malinowska-Petelenz

## 3. Size and splendour

However, prestigious and impressive buildings by outstanding architects do get built in Las Vegas. Nevertheless, claiming that they define the city's character and the direction of its development would be far from the truth. Although often built using the best materials and characterised by high class design, they remain difficult to identify in the sea of plastic, excessively colourful logos, flashing, attention-grabbing neon signs or the tangle of meanings, functions and proportions of the entirety of the surroundings. Today, twenty storeys tall hotel buildings and casinos, interspersed with swimming pool complexes and entertainment and congress halls, are taking up larger and larger parts of the city[6]. Fortunately, new avenues and structures of smaller size are being built, such as the aesthetic-shock-inducing, dancing and dynamic, almost Baroque Lou Ruvo Center for Brain Health[7] by Frank Gehry or the Las Vegas Library and Discovery Museum[8], built according to a design by Antoine Predock.

This last building is a particularly important example of serious and beautiful architecture which has resisted the omnipresent trumpery. The structure, with a rich visual expression,

[6] More [in:] [18, p. 68].

[7] The Lou Ruvo Center for Brain Health of the Cleveland Clinic, design by Frank Gehry, Las Vegas, Nevada, 2010; academic centre focused on conditions of the brain - particularly Alzheimer's and Parkinson's diseases, which also performs prophylactic checkups for risk group members.

[8] Las Vegas Library and Discovery Museum, design by Antoine Predock, Las Vegas, Nevada, 1990


Fig. 6. The CityCenter complex, with the Crystals shopping centre in the foreground, design by Daniel Libeskind, 2009; in the background: Veer Towers, design by Helmuth Jahn and Mandarian Oriental, design by Kohn Pedersen & Fox; phot. by B. Malinowska-Petelenz

built according to the modern regional style, is clearly linked – both in form and colour – with the desert environment, in which it was created. Antoine Predock found inspiration in the local architecture of the South West and – similarly as in his other projects – avoided banal reproduction, instead proposing imaginative and highly individual variations on traditional subjects [6, p. 82].

As a part of improving the image of the city, in the very centre, near the Las Vegas Strip, between the famous Bellagio and Park MGM Las Vegas hotels, on 27 hectares, a gigantic, mixed-use complex of casinos and hotels, the CityCenter[9] has been built. It is composed of six glass tower buildings, each signed with the name of a famous architect, furnished with artworks by world class artists[10] and packed with advanced technologies. Without a doubt, it is the twin Veer Towers (with a residential function, designed by Helmut Jahn) that are the most distinct, slanted by 5 degrees relative to each other[11]. Two facades in the form of a checkerboard of yellow panels and glass were covered with a veil of metal blinders. The remaining buildings include the Aria Resort & Casino[12] – a gigantic hotel with 4004 rooms, luxurious apartments and a casino composed of two tower buildings built on an arch-shaped plan (of which one was placed from

[9] Opened in December 2009.

[10] E.g. Nancy Rubins, Franka Stelli, Henry'ego Moore'a, Richarda Longa.

[11] More [in:] [18, pp. 152–155].

[12] Aria Resort & Casino, designed by. Pelli Clarke Pelli Architects,


Fig. 7. "The Tree House", designed by. Rockwell Group, CityCenter complex, design by Daniel Libeskind, 2009; phot. by. B. Malinowska-Petelenz

the front with its convex side, while the other with the concave one), a hotel belonging to the Mandarin Oriental chain[13], Vdara Hotel & Spa[14] as well as the Harmon Hotel[15]. At the base of this gigantic complex are the silvery titanium massings of the Crystals shopping centre by Daniel Libeskind, dynamically shaped as if having been broken up.

In Las Vegas every sensation has to be grand, unforgettable and unique, although situated on a paradoxically common reproduction and repetitiveness. The aforementioned CityCentre is an enormous urban structure, which at first glance should stand out from the gaudy theme park surroundings. It is a closely-packed complex of elegant big city tower buildings with modern silhouettes, standing among low-rise kitschy buildings. However, as it happens, the impact strength of individual forms adjacent to CityCentre has remained dominant. Kitsch and chaos win – using elements that are "purely external, the easiest to claim and put to use" [13, p. 228], generating, in effect, a spatial, urban and architectural anarchy. Not even the considerably-sized "Big Edge" sculpture by Nancy Rubins, standing at the foot of the CityCenter complex, can power through this chaos and hyperstimulation. Rubins' sculpture looks perfect on photographs, but in reality it blends in and disappears in the context of the excessively colourful and loud space, in which nothing is important, yet each and every element would clearly like to be such.

13 Mandarian Oriental, desinged by. Kohn Pedersen & Fox,
14 Vdara Hotel & Spa, designed by RV Architecture,
15 Harmon Hotel, design by Foster+Partners,

Fig. 8. "Fiori di Como" – suspended glass ceiling by Dale Chihuly, Bellagio casino and hotel, Las Vegas, Nevada, 1998; phot. by B. Malinowska-Petelenz

Just a couple of months ago, the Hotel Palms Casino Resort added the purchase of Damien Hirst's[16] gigantic work "Demon with bowl"[17] (an almost twenty-metres tall sculpture[18] of a headless beast-like athletic figure) to this melting pot of visual stimuli. The building already has a bar designed by Hirst, which features his thirteen-metre long shark in formaldehyde kept in three steel tanks – one of the artist's iconic works. Similarly, Wynn Hotel Las Vegas (designed by Marnell Corrao Associates), which – apart from such banal attractions like a waterfall and a lake inside the building – attracts visitors through fashionable and big art: at present – with a statue of Popeye by Jeff Koons [1]. Koons – ever the chief scandalist of contemporary art[19], one who does not even try to hide his love of kitsch – was a perfect fit for this space.

We can also add the Japanese artist Yayomi Kusama – whose works could be seen at the Bellagio[20] hotel for a couple of months[21] – to the group of eminent artists who perfectly blend in with the hybrid aesthetic of Las Vegas, while still appearing as question marks in the conscious of the arts consumer. The artistic aspirations of this place are also signified by Dale Chihuly, an American sculptor and author of large-format glass installations, who is also the author of the monumental Baroque glass ceiling in the main hall of the famous hotel.

16 A British artist of the Young British Artists generation

17 The work's original copy already had its presentation, which took place in 2017 For the purposes of the *Shipwreck of the Unbelievable* exhibition in the museum of the collector Francois Pinault – Palazzo Grassi in Venice, it was made from resin. It was believed that a metal version would be too heavy. After the end of the exhibition the resin statue was destroyed, quoted [from:] [22].

18 2017, Venice, Palazzo Grassi and Punta della Dogana, „Treasures from the Wreck" exhibition.

19 „Made in heaven" is one of his more well-known and kitschy works – a cycle of works inspired with Koons' and his wife's – Ilona Staller, also known as Cicciolina – erotic life. A couple of years after their divorce (the marriage lasted a year) Koons destroyed most of the works.

20 At the Bellagio Gallery of Fine Arts, to be precise.

21 Between November 2018 to the end of April 2019.

Fig. 9. Paris Las Vegas – view from Bellagio hotel (photo by B. Malinowska-Petelenz)

Meanwhile, Kusama is a Japanese artist who has lived in a mental institution for many years and is also one of the best-selling active contemporary artists. Polka dots are a distinct element of her works. Kusama loves repetition and simplicity, which she transforms into so-called *Infinity rooms* – spaces that resemble historical mirror galleries, but in the case of Kusama they are without the element of deformation. Ornamentation does appear, however – in small lamps, the aforementioned polka dots and glistening metal details. Such an installation is not simply viewed – it is experienced, by entering it and typically taking dozens of photographs. The matter was similar in the case of the installation in Las Vegas – at the Bellagio Gallery of Fine Arts [23], Kusama exhibited two of her works: "Narcissus Garden"[22] and "Aftermath of Obliteration of Eternity". In the first, a room was filled with 750 suspended steel spheres, while in the other, delicate LED lamps. In both cases, ideally infinite, overaestheticised spaces that praise the visitor and place them on a pedestal of the entirety of the experience. And although it is difficult to conclude whether Kusama creates kitsch, design or art of the Instagram generation (infinity rooms are excellent spaces for taking selfies), it is certain that these hybrid works belong to some of the most popular and bestselling artworks around the world, constituting an intriguing field for negotiation between art and entertainment – in both variants creating a high-quality immersive experience.

[22] A smaller version of the installation „Narcissus garden", initially presented in Venice during the 33rd Arte Biennale.

## 4. Conclusions

Las Vegas is a stunning city. A city that devours, that never has enough fun, lights, money and consumption. It is a city of casinos, of Bugsy, a city of many a film dream – from the classic "Casino" (directed by Martin Scorsese) or "Leaving Las Vegas" (directed by Mike Figgis), through the oneiric "Fear and Loathing in Las Vegas" (directed by Terry Gilliam), to "The Hangover" (directed by Todd Phillips). Las Vegas is a city that does not sleep, does not fast, does not rest – after all, the show must go on and the louder, the better.

Las Vegas is also a melting pot of the best and worst achievements of the culture of the end of the twentieth and the beginning of the twenty-first century: flooded with plastic and cheap advertisements, but also the best and most expensive of what architecture has to offer. It offers fun from cheap roadside diners, but also *exclusive entertainment* from five-star hotels, in which even the greatest vices take on the character of luxurious and almost elegant amusement. It is also a city that presents front-page art that makes the headlines of sales reports. It is a city of kitsch, camp, wealth and trumpery – a city in which every element of the aesthetic discourse gets a sudden shot of botox, after which everything appears larger, fuller and more engrossing. Right until the end.


Fig. 10. The Strip, Las Vegas, Nevada; drawing by B. Malinowska-Petelenz

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TECHNICAL TRANSACTIONS 6/2019
ARCHITECTURE AND URBAN PLANNING
DOI: 10.4467/2353737XCT.19.061.10614
SUBMISSION OF THE FINAL VERSION: 3/06/2019

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# Applying the idea of creativity – *creative syntax* as a tool of placemaking. Case study of the downtown area of Poznan in Poland

# Wdrażanie idei kreatywności – *creative syntax* jako narzędzie placemaking'u. Przykład śródmieścia Poznania

**Abstract**

The aim of this study is to draw attention to the necessity of creating places revitalizing social life within the downtown public space. It is to underline the necessity of creating the scenographic background of the city life, through the creation of specified urban elements which have an impact on the city's choreography. The study employs a multicriterial, original research method which allows the subject matter to be examined within the following aspects: spatio-compositional, semanto-perceptive, and socio-economic. As a result of investigation, the desired direction of the development activities has been achieved within the scope of the utilization of the trump areas for the creation of a creative public space and within the scope of the utilization of the deficit space for the creation of places – focal points of spatio-social activity contributing to the revitalization of the downtown area.

**Keywords:** creative syntax, public space, spatial and social attractiveness

**Streszczenie**

Artykuł prezentuje badania dotyczące tworzenia miejsc aktywizujących życie społeczne w przestrzeni publicznej centrum miasta. Artykuł przedstawia przeprowadzone przez autorkę badania ścisłego obszaru centrum Poznania z zastosowaniem wielokryterialnej metody dotyczącej aspektów: przestrzenno-kompozycyjnych, semantyczno-percepcyjnych i społeczno-ekonomicznych. W wyniku badań sformułowano pożądany kierunek działań rozwojowych w zakresie wykorzystania przestrzeni atutowych do tworzenia kreatywnej przestrzeni publicznej oraz w zakresie wykorzystania przestrzeni deficytowej do tworzenia miejsc aktywności przestrzenno-społecznej. Działania te mogą wpłynąć znacząco na ożywienie przestrzeni publicznej centrum.

**Słowa kluczowe:** syntaksa, przestrzeń publiczna, przestrzenno-społeczna atrakacyjność

## 1. Introduction

Nowadays, in Polish development conditions, creativity, culture and art may be considered as important factors conducive to the revival of the downtown space, both in the spatial as well as the socioeconomic dimension. This research is based on the assumption that the creative space is to revive the downtown, providing an egalitarian, vibrant, friendly and changing public space, where the most important thing is to create opportunities for interaction and social contacts, as well as to educate and inspire through the development of creative potential[1].

Areas of creativity – *creative syntax* at work are understood as a planned spatial arrangement which favours the synergy of creative activities and increasing demand and supply in the field of creativity [14]. While designating areas of creativity, it is necessary to take into account functions related to culture and art, because the creation of enclaves in downtown districts, where culture supports creativity, is a significant opportunity for development, which supports the vitality of the Old-Town districts. Owing to the location advantages of the city centre, such as the proximity of public and private institutions, organisations or companies operating within the realm of art and culture, it is possible to increase synergy and exchange of activities and ideas, as well as co-operation between these entities.

When defining creativity, the author refers to Landry [4,10] who understands it as a readiness to unconventional, flexible interpretation and assessment of changing conditions and situations in which tradition is as attractive and desirable as modernity. Creativity can be an element conducive to the creation of public space that supports the exchange of ideas, resources and goods, and also provides a full spectrum of social interactions.

The importance of these aspects of public space is also emphasised by Rykwert [12, pp.25, 30], who claims that the climate and substance of the city are always perceptible to residents and visitors. Spatial resources, consciously or subconsciously absorbed, seen, touched, permeated, represent a graspable representation of something intangible, i.e. the identity and culture of the local community. Representation is understood as reflection, intention or project, because urban tissue and the image of the city are always the result of human will. The city is never passive. There is still a continuous interaction between man and matter and image – changing the space we change the society and vice versa. Each description of the physical shape of the city, which can be drawn up on the basis of a movement pattern, reflects a constant and subtle dialectic between the recipients of the space and the physical form that surrounds them, which affects the image of the city as radically as economic or political life[2].

This paper discusses the issues of culture and art in the urban space, which, in the author's view, constitute important elements of creative space equipment, balancing meaningfully between the real and the emotional world. The role of culture and art in city life and development can be summarised in four areas [18]:

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1 The author understands the creative potential as a functional basis, which can underpin the development of creative features, stimulating social change, and thus favouring the generation of economic benefits. Creative potential expressed spatially is the concentration0 of economic activity in the field of the creative sector.

2

- Semantic – as a cultural offer contributing to the creation of the city's image,
- Spatial – understood as cultural districts of high attractiveness for new residents and significant developmental and social dynamics,
- Social – in which culture is an important factor integrating the local community and strengthening the identity of the place, as well as
- Economic – according to which culture and art should be perceived as elements constituting a strong tourist magnet and of great importance in the context of promoting the city.

Perceiving the areas of creativity as a *creative syntax* was adopted in relation to linguistic meaning, in which syntax means a system of formal dependencies between individual elements. Syntax is a system composed of individual elements such as words, relationships and rules that allow you to create an infinite number of yet unknown phrases [20]. The area of creativity – *creative syntax* is defined by the author as a well thought-through spatial arrangement of surface character, characterised by concentration of creative potential and compositional values, as well as high visual attractiveness and emotional significance.

The assumption of determining the areas of creativity is to articulate assets existing in the downtown and indicate deficits, which owing to creativity have a chance for development and activation.

Deficits are considered in the context of the possibility of transforming them into assets, thanks to the synergy of activities, places and creative potential. The main goal of forming creative areas – *creative syntax* is to increase the attractiveness of the downtown space understood mainly as the attractiveness of the place, expressed by spatial, functional, social and economic qualities that form the basis of the placemaking idea. In this sense, the area of creativity is perceived by the author as a stage equipped with scenography, and people are participants who succumb to urban choreography.

In the context of the relativity of space with the recipient, issues related to the urban composition are essential. Searching for the right solutions, it is crucial to explore the existing downtown space in terms of the possibility of adapting it to new needs – playing a story of everyday and unusual life in a temporary urban theatre. In this sense, the role of an architect-urban planner is not limited to creating a scenography background for urban life, but above all, it is meant to influence the choreography of the city by creating specific affordances. Shaping the interdependence of participation in urban life, creating cognitive values of urban space, which are subordinated to the multi-sensory reception and interaction of space, affects the recipient's satisfaction interacting with the city, providing him/her with a full range of positive emotional experiences related to comfort, convenience, security or pleasure. The concept of designating creative areas – *creative syntax* should be seen as a possibility to stimulate economic gains and downtown district activation[3] because the creative potential on the one hand translates into direct financial effects for the city, and on the other hand – into indirect profits – understood in the context of the development of tourism potential based on

[3] Hawkins [5] notes that in today's world, people who own ideas have much more potential than owners of material goods.

the use of existing districts of unique character and constituting the basis for the development of the economy of experience, economy of sensations [5,8] The growing demand for experience goods is an opportunity to develop the cultural offer of the city centre, due to the special atmosphere, authenticity, uniqueness and sense of community with other recipients. An important factor is also the quality and aesthetics of public space, which together with a wide cultural offer can activate almost pro-consumer participation in culture [13, p.194-195][4]. Throsby [16, p.73] emphasizes new orientations and changes in the modern economy, speaking of a departure from a standard model focused on goods for the sake of a new model focused on people.

The success of the experience economy depends to a large extent on the attractiveness of urban space, which is why in the research it is so important to provide space in the downtown area (placemaking idea), whose cognitive value will be interesting enough to attract new customers – residents and tourists – and thus affect the economic activation of the area.

## 2. Research idea – the role of culture and creativity in downtown development

The essence of these considerations is an attempt to translate the existing spatial values of a downtown area into desirable effects of social vitality and specific economic results. The research is to define the idea of creative syntax and introduce an original method of identification, assessment and promotion of creative potential located in the city centre to improve the attractiveness of spatial offer and to strengthen social revival and economic activation. Creative potential, which is defined as a concentration of economic activity of the creative sector, is understood as an opportunity to develop creative functions that serve to revitalize and increase the attractiveness of the city centre thanks to culture and art. In this approach, it is very important to articulate the individuality of places through the introduction of the urban equipment specially designed for the given space within a participatory planning process. This idea is close to the assumptions of design intervention. The aim is to individualize the place taking into account the function of time – the users change and so do the needs and visions, therefore the spatial equipment should alter in a certain scope as well. The temporal perspective of proposed urban furniture is short – up to two or three years. Nevertheless, it is crucial to ensure continuity of these short-term solutions' implementation and to understand it as an investment in the development of social capital, in which profits may appear on the longer time horizon. The key element of the work is to study the role of the identified creative syntax in the context of stimulating social activity, revitalizing the inner city space and providing the basis for the development of the innovative idea of an experience economy [8,17], the application of which can positively affect city economy.

The research concerns three problem areas:

1. recognition and spatial designation of areas of creativity – creative syntax, due to the presence of features recognized by the author's methodology,

[4]

2. comparative analysis within the scope of the designated creative syntax and a system of their spatial connections,
3. designation of a sequential road offer system within the given creative syntax, for which the spatial and emotional value was evaluated in relation to the adopted compositional and visual determinants and distinguishing features, as well as the degree of road attractiveness in various ranges quality – instrumental, experimental and semantic – with reference to the marketing tool "AIDAS" – Attention, Interest, Desire, Action, Satisfaction [15, p. 58].

The starting point for the research was the diagnosis of the role of creativity and culture in the development of the analysed cities, on the basis of the European Union ranking – "Cultural and Creative Cities Monitor"[5]. For the author, the most important ranking of the tool "Cultural and Creative Cities Monitor", is the index of cities of culture and creativity "C3", developed by categories with regard to their size and population. It presents quantitative data on creativity and culture in cities, included in twenty-nine indicators relating to nine dimensions reflecting three main aspects: cultural, social and economic viability of cities:

1. The aspect of cultural viability – studied in the field of cultural infrastructure and participation in culture,
2. The aspect of creative economy – illustrates the role of the culture and creativity sectors in the economic recovery, through the creation of new jobs and the development of innovative potential,
3. The aspect of a favourable environment – identifies tangible and intangible assets that help cities attract creative talent and stimulate cultural involvement.

In her research, the author refers to all three aspects of evaluation included in the "C3" ranking, which were taken into account and interpreted in terms of composition, offer and semantics, assessed according to the adopted, original method. The aspect of cultural viability is examined in the compositional and spatial layout devoted to the identification of the presence of creative functions within the city centres of the cities studied. The aspect of creative economy is included at the level of identifying a conducive *milieu*, which is a development potential in the field of creativity, resulting from accumulation of spatial activities related to the creative sector. The aspect of the desired environment is examined in the compositional-semantic layer of the selected, most attractive sequences defined within the creative areas – *the creative syntax.*

According to the adopted methodology, the *creative syntax* area is composed of linear systems and smaller surface elements that occur in specific spatial and semantic relationships. The author defines them in the following way:

1. rules: expressed in the form of linear connections of designated surface systems of creative areas – *creative syntax*, in order to ensure the desired compositional and offer gradation;

[5] "Cultural and Creative Cities" is a tool for monitoring and assessing the functioning of culture and creativity in European cities, using quantitative and qualitative data. Source: [19].

2. relationships: spatial, semantic, perceptual and sensory, underlying the designated sequential road offer systems, which serve to underline the compositional and spatial values of the system, as well as to clearly translate semantic values and aesthetic and emotional experiences into the spatial language;
3. words: individual elements delineated within the creative area – *creative syntax*, with free access to – creative public spaces or of local character – places understood as focal points of social activity that provide spatial flexibility, changeability of functions and attractiveness of the spatial offer to provide information about the social revival of the downtown areas.

## 3. Research method[6] – *creative syntax* as a tool of the placemaking process. Case study of the Poznan downtown area

The city of Poznan was chosen by the author as the case study for detailed research. Poznan ranks second in the field of culture and creativity according to the "C3" index by "Cultural and Creative Cities Monitor" just after Warsaw which, as the capital of Poland, is of other scientific interest. Poznan's position is strong especially in the aspect of the creative economy. According to the "C3" index, Poznan is shown to be the definite leader in terms of the number of new jobs in the creative sectors and it also has good grades for a creative environment, especially in the areas of human capital, education as well as local and external accessibility.

The research was carried out in three stages. The first stage is used to identify the existing situation regarding the occurrence and concentration of creative potential, as well as the identification of advantageous and deficit spaces and their compositional-spatial connections. The result is presented in graphic indications in the form of dots illustrating the spatial location of businesses provided with creative activities. About 4620 registered activities were identified on a surface of 812 ha, which makes approximately 48.6% of the entire downtown area (Fig. 1).

The second stage involves designating creative areas – *creative syntax*. Areas of creativity – *creative syntax* have been set within the city centre of Poznan, minimized according to the provisions of existing planning documents. In order to determine the areas of creativity – *creative syntax* – a business situation related to the creative sector was diagnosed, which, according to the author, constituted the desired milieu conducive to the development of creativity. Then areas of concentration of creative potential were indicated as representing the most favourable spatial environment conducive to activities serving the development of creative functions and, as a result, a social revival of the downtown space; thus providing the basis for its innovative economic activation. The combination of creative potential is, according to the author, a *sine qua non* condition for designating creative areas – a *creative syntax.*

In the next step, the spaces characterised with the desired features were indicated – built-up and undeveloped structure related to the existing creative functions as well as the deficit space – depreciated built-up and undeveloped structure. The elements identified are connected by

[6] This research method is thoroughly presented in the book written by this author concerning this issue [11].

public spaces of a detaining or leading nature, both with hardened surfaces (streets, squares) and soft surfaces (squares, parks). By identifying these elements, it is possible to determine the areas of creativity – *creative syntax* (Fig. 2).

The third stage of the research concerns the designation and detailed evaluation of a selected sequential road offer system within creative areas – *creative syntax* (Fig. 3). The continuity of the picturesque sequences of the sequential road offer system was assessed along with the main distinguishing factors for impressions affecting the quality of spatial relationships, constituting the basis for qualitative assessment according to accepted determinants of spatial values in accordance with the perceptual-experience pattern of orientation / experiencing / remembering. Analysis of the selected sequential road offer system concerned accentuation and string rhythmisation (dominants, accents, directions), of sequential rhythms (urban interiors of leading and retaining character) as well as perceptual continuity and continuity of functions.


Fig. 1. Identification of the existing creative potential defined by research within the city centre of Poznan (author's own elaboration)

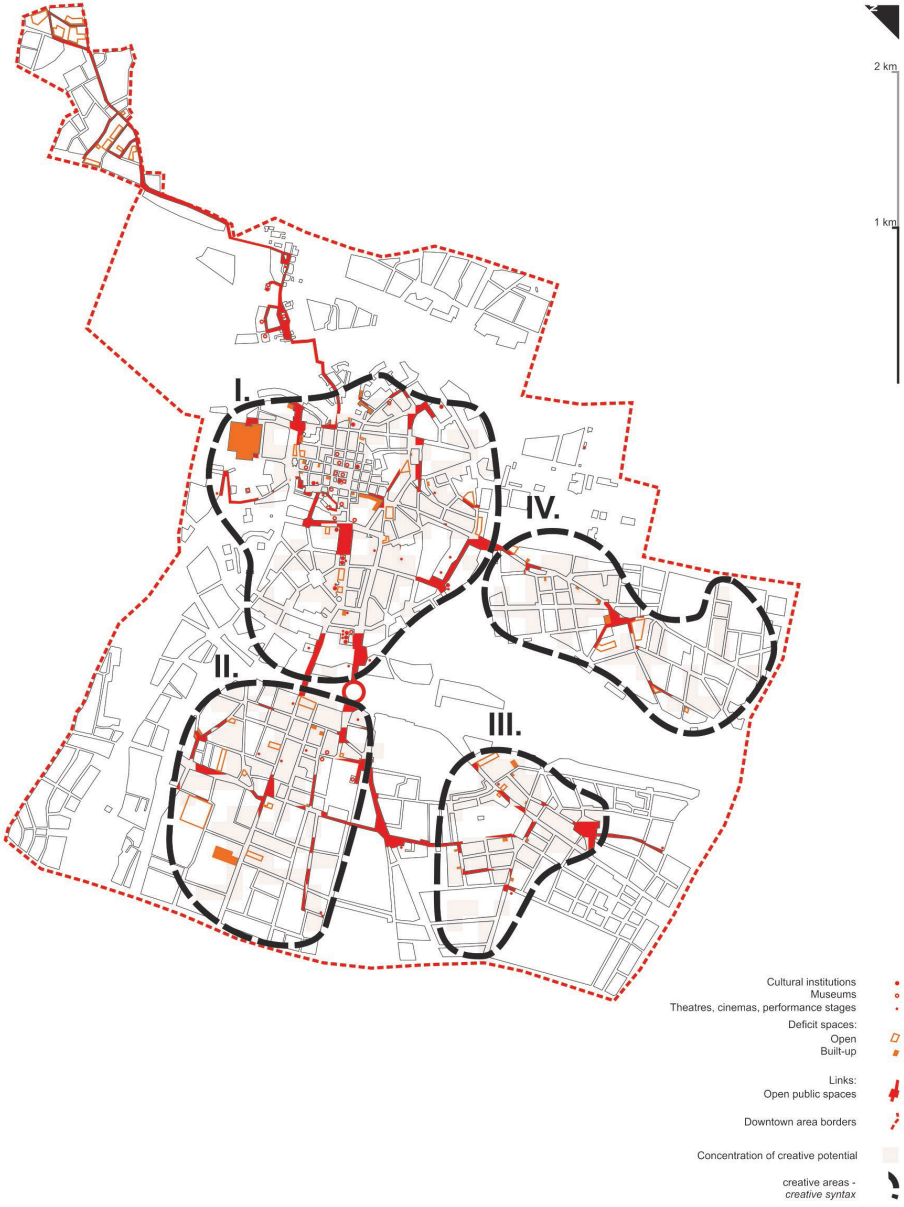



Fig. 2. Identification of spaces with desirable features and deficit spaces and their connections in relation to the concentration of creative potential, as well as designation of creativity areas – *creative syntax* within the city centre of Poznan (author's own elaboration)

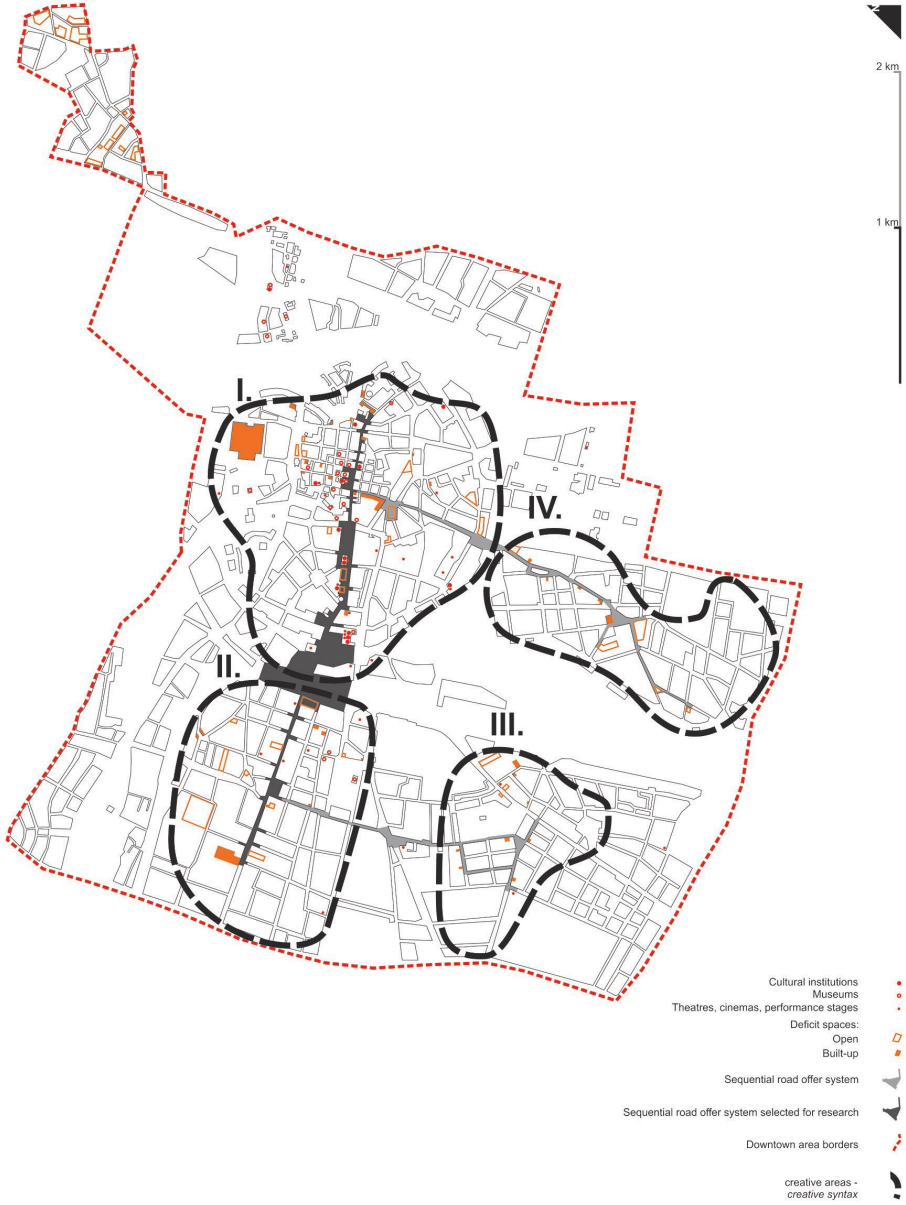



Fig. 3. Indication of the sequential road offer system chosen for the detailed research including Main Market Square (marked with black outline) within the designated areas of creativity – *creative syntax* within Poznan downtown (author's own elaboration)

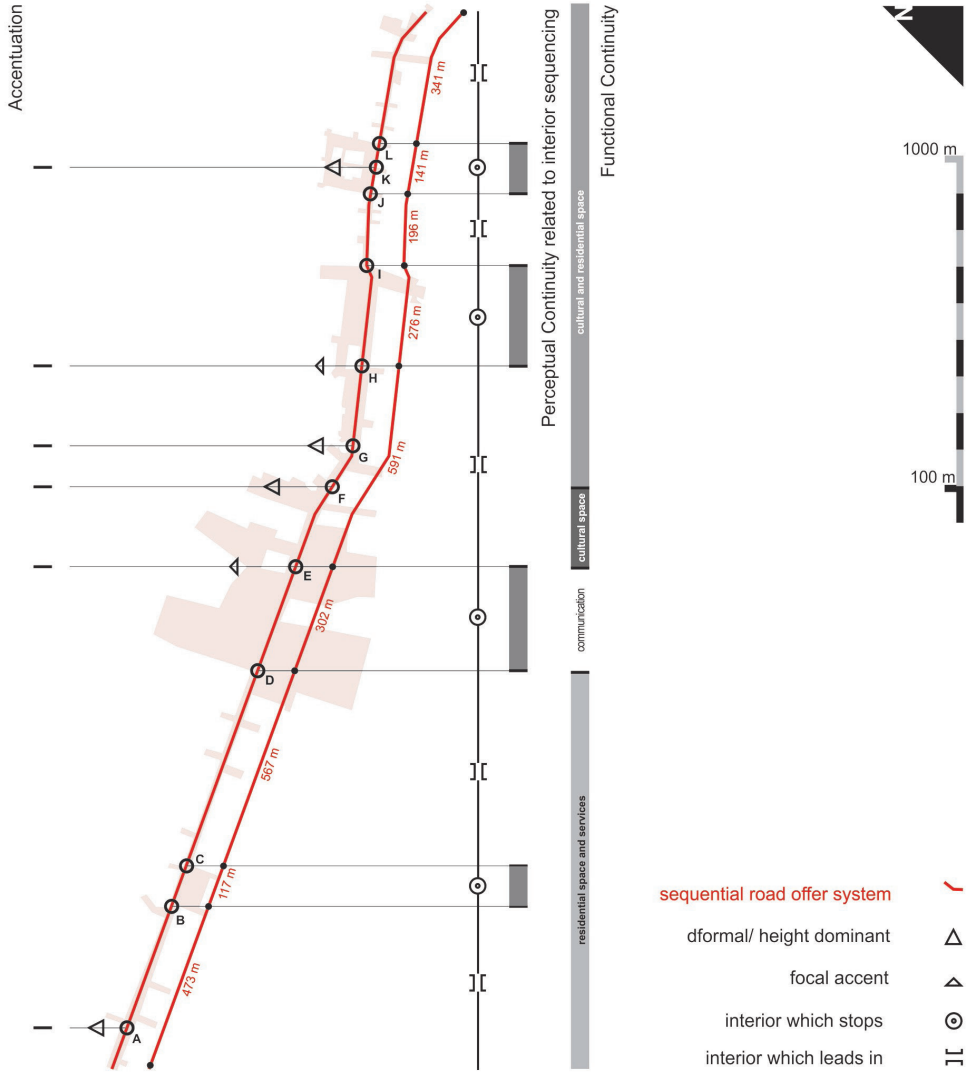



Fig. 4. Valuation rating regarding the continuity of scenic sequences and main distinguishing factors affecting the quality of spatial relationships of a selected fragment of the sequential road offer system within the designated areas of creativity – *creative syntax* within the city centre of Poznan. Road offer system including Main Market Square (author's own elaboration)

As a result of the research, at this stage, the creative area was assessed – *creative syntax* – using the semantic differential method to determine the degree of spatial stimulation according to the adopted classification. The assessment of the degree of attractiveness of the functional and spatial offer of the sequential road offer system with the use of a marketing tool which presents the emotional template of supply and demand for creativity and by creativity has also been carried out.

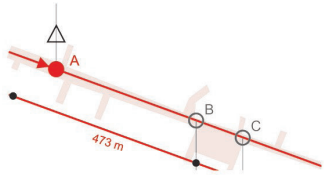
Following the author's method, the assessment was made of the sequential road offer system in terms of instrumental, sensory and semantic determinants of spatial values. The evaluation of separate fragments of road offer system divided by identified sequential views from A to K sections were done to valourize it in reference to three aspects: the spatial layer – orientation (intuitive or forced), the sensory layer – experience (stimulating or silencing), and the semantic layer – remembering (positive or negative) what is presented below in the graphic way (Fig. 5).

The result of the research are recommendations regarding actions that should be taken to revive the downtown space through creativity within indicated creative public spaces and places understood as socio-spatial activity focal points. The proposed directions of action are: preservation, development and stimulation of local values. The spaces marked with a black outline were selected for preservation or development (Fig.6). For the preservation there were intended those spaces for which the determinants of spatial values of instrumental, sensory and semantic quality were the highest rated, which means the following evaluation: intuitive orientation, stimulating experience, positive remembering. Spaces of desirable features in which there was identified the lack of one of the three components in terms of instrumental quality (orientation), sensory (experience) and semantic (remembering) were qualified for development. In these spaces, which are locally related to existing creative functions, it is recommended to introduce new elements of public space equipment that, through their artistic and creative value can provide new stimuli that increase spatial development.

Deficit spaces were designated for stimulation (marked with an orange outline in the case of spatial gaps and orange filling in built-up areas), the assessment of which showed the largest deficiencies in instrumental (orientation), sensory (experience) and semantic (remembering) layers (Fig. 6). These spaces were diagnosed as those with the highest development potential, in which it is recommended to create places that can be socially activated through the use of creativity, both at the level of function and urban equipment.

**VIEW A IN SEQUENTIAL DRAFT / ROAD DIRECTION FROM LEFT TO RIGHT**

| INSTRUMENTAL DETERMINANTS OF SPATIAL VALUES | |
|---|---|
| ORIENTATION | |
| ORDERLY | DISORDERLY |
| PLANNED | UNPLANNED |
| STABLE | UNSTABLE |
| COMPACT | DISPERSED |
| HOMOGENIC | HETEROGENIC |
| CLEAR | UNCLEAR |
| REGULAR | IRREGULAR |
| SUMMARY OF SEMANTIC DIFFERENTIAL | |
| **INTUITIVE** | **ENFORCED** |
| 3 | 4 |

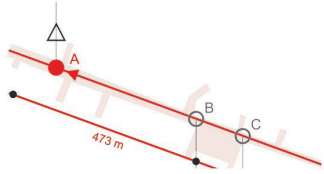



| SENSORY DETERMINANTS OF SPATIAL VALUES | |
|---|---|
| EXPERIENCING | |
| VARIED | MONOTONOUS |
| CHANGING | CONSTANT |
| DECLARATIVE | WITH NO AFFORDANCE |
| EMOTIONAL | RELAXING |
| ACTIVE | PASSIVE |
| HIERARCHICAL | EQUAL |
| DYNAMIC | STATIC |
| SUMMARY OF SEMANTIC DIFFERENTIAL | |
| **STIMULATING** | **APPEASING** |
| 5 | 2 |

| SEMANTIC DETERMINANTS OF SPATIAL VALUES | |
|---|---|
| REMEMBERING | |
| CHARACTERISTIC | UNCHARACTERISTIC |
| COMFORTABLE | UNCOMFORTABLE |
| ATTRACTIVE | REPELLING |
| INTERESTING | UNINTERESTING |
| FRIENDLY | UNFRIENDLY |
| ENCOURAGING | DISCOURAGING |
| SATISFACTORY | DISSAPOINTING |
| SUMMARY OF SEMANTIC DIFFERENTIAL | |
| **POSITIVE** | **NEGATIVE** |
| 1 | 6 |

**VIEW A IN SEQUENTIAL DRAFT / ROAD DIRECTION FROM RIGHT TO LEFT**

| INSTRUMENTAL DETERMINANTS OF SPATIAL VALUES | |
|---|---|
| ORIENTATION | |
| ORDERLY | DISORDERLY |
| PLANNED | UNPLANNED |
| STABLE | UNSTABLE |
| COMPACT | DISPERSED |
| HOMOGENIC | HETEROGENIC |
| CLEAR | UNCLEAR |
| REGULAR | IRREGULAR |
| SUMMARY OF SEMANTIC DIFFERENTIAL | |
| **INTUITIVE** | **ENFORCED** |
| 5 | 2 |




| SENSORY DETERMINANTS OF SPATIAL VALUES | |
|---|---|
| EXPERIENCING | |
| VARIED | MONOTONOUS |
| CHANGING | CONSTANT |
| DECLARATIVE | WITH NO AFFORDANCE |
| EMOTIONAL | RELAXING |
| ACTIVE | PASSIVE |
| HIERARCHICAL | EQUAL |
| DYNAMIC | STATIC |
| SUMMARY OF SEMANTIC DIFFERENTIAL | |
| **STIMULATING** | **APPEASING** |
| 4 | 3 |

| SEMANTIC DETERMINANTS OF SPATIAL VALUES | |
|---|---|
| REMEMBERING | |
| CHARACTERISTIC | UNCHARACTERISTIC |
| COMFORTBLE | UNCOMFORTABLE |
| ATTRACTIVE | REPELLING |
| INTERESTING | UNINTERESTING |
| FRIENDLY | UNFRIENDLY |
| ENCOURAGING | DISCOURAGING |
| SATISFACTORY | DISSAPOINTING |
| SUMMARY OF SEMANTIC DIFFERENTIAL | |
| **POSITIVE** | **NEGATIVE** |
| 0 | 7 |

Fig. 5. Evaluation by means of the semantic differential method of a selected fragment of the sequential road offer system within the designated areas of creativity – *creative syntax* within Poznan downtown to determine the degree of spatial stimulation according to the adopted classification. Road offer system including Main Market Square – sequence A to B (author's own elaboration)

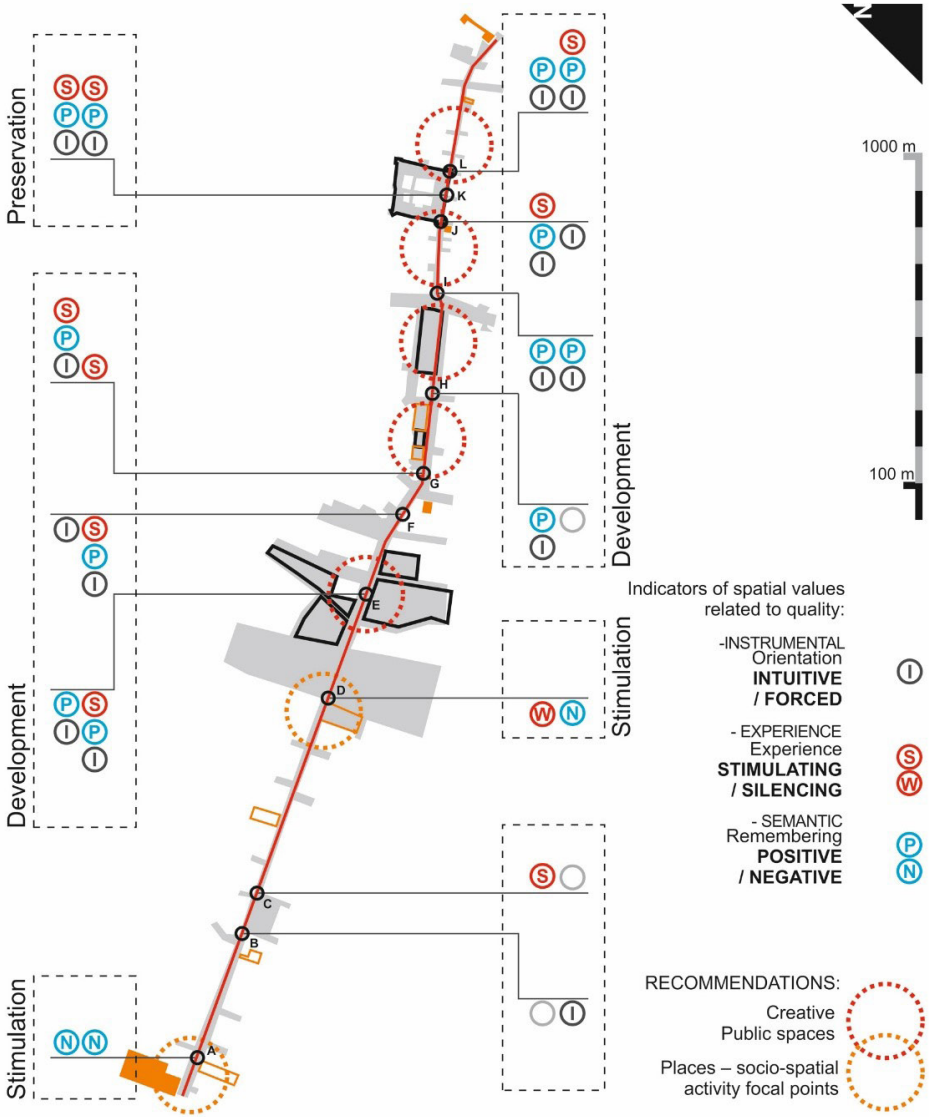



Fig. 6. Summary of research and recommendations – a reference to the most developmental areas of creativity in spaces of desirable features and deficit spaces within the designated areas of creativity – *creative syntax* within Poznan downtown (author's own elaboration)

## 4. Results and discussion

Determination of the degree of development opportunities in the field of creativity within the city centre of the examined cities follows from the identification and assessment of spaces of desirable features and deficit spaces, which were considered to be the most important components in this respect. According to the adopted research method, the more deficits in which it is possible to introduce the desired development trends and activities, the greater development of creative potential. The following principle was adopted: those spaces in which only deficit spaces or those in which both the spaces of desirable features and the deficit spaces were identified were accepted for detailed research, whereas the spaces with no spaces of desirable features or deficit spaces or those with only the spaces of desirable features were rejected.

The desired directions of development activities as regards the use of the spaces with desirable features to form creative public space contributing to the revival of the public space through creativity, culture and art were also formulated. The indicated spaces of desirable features are built-up spaces with a creative or undeveloped function located in their immediate vicinity. Identified deficit spaces are vacant or undeveloped plots, both in municipal and private possession. According to the author, with the appropriate organizational and financial support of the city and non-governmental organizations, they can be temporarily arranged and used for the needs of local communities before investment activities are undertaken within them, which may take several or several dozen years. Selected spaces with the highest development potential in terms of creativity can, with appropriate use, improve the offer quality, and also influence the revival and socio-economic activation of the city centre. According to the adopted methodology, a very important aspect regarding the desired direction of development is homeostasis, understood as balancing socio-cultural and economic forces. It is about finding a balance between development and protection, thanks to which space can retain its stimulating and inspiring character through some understatements. According to this principle, recommended for development in the field of creativity are those spaces of desirable features, which in the future may contribute to increasing the spatial and social attractiveness of the city centre, and deficit spaces that economically inactive, with appropriate stimulation, can become socially active.

Social benefits are long-term effects, such as education concerning responsibility for common space, building social awareness in urban coexistence, building social capital of the city by inspiring creativity, as well as increasing spatial attractiveness, perceived in the context of building the desired image and iconicity of the city, which can translate into specific economic results.

## 5. Conclusions

These considerations have been underlain with the idea that recommends appropriate use of current conditions conducive for the development of creativity understood as a high EU rating as per the "C3" index and conducive for the accumulation of creative function in

the downtown area. The author is of the opinion that we shall make good use of favourable conditions and aspire to expand creative activities into the area of municipal management. We shall, furthermore, strive to ensure the downtown space with its iconic, spatial meaning, which may significantly affect the quality of space and its offer and promote the downtown in a variety of aspects: spatial – attractiveness of downtown space, including public space; social – activation of local entrepreneurship, education and development of social potential; and economic – the economy of experiences, development of functional and spatial offer in the area of creativity and accompanying services.

The research has given a presentation of a method that can be used for the balancing of the spatial and social effects with the economic effects to preserve an appropriate cycle of creativity. The research was not intended for the purpose of defining detailed spatial decisions for obtaining defined spatial effects because these effects can hardly be unambiguously defined and generalised – therefore these decisions may differ depending on the local needs and conditions of development at a particular moment in time. The main goal of the author is to stress the fact that stimulation for development and balancing the economic factor, preventing its dominance, are the most important things. In the author's mind, for the downtown space to be creativity inspiring and stimulating, certain understatements and semantic openness need to be retained because space that is irresponsible and changeable can prove to be highly active from a social point of view.

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TECHNICAL TRANSACTIONS 6/2019
ARCHITECTURE AND URBAN PLANNING
DOI: 10.4467/2353737XCT.19.062.10615
SUBMISSION OF THE FINAL VERSION: 4/06/2019

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# Protection of historical trees in the city area using the example of a historical manor alley in Zemborzyce

# Ochrona zabytkowych drzew na terenie miasta na przykładzie historycznej alei dworskiej w Zemborzycach

**Abstract**

Alleys are one of the classical elements of open space topography as well as in cultural landscape and city space. These historical plant forms which have survived to our times require special conservatory attention – protective and maintenance works. In this study, one method of evaluating the condition of old trees is presented. The trees are the remains of the alley layout at the former manor house in Zemborzyce. In 2015, an inventory of alley trees was carried out and the internal structures of the examined trees were evaluated using sound tomograph PICUS. The non-invasive method used is especially recommended to evaluate the health condition of valuable, old trees. It allows us to examine each tree extensively and carry out individual procedures according to conservatory rules.

**Keywords:** Lublin, historical alley, evaluation of the trees' condition, sound tomograph PICUS

**Streszczenie**

Do klasycznych elementów ukształtowania i wyposażenia przestrzeni otwartych, jak również krajobrazu kulturowego i przestrzeni miejskiej należą aleje. Te zabytkowe formy roślinne, które przetrwały do naszych czasów, wymagają szczególnej uwagi konserwatorskiej – prac zapobiegawczych i pielęgnacyjnych. W prezentowanej pracy przedstawiono jedną z metod oceny kondycji drzew wiekowych, które są pozostałością układu alejowego przy dawnym dworze w Zemborzycach. W roku 2015 wykonano inwentaryzację drzew alejowych i oceniono wewnętrzne struktury pni badanych drzew za pomocą tomografu dźwiękowego PICUS. Zastosowana bezinwazyjna metoda jest szczególnie polecana przy diagnozowaniu stanu zdrowotnego cennych, starych drzew. Pozwala na staranną ocenę każdego egzemplarza oraz określenie indywidualnych kryteriów postępowania zgodnie z poszanowaniem zasad konserwatorskich.

**Słowa kluczowe:** Lublin, aleja zabytkowa, ocena kondycji drzew, tomograf dźwiękowy PICUS

## 1. Introduction

In Lublin, as in most urban agglomerations, some imbalance between urban space and nature has been observed in the last several years. Urbanization pressure and especially the development of the road transport and building industry, has led to the reduction of green areas and the number of trees. It refers both to the city centers as well as to the suburbs where the population growth is increasing ten times faster than in the city centers [25]. These changes have led to the loss of existing green wedges and their connections with ecological areas surrounding the city. All protective actions connected with the nature preservation of the city which influence the improvement of climatic, health as well as social and economic conditions are of great importance.

Revitalization politics has played an important role in shaping the area of Polish cities for over twenty years. As a part of regional development, the aspect of nature has been taken into consideration within the Lublin voivodeship over the last few years. An example of this is the complex revitalization of Krzna valley in Biała Podlaska and Bystrzyca in Lublin and Wieprz – Krzna canal water system [10]. These actions are also concentrated on the revitalization of historical objects and their surroundings- our regional heritage which should be protected and consciously managed. Alleys are one of the compositional elements of garden art and urbanization. A lot of them have survived to our times in a different condition. These alleys are created by old trees which require thorough evaluation by ascribing special action criteria and further maintenance [24, 18]. Lack of protection of these important, in most cases city-based plant forms, leads to the disappearance of old layouts which are included in the green areas of a given region.

## 2. History and spatial conditions

At present Zemborzyce, one of Lublin districts in the south of the city, consists of open spaces and mostly rural landscape. The landscape axis of Zemborzyce which marks the road system and building development is Bystrzyca valley, 2 km wide and located in this district. For this reason, in 1970-1974 an artificial water reservoir with retentional and relaxation purposes named Zemborzycki Reservoir was localized.

The oldest records of Zemborzyce date back to 1364. At this time, on the order of king Casimir the Great, a special document to locate a village near Lublin using Magdeburg Law was prepared and this name was given to it. Zemborzyce is located on the Royal Route leading from Cracow to Lublin and further to Vilnus, which helped its development. Probably in those days, there existed a wooden manor, outbuildings and a garden [1]. A plan from 1823 shows that in Zemborzyce, at the point where the Bystrzyca valley widens, a manor surrounded by a garden marked by the alleys crossing at right angles was built. Next to the manor house there was a pigpen, a hen house, a chamber and a farm house facing north [28]. The manor house building was wooden - the same as the rest of the buildings. After the January Uprising, the owner of the manor became General Major Teodor von Rüdygier, followed by his heirs,

among others, the son-in-law of General Duke Bielajew. During the time of General Rüdygier and his heirs' management, the manor house was extended and it consisted of 53 buildings, including brick ones and a classicist manor house [16]. Presently, only two buildings have remained – a stable and a historical granary[1] [14] as well as historical trees of different ages represented by alley forms.

The oldest alley in the area of the manor house in Zemborzyce is still a clearly marked lime tree alley formerly localized to the north of the manor and directed from east-west. It probably comes from the 18th c. and in those days it marked the northern border of the garden, separating it from the manor farm [8]. Nowadays, it is represented by twenty small-leaved lime trees (*Tilia cordata* Mill.), which in 2017 were declared a natural monument by City Council Resolution [20]. The trunk's circumferences reaches 360 cm. It seems that the oldest trees may be 220-250 years old [27].

Another remaining plant form is a part of a former tree row, which at the turn of the 18th and 19th c. constituted a closure of the interiors in the west part of the park. Their layout led to the south, opening to the vast manor meadows[2] [12]. The basic species of the tree rows, in the past as well as today, is a small-leaved lime (*Tilia cordata* Mill.) Since 1997, by Resolution nr 4 of the Voivodeship of Lublin, fifty trees shaped in tree rows were classified as natural monuments [13]. After twenty years, forty nine of the remaining trees[3] create a wide, 150 m long lime alley, which in the northern part joins a horse chestnut alley from the west and the oldest lime alley from the east.

To the west of the manor complex there leads the third horse chestnut alley. It is straight and it can be seen on the maps from 1823 and as in the past when it was an alley leading to the manor house, it plays the same role nowadays[4]. The age of the thirty two horse chestnuts (*Aesculus hippocastanum* L.) of this alley is estimated to be about 120-240 years old[5]. Since 2017 they have been protected and classified as natural monuments [20].

The historical alleys in the area of the former manor complex in Zemborzyce are in good condition. All require systematic control and diagnosis of the trees' health condition. The aim of the study is to evaluate chosen trees creating a wide lime alley which comes from the turn of the 18th and the 19th c. In the research, a non-invasive diagnostic method of sound tomography was used, which allows us to discover the infection and decay of the internal structures of a tree trunk at the height of measure. Such examination is an important addition to the complex diagnosis of the trees and the whole alley. It allows us to predict and plan the range and time of protective and maintenance works [22].

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1 The granary was to the south of the manor, which was destroyed in the sixties of the twentieth centry.

2 At present to the whole reservoir.

3 Thirty four from the west side and fifteen trees from the east.

4 Currently it leads from Krężnicka Street.

5 The trunks' circumferences reach from 212 to 414 cm.

## 3. Research methods

In the years 2017-2018, research was conducted to evaluate a lime alley preservation in the former manor-park complex in Zemborzyce, which at present is a part of the Marina recreation center at Zemborzyce Reservoir. The manor park complex with a preserved granary and the remains of a park is on the list of the monuments of Lublin under numbers 1713 and 1714 [11]. As part of the research work, a detailed dendrological inventory of a lime alley consisting of trees aged from 150 to over 300 years old was conducted. In 1997 this plant form had fifty trees and it was protected by the law [13]. Nowadays, it plays the role of a two sided, homogenous lime tree alley with an admixture of two trees of the following species: horse chestnut (*Aesculus hippocastanum* L.) and white poplar (*Populus alba* L.) and it consists of forty nine trees. The research conducted covers the measurement of the alley trees: height (m) by the use of a laser distance meter- Nikon Forestry Pro and trunk circumference (at the height of 1.3 m). The estimated age of the plants was defined using age charts by L. Majdecki in 1980-86 [15], a tree age calculator [27] and increment factors defined by the International Society of Arboriculture and published by the Missouri Department of Conservation [26]. Alley trees were localized on the map using GPS, by means of a module in a central unit (tomograph). In 2018 a tomographic diagnosis of six randomly chosen small-leaved limes, which constitute this form of forest cover was made- four trees on the west and two on the east.

For localizing possible defects inside the trunks of examined limes, PICUS Sonic Tomograph 3 of the German company Argus Electronic GmbH was used. The device uses the speed of sound waves in the wood which depends on its density and flexibility. The device records the time of acoustic waves by a system of sensors, generated at each measure point. Most defects inside the trunk, especially the presence of decay, lead to a reduction in the density and flexibility of the wood, which results in the reduction of the speed of waves at the point of damage. The results of the conducted research show a tomogram – a graphic picture which presents an actual internal structure of a trunk cross- section at the height of a tree examination in detail and in some cases it allows us to detect the early stages of tree decay [5, 2, 3, 4]. Photographic documentation was made using the camera NIKON D5300. The research covers the library and archive query connected with the village of Zemborzyce. Cartographic materials from the National Archive in Radom with a map of Zemborzyce from 1823 were analyzed.

## 4. Evaluation of the chosen alley trees

Cartographic analysis and measuring the trees' trunk circumferences prove the age diversity of lime trees growing on both sides of the examined alley. From the west there grow small-leaved limes (thirty two plants) which belong to a younger generation in comparison to the trees from the east side (fifteen plants). Their biggest circumferences reach from 250 to 290 cm, while the circumferences of the lime trees from the older generation (fifteen trees) are from 342 to 475 cm. These values as well as the irregular planting of the trees can prove that these plant forms had a different role in the former manor complex than they have nowadays.

The health condition of all forty seven small-leaved lime trees that make up the examined alley is varied. The younger trees are in better condition. At the height between 1.4 and 1.8 m there appear some branch-offs which change into V-shaped branching in some of them. In the tree row of older limes, plenty of dead branches (25-30%) can be seen and a bigger number of suckers and clusters of mistletoe (*Viscum album* L.) are at the bases of the trunks. Besides, in the case of 30% of the trees there is decay extending deep into their internal parts which results in an imbalance of the tree static leading to tilting (inv. no. 40) to the south of the adjacent lime tree. In some lime trees, some loss in the outer part of a trunk extending from 0.8 to 1.5 m was observed. In younger generation lime trees creating the western row, some traces of their maintenance are noticeable. Some trees were operated on which resulted in their being cut down at a high level and damaged branches were removed as a result of breaking or decaying processes. Edges of the wounds are in most cases well healed. On some trees, one can see internal loss of a different size. Small holes are seen (inv. no. 8, 13 and 14), but also damage as a result of atmospheric factors (rain, snow) which cover a large part of the trunk (inv. no. 10 and 11). Some tree crowns are asymmetric with an imbalanced static. Two of the examined trees have their main branches joined with elastic Cobra bonds and steel ropes at the higher parts of the crown (inv. no. 8 and 12) because of dangerous V-shaped branching. In the tree crowns, dead branches only make up 10-15% of the total, which shows the vitality of the trees.

Four trees on the west side of the alley (younger plantings) and two on the east side (older plantings) were randomly chosen to evaluate the internal structures of the tree trunk. On the basis of the tomograms following computer processing it was shown that the younger trees aged 150-180 years are in better health condition than older ones (300 years old). Apart from the easily noticeable processes of internal structure decay of the tree trunks, especially in their heartwood part, presently there is no risk of breaking or blowdown. The destructive processes are still not very advanced so the thickness of the wall guaranteeing the mechanic strength of the tree trunk has a large margin of safety. On the attached tomograms, a safety border marked with a red line beyond which humus decay does not extend is seen. It is only in tree number two (Fig. 1) in the north-west side that the humus center spreads to the outer part of a tree trunk. The area with the most destroyed part of the tree trunk is marked with a blue color and it is in the central part of the tree trunk. The purple color is a sign of a tree with better mechanic strength (less destroyed) and green designates so called 'wood in process'- not yet destroyed, but at the same time not mechanically strong. In case of the examined trees with a smaller trunk circumference (Fig. 2–4) the minimum thickness of the wall seen as a safety border, is from over 9 to almost 14 cm. In the case of the trees with big circumferences and where the decay process is low, this wall has a bigger thickness- over 14 cm (Fig. 5 and 6).

Comparing younger trees with older ones, the bigger resistance to infection of the younger trees is noticeable. In the case of the lime tree with the biggest circumference (474 cm), which is the oldest among the examined trees (inv. no. 39), the fungal infection is more advanced than in the rest of the trees (Fig. 6). In this case it has developed on the east side of the tree trunk covering a bigger area on the cross- section. As a result of ongoing wood decay, there appeared a risk of internal cuts which can lead to a trunk break in future (yellow lines on the tomogram). Trees in the younger tree row are in better health condition than the trees in the

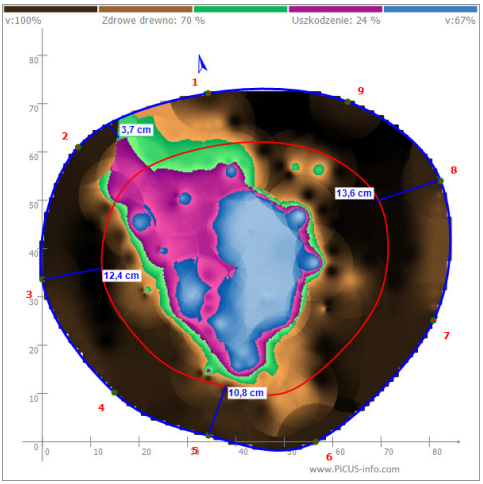


Fig. 1. Tomogram of the interior of the trunk of lime-tree No. 2 (by W. Durlak, 2018)

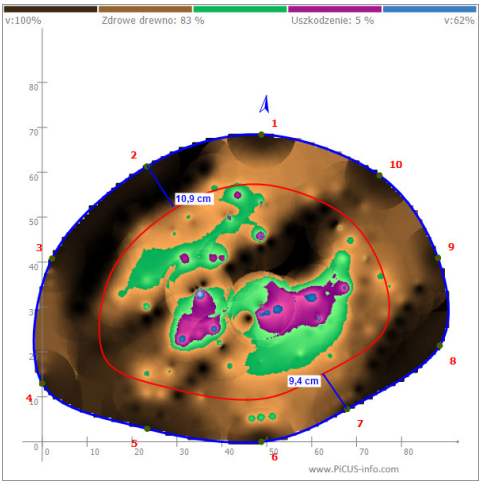


Fig. 2. Tomogram of the interior of the trunk of lime-tree No. 9 (by W. Durlak, 2018)

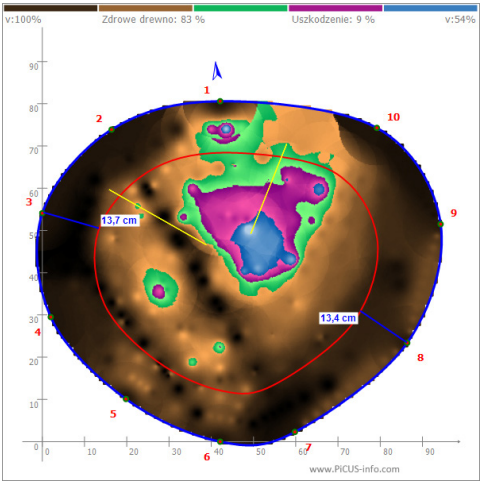


Fig. 3. Tomogram of the interior of the trunk of lime-tree No. 12 (by W. Durlak, 2018)

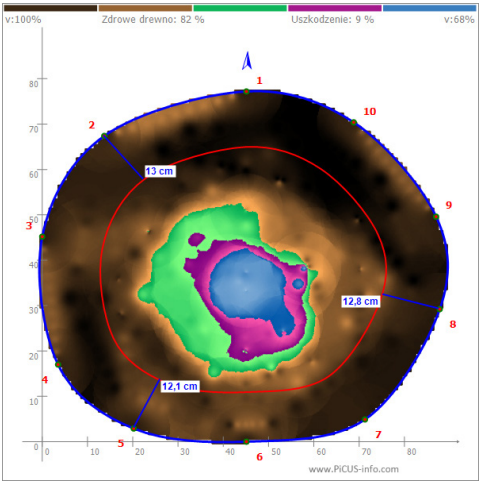


Fig. 4. Tomogram of the interior of the trunk of lime-tree No. 14 (by W. Durlak, 2018)

older one, where the decay processes inside the trunk are more advanced and will probably become stronger with the passage of time.

The predominance of sound tomography over other research methods is primarily determined by its non-invasive nature. For many years, the only available instrument for the detailed evaluation of the internal structure of the growing tree was the Pressler borer. However, this method requires interference in the internal tissues of the tree. In the case of particularly valuable ancient trees, its use is controversial [2, 23].

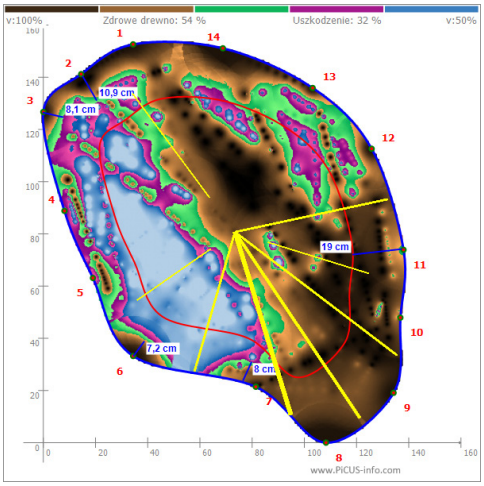


Fig. 5. Tomogram of the interior of the trunk of lime-tree No. 37 (by W. Durlak, 2018)

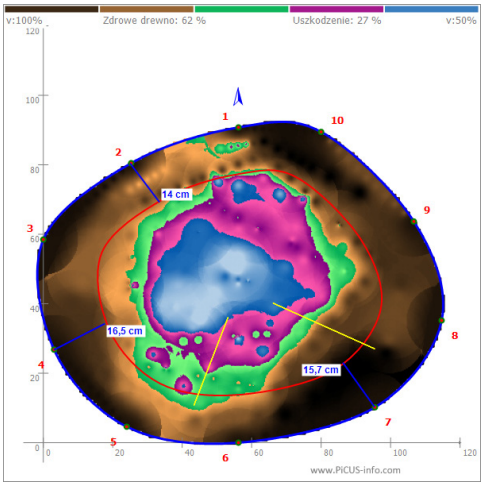


Fig. 6. Tomogram of the interior of the trunk of lime-tree No. 39 (by W. Durlak, 2018)

## 5. Summary

Poland is one of very few countries in Europe with a large number of old trees [17, 9]. They appear in urban green spaces, especially in historical gardens, in cemeteries and open areas. These are single trees, clusters or alleys with native species such as petiolate oak, common beech, small-leaved limes, and some foreign species (e.g. silver maple, tuliptree, ginkgo) [6, 19]. In Poland in 2016 (according to the GUS data), the following number of trees were under protection: 30 063 single trees, 3734 clusters of trees and 770 alleys including the Lublin voivodeship of: 1165 trees, 180 clusters of trees and 57 of alleys [7]. These forms are of great educational value, influence the quality of the environment and the evaluation of landscape esthetic. as well as improving its diversity and attraction. This role has been played by historical alleys in Zemborzyce, one of Lublin's districts, which in the 70s of the 20$^{th}$ c. was the place of recreation for the inhabitants of the city. Today, two lime alleys and one chestnut alley are the main cultural, natural and esthetic value of the recreational Marina area increasing its attractiveness. Conducted tomographic studies showed that decay processes inside the older lime trees trunks are more advanced and will increase with the passage of time in comparison to younger trees. Fungal infection is more advanced and covers a bigger area of the trees' cross- section (Fig. 6). As a result of an ongoing wood decay, a risk of internal cuts appeared, which could lead to a trunk break in the future (yellow lines on a tomogram).

Lime trees, often seen in historical and modern manors and park complexes, have soft wood, easily influenced by biocorrosion. The decay processes begin in a core part of a tree trunk spreading along its circuit with different speeds or they appear as a result of destruction localized in its peripheral structures. It results in fast infection spreading into the trunk. This process is much faster in older trees in which natural protection methods (creating a compartmentalization barrier, are not as strong as in younger trees [21]. That is why the permanent control of the health condition of trees making up the alley on the area of the

former object is advised. These valuable remains of culture, which many tourists can admire and learn about their history, require constant monitoring, systematic actions undertaken by specialists and the authorities of a Member State as well as by territorial and local authorities.

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TECHNICAL TRANSACTIONS 6/2019
ARCHITECTURE AND URBAN PLANNING
DOI: 10.4467/2353737XCT.19.063.10616
SUBMISSION OF THE FINAL VERSION: 1/06/2019

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# The sphere in architecture as an example of an elementary form

# Kula w architekturze jako przykład formy elementarnej

**Abstract**

This article is an attempt to analyse the use of the sphere in contemporary architecture in connection with first historical examples of designing with the use of this solid figure. The strong form, introduced by architects as a shape with complex symbolism, conveys various ideas contained in design projects. At the same time, the sphere reflects the tendency towards elementarisation of form, replacing figurative architecture with abstraction. Such a phenomenon constitutes a peculiar paradox in connection with the fact that spherical buildings are some of the most famous examples of ***architecture parlante*** in the Enlightenment.

**Keywords:** architecture parlante, sphere

**Streszczenie**

W artykule podjęto próbę analizy wykorzystania formy kuli w architekturze współczesnej w powiązaniu z historycznymi, pierwszymi przykładami projektowania z zastosowaniem tej bryły geometrycznej. Silna forma, wykorzystywana przez architektów jako kształt o złożonej symbolice, przekazuje różnorodne idee zawarte w projektach. Jednocześnie kula odzwierciedla tendencję do elementaryzacji formy, zastąpienia architektury figuratywnej przez abstrakcję. Takie zjawisko stanowi swoisty paradoks w powiązaniu z faktem, iż kuliste budynki są jednymi z najbardziej znanych przykładów oświeceniowej architecture parlante.

**Słowa kluczowe:** architecture parlante, kula

## 1. Introduction

*Das Dasein ist rund, being is round*, Gaston Bachelard wrote in *The Poetics of Space*. At the same time, a traditionally understood architectural structure – consisting of walls and a roof – is an orthogonal space. There are, however, examples of the use of a form in construction that is – apparently – so different from archetypical human dwellings. This form is the sphere – the solid that opposes the force of gravity and the requirements of function. At the same time, the spherical space symbolically corresponds to the first 'place of residence' of each person – the human womb. Thus, it is ontologically connected with habitation. According to Rudolf Arnheim, the prototype of an independent dwelling is a bird's egg [2, p. 55].

Architectural literature does not devote much attention to the sphere in the art of building. Spherical architectural structures are rarely constructed; in most cases, they remain within the realm of utopian projects. While the cuboid is a solid archetypically attributed to buildings (e.g. Laugier's hut), the form of the sphere is closer to the interior hollowed out in the cave. Analysis of the proportions of the Roman Pantheon reveals the interior that ideally contains a sphere.

However, in both historical and contemporary architecture – such as 'paper' *architecture parlante*, Fuller's high-tech visions, buildings from the twentieth and twenty-first centuries – there are few characteristic examples of spherical structures. The aim of the analysis of architectural literature and the structures themselves, both on the basis of drawings and original descriptions or articles in professional journals, is to answer the question about their ideological origin, design problems related to the spherical shape and the way they are solved by architects.

The research problem addressed in the following paper is the symbolism of the sphere in architecture, from the first examples of its application to contemporary times, and the answer to the question of whether, referring to such an elementary form, the creators of spherical buildings do not keep asking the same questions through their projects, regardless of the time of creation. In the research, a comparative case study was used – an analysis of the number of similar examples that aims to find universal patterns in the design process. According to Richard Foqué, it is the generalisation of individual solutions leading to the creation of contextual knowledge, as contextuality is an inherent feature of architecture [8, p. 212, 213][1].

The concepts of elementarity and elementarisation adopted in the article correspond to their meanings used in the Department of Elementary Architecture at the Faculty of Architecture of Cracow University of Technology. This meaning is defined by Marcin Charciarek, describing the range of the academic-didactic subject: "Elementary means basic, original, inseparable (perhaps – modest) – the simplest in thinking and creating fundamental meanings to architecture – through its geometrical and material references. We discover it in specific designing 'tactics', but also in theories referring to meanings fundamental to the contemporary – from proto-modern 'primitive hut' of Abbé Laugier, stripped of ornaments 'cave' of Adolf Loos, Louis Kahn's 'preform', Le Corbusier's purity and Tadao Ando's purity of forms" [3, p. 6].

[1] Case studies as a method of research in architecture and the theory of Richard Foqué has been described by E.A. Niezabitowska [14].

## 2. The sphere as an element of 'speaking architecture'

in a symbolic sense, the sphere is an image of integrity and perfection. Since the time of the Presocratics, it has meant infinity – homogeneous, single, equal to itself only [6, p. 214, 215]. The introduction of this elementary solid into architecture for the first time can be attributed to the architects of the French Revolution: C.N. Ledoux, L.E. Boullée and J.J. Lequeu. In the eighteenth century, the sphere did not appear in detailed designs, but it did in purely conceptual drawings. Its application is related to the issue of uncompromising elementarisation of form in architecture and overcoming the law of gravity.

The overcoming of gravity was achieved at the end of the eighteenth century through the first balloon flights. At the same time, artists began to seek sources of inspiration for the arts in astronomy [18, p. 91; 9, p. 154], which was quite directly reflected in the project for the Cenotaph (Fig. 1) by Étienne-Louis Boullée (1784) – an unconstructed mausoleum for Newton. The building was given the form of a sphere on a massive round plinth with ramps. Its vault was to depict the sky with holes – the stars.

The later Temple of Nature (1793) by the same architect also adopted the form of a variation on a sphere. In this project, two hemispheres are integrated under a flat dome. The semi-circular vault covered a specific 'nest' – a round recess surrounded by a colonnade of the same shape lined with stones – with a mysterious hole towards the 'interior of the earth'. The building has different proportions than the Cenotaph – it is flatter, and the surrounding solid with the colonnade is higher, which makes the central spherical part less visible.

Subsequent architects increasingly 'detached' the Platonic solid from the ground. While in the Cenotaph it was still resting on a plinth, Jean Jacques Lequeu optically concealed the contact of the spheres with the ground in his designs by means of surrounding colonnades with a circular outline. His Temple of Earth (1790) and Temple of Equality (1791) (Fig. 2) are two buildings with a very similar spatial model – single-space model, with a staircase entrance, raised floor and a spherical structure inside. The Temple of Earth sphere is supposed to be a fairly direct symbol of the globe, as indicated by the world map painted on it (and the sky map on the inside).

The design project of the House for a Cosmopolitan (Fig. 2) by Antoine Laurent Thomas Vaudoyer (1783), as Hans Sedlmayr points out, was formed in a similar way. Sedlmayr symbolically justified the form of the structure by linking the silhouette of a cosmopolitan (one 'devoid of roots') with a moveable solid detached from the ground [17]. However, there is a significant difference between Vaudoyer's building and the other projects described here. The House for a Cosmopolitan is divided into five floors interconnected by a round staircase. The rooms were separated and therefore the interior does not reflect the conciseness of the spherical solid. However, Vaudoyer's building can be considered as an anticipation of later tendencies – the attribution of elementary solid forms to residential buildings [4, p. 20]. At the same time, one has to agree with the words by Hanno-Walter Kruft who criticised the project strongly, arguing that even the smallest trace of *le bon goût* was lost here [13, p. 165].

The design for the House of the Farm Guards (Fig. 2) by Claude Nicolas Ledoux (ca. 1770) – also criticised by Kruft for its misguided symbolism – received the purest form of all

the above examples. The sphere without windows was placed here in a rectangular[2] lowering of the terrain, which allowed the architect to show it almost in its entirety. Four door openings on four sides of the sphere flanked with columns lead to the interior of the house, preceded by walkways with stairs running above the lowering. Ledoux achieved the greatest conciseness of the external form of the sphere of all the above buildings[3]. The interior of the house was designed as a three-storey structure divided into regular rooms (nine on the ground floor and the underground floor and eight on the first floor). Inside the sphere, there is a kitchen stove with a high chimney. In the projections and cross section of the building, windows illuminating the rooms were sketched in, which cannot be seen in the perspective view.

## 3. The sphere as the basic form

*Das Dasein ist rund*. It would seem natural that surrealists, for whom habitation symbolised the comfort of foetal life and the basis constituted primitive models of dwelling such as a cave, grotto and hut, should tend towards the form of a sphere. However, these places are characterised by delicacy and tactility of space, whereas buildings in the sphere are characterised by a purist form – cleaning it of all unnecessary elements. At the same time, Platonic solids are associated with the aesthetics that is closer to machine technology than organisms from the living world.

The sphere is the ideal of architectural purity. It 'fights' gravity by levelling the difference between the top and bottom and connection to the ground at one point only. Due to this detachment, the building is not related to any particular landscape or history [10, p. 232]. Karsten Harries describes Platonic solids – including the sphere – as forms used in the architecture of 'spiritual order'. The language of geometry is the universal language of art. It is the language of the spirit[4]. It is geometry, straight lines and basic colours that Harries links with absolute beauty, eternity and timelessness.

Elementary architecture uses the design method described by Aleksandra Satkiewicz-Parczewska as 'a demonstration of the simplest form' [16, p. 36–41]: the use of a single free-standing elementary solid shape from the catalogue of 'compositional archetypes'. According to Satkiewicz-Parczewska, the choice of similar forms accompanies the search for a new vision of the future. It may be added, however, that this mechanism does not concern only contemporary architecture. The eighteenth-century architects from the 'architecture parlante' trend also turned to the simplest, natural forms in their search of primordial values [18, p. 92, 93].

Satkiewicz-Parczewska calls the use of the compositional archetypes forms 'architecture of stillness' [16, p. 37]. However, in the case of the sphere – referring to the 'architecture parlante' trend again – it is difficult to talk about the static form. According to Przemysław Trzeciak,

[2] The lowering has a rectangular shape in the perspective and a square shape in the projection.

[3] This is confirmed in the words by Kruft who points out that the cross section of the building indicates that the residential function was sacrificed in favour of the symbolism of an ideal form [13].

[4] Unlike the carnal language of nature, Harries refers to the thoughts by Plato, Le Corbusier, Hans Hollein and Theo van Doesburg, among others [10, p. 228–233].

buildings in the shape of a sphere or a cylinder in the eighteenth century were supposed to give the impression of being 'free from the gravity forces', free from restrictions, not only as a reflection of scientific discoveries and interests of the Enlightenment period, but also as an expression of rebellion against the formalistic late Baroque and Rococo traditions [18, p. 91].

According to Trzeciak, revolutionary French architects "gained the impression of timeless abstraction and monumental synthesis in which the remnants of tradition, including the ancient one, were almost erased" [18, p. 93]. Harries also raises the subject of timelessness – the struggle mankind is waging against the 'terror' of time [10, p. 228–239] – referring to the architecture of Platonic solids, including the sphere.

## 4. The sphere in the twentieth century

The sphere of the Lenin Institute (Fig. 3) by Ivan Leonidov (1927) has never been constructed. The glass spherical structure was to be a cinema for up to 4,000 people and a planetarium. It was planned that the room could be divided by means of moving walls. In the drawings, the planetarium building looks as if it was levitating in the air, held only by lines similar to guylines. This method of connecting the spherical building with the ground had never been applied before. The glass form of Lenin's planetarium with a steel frame was supposed to be a metaphor of enlightenment and, at the same time, constitute a universal symbol [7, p. 311]. Its lightness, clarity and ropes bring to mind a balloon – a object detached from the ground instead of a solid structure founded in it.

In Leonidov's project, there is a tower and a horizontal body of an office building next to the sphere of the auditorium. All the solids were composed like the abstract paintings by El Lissitzky. The suprematist compositional means correspond to the mechanistic inclinations of the 'spiritual order' that Harries attributed to the Platonic solids.

The Perisphere (Fig. 4) by Wallace Harrison and J. André Fouilhoux (1939) is a pavilion for the world exhibition in New York entitled 'Building the World of Tomorrow'. The project of the ideal city was exhibited inside the white sphere. Together with the cone – The Trylon – the sphere of the Perisphere was a significant exhibition building, visible from afar (the cone was 186 m and the sphere was 55 m tall) – its symbol and the most recognisable structure. Both elements were snow-white, surrounded by a ramp, and the sphere was placed on five steel pillars. Visitors entered the sphere by riding an escalator from the Trylon and overlooked the exhibited city from the moving platforms. The large snow-white solids were to symbolize finiteness and infinity. The architects planned concrete as their finishing material. However, budget restrictions forced them to use gypsum shell plastered with stucco, which rendered the creation of a smooth surface impossible.

Fuller's Biosphere (Fig. 4) in Montreal (1967) is a steel structure with a polycarbonate coating – designed as an American pavilion for the world exhibition[5]. The transparent sphere

[5] Inside the sphere, it was not Fuller but Cambridge Seven Associates Inc. that planned an orthogonal building consisting of platforms and communication elements.

is double-layer. The outer shell (made of spherical triangles) is 76 m in diameter and is 62 m high, and the inner shell (made of hexagons) is about 1 m away from it and connected by steel pipes. Nowadays, the Biosphere covers the orthogonal buildings of the Environment Museum. The buildings were designed by Éric Gauthier as a result of a 1992 competition.

La Géode (Fig. 5) in Paris by Adrien Fainsilber and Gérard Chamayou (1985) is a 3D cinema whose spherical form results from its function. The sphere is 36 m in diameter and has a mirror finish of triangular stainless steel panels. The cinema is a fragment of the Cité des Sciences et de L'industrie, but the form of the sphere was set aside from the main body of the building and placed in a square pool, thus solving the problem of its contact with the ground. La Géode is accessed from the ground floor, under the level of the pool.

Pedro Ramírez Vázquez used a similar concept – a cinema in the sphere – three years earlier (1982) in the Cultural Centre (Fig. 5) project in Tijuana (CECUT). The sphere in Tijuana, however, has a concrete shell. It is adjacent to an irregular symmetrical solid with external stairs, hiding the place where Domo IMAX meets the terrain.

Opened in 1989, the Swedish National Arena (Fig. 6) – the Ericsson Globe building in Stockholm, designed by Berg Arkitektkontor AB, is a spherical building with the world's largest diameter. The steel, concrete and glass structure is surrounded by lower solids. The building is not a full sphere though – it is 110 m in diameter and 85 m high. The white body covered with aluminium plates includes small round and square holes. The whole width of its interior is occupied by the space of the stadium and the stands. The Ericsson Globe building is part of the Swedish Solar System (SSS), a 1:20,000,000 scale solar system model whose components (planets, asteroids, comets, etc.) are dispersed throughout the whole of Sweden[6]. The stadium is a model of the sun.

The sphere of the Holy Trinity Church (Fig. 6) in Geneva, designed by Ugo Brunoni (1994) – a solid clad in granite slabs placed in the outer pool – symbolises the Holy Trinity and life. The interior is illuminated by fourteen windows. The entrance is via a footpath over the pool that leads to the adjacent solid[7]. The position of the sphere in the corner and 'sinking' into the pool means that it is not visible in its entirety. Brunoni placed a geometric tower with a cross on the top of the sphere.

## 5. The new 'form' of the sphere

Structures of spherical forms are also being built in the twenty-first century. Some of these are currently in the design stage or under construction.

The Obama Presidential Library (Fig. 6) concept design by Aras Burak Sen (2015) is a building with a body in the form of a sphere in which eight storeys were given the form of

[6] More about Swedish Solar System in [12].

[7] A characteristic example in which the form of a sphere was also used combined with another solid is the church Chiesa Madre in Gibellina (Italy) by Ludovico Quaroni and Luis Anvers (1972–1987). The white puristic sphere is in the centre of this complex, surrounded by the stairs of the amphitheatre, but in two places, the corners of the solids were 'wedged' into it on a plan similar to squares.

bridges (three on each storey), running in the open space of the sphere in different directions between its vertical axis and shell. Each of the enclosed 'bridges' ends with a hole in the shell of the solid, presenting a different frame of the city. The project received one of the two main prizes of equal importance in the competition for the concept for the Obama Presidential Library. The jury awarded it for the form and its symbolic foundation: monumentality and the operation used by the architect to break up the Platonic solid. The openings in different directions reveal views of varied urban environments. The project also emphasises the fact that each floor is to present one year of Obama's presidency, united in a homogeneous narrative [5]. At the lowest level, bridges (named Bridges of Hope by Burak Sen) form a sign of peace, connecting the library with its surroundings. Below them, an amphitheatre was designed in the crust of the sphere – a place of political debate and free speech – an open space as a fragment of an open-access public space. The amphitheatre is supposed to reflect the essence of democracy[8].

The Nur Alem building (Fig. 6) designed by Adrian Smith and Gordon Gill Architecture – the Kazakhstan pavilion at 2017 Expo in Astana – is currently the largest spherical building in the world. It is 80 m in diameter and 100 m high. The sphere is made of glass on a steel structure. It is placed on an undulating plinth made of the same material. Owing to the use of bent glass panels, the body of the building is smooth – without unnecessary edges. The building has eight floors, including one in the plinth and seven in the sphere. The ceilings were moved away from the surface of the sphere. They have an irregular undulating outline and leave a void between the floor and the glass cladding. Inside the sphere, the central core constitutes its construction and provides a vertical access system.

The Nur Alem building was designed to create energy. Photovoltaic elements and two wind generators were installed at the top of the sphere. The sphere is indented. The level with the elements that create energy is both a viewing platform and a venue where accompanying events are held. Visitors can observe the city and the advanced infrastructure that creates electricity. Currently, the building serves as the Museum of Future Energy [11].

Two projects under construction, designed by world-renowned architects, use the form of the sphere in different ways: the Berggruen Institute (Fig. 7) by Herzog & de Meuron (Los Angeles, 2015–) and the Academy Museum of Motion Pictures by Renzo Piano (Los Angeles, opening planned for 2019). The spheres, which constitute parts of the structures, differ in scale and form.

The campus of the Berggruen Institute is to be located in the mountains of Santa Monica – on a hill presenting the silhouette of the campus. The building was designed as a contemporary realisation of the monastic space model. The architects considered it to be archetypical for a scientific facility that requires two types of space – a common space and individual work rooms enabling isolation. The body of the building is to take the form of a reinforced concrete grid elevated above the terrain and filled with wooden walls. An important element of the project are two spheres of different sizes. The smaller sphere is to serve as a water reservoir and the larger sphere as a lecture hall. The concrete sphere of the hall was visually 'broken' into two opaque shells connected by a strip of glass.

[8] The project description in [15].

According to the architects, both of the spheres are designed to reflect the mission of the institute both formally and symbolically as a cultural and ecological message. Jacques Herzog explains their application by the ambivalence of the spherical form, its presence in architecture both as a banal and symbolic element[9]. He also emphasises its 'artificiality' – the suggestion of imbalance and acting against nature. At the same time, being an element of utopian architecture since the eighteenth century, it has not yet entered the dictionary of building forms. According to Herzog, the sphere is to be a 'pure presence' without the need to be explained [1].

The Academy Museum of Motion Pictures (Fig. 8) in Los Angeles (2019) designed by Renzo Piano will be housed in the existing May Company Building (later renamed the Saban Building) from 1939 and a new spherical building connected to the existing structure with glass walkways on the above-ground floors. Inside the added 38 m high sphere, there is a cinema that will seat up to 1,000 people and a glass-covered rooftop terrace. The sphere was undercut along with the slope of the theatre floor and placed on wide poles so that it does not touch the ground. A part of the sphere protrudes, emphasising the operator's room. The renderings of the building show material solutions that were not used in previous sphere projects – opaque bright walls made from spherical squares and a glass roof lowered on to them. Owing to this treatment, the transparent part of the sphere moves smoothly into the non-transparent walls below.

## 6. Conclusions

The article has analysed seventeen examples of buildings in the form of a sphere designed in the years from 1784 to 2019. The structures are located in different parts of the world and come from different cultural circles. Seven of the aforementioned buildings have been completed and one is still under construction.

The functions of the discussed structures are mostly related to public utility (only two of them are single-family houses[10]), but they can be systematised into the following groups: a temple or commemorative structure; an auditorium, cinema or stadium; an exhibition

[9] One should agree with the Jacques Herzog's view. Although the sphere is not a commonly used shape, it is not difficult to find examples of buildings of spherical forms, nowadays, often glass buildings, devoid of a deeper symbolic meaning. The sphere is to be a purely visual treatment in them. Such examples include planetaria (the form justifies the function here), but also Silver Legacy Resort and Casino in Reno (Urban Design Group, 1995) or an element of a shopping centre in Toronto. The Saudi Press Agency (GHI Formwork, 2010), where a map of the world was painted on the outer reinforced concrete crust – it creates a globe – can be considered to be one of the most vivid examples of a banal translation of a spherical form into a building. In turn, in Shonandai Cultural Centre in Fujisawa (Itsuko Hasegawa, 1990), large spheres are accompanied by forms of sloping roofs, creating spatial chaos. The resulting architecture is supposed to bring to mind the natural landscape, and the largest sphere is to symbolise the earth again, which can be seen in a map of the globe painted on its surface.

[10] More single-family houses with spherical forms have been constructed, but they lack purity of form and the tendency towards elementarisation of architecture. Bolwoningen (constructed in the years 1980–1984) designed by Dutch artist Dries Kreijkamp in Hertogenbosch, Netherlands, can be given as an example here.

space or library. Other examples of architecture of spherical forms also have similar functions – these have been identified but not included in the article.

Most of the spherical buildings described above were designed and constructed of three types of materials: concrete, metal (steel or aluminium) and translucent material – glass or polycarbonate on a steel frame. The concrete solid enables aesthetic conciseness (connected with universalism and timelessness) while the transparent elements are associated with ecology and futuristic thinking. In this way, the architects have achieved the purity of the spherical form, opting for transparency or opaqueness. Only one of the above examples has a façade made of granite slabs with clear divisions (Church of the Holy Trinity in Geneva), whereas in two other buildings, the materials were combined – concrete with a strip of glass or concrete with a glass roof around the top of the sphere.

A significant design problem is the planning of the place where the sphere and ground meet. The drawings of the examples from the eighteenth century show a circular base with stairs and a colonnade (in the Cenotaph – a ramp). Only the House of the Farm Guards is solved in a more decisive way; it is placed in a lowering of the terrain. Subsequent examples most often constitute an incomplete solid 'dug' into the ground. Two examples are the buildings located in a water pool and two others were raised on a plinth[11] or pillars. The most original solutions were never constructed: the connection of the solid with the terrain by means of ropes in the auditorium of the Lenin Institute and the placement of the sphere in a pit forming an amphitheatre in the Obama Library.

The public function and purity of form are conducive to treating the sphere as a shape corresponding to a tendency towards monumentalisation. Most of the above examples are structures with clean walls that are devoid of ornament. The number of door and window openings has been limited. Although J.J. Lequeu and Vadouyer still used a round colonnade adjacent to the sphere in the eighteenth century, later buildings were usually an attempt to 'demonstrate the simplest form' – as Satkiewicz-Parczewska puts it. In two cases, other solids adhere to the buildings, disturbing the purity of the composition – in one case there is also a square skylight. A completely different object is the proposal for the Obama Library Burak San. Here the sphere was 'broken' by numerous window openings and vertical slots from which walkways in the form of bridges run out.

Of the examples in which a map of the world has been depicted on the surface of the sphere to form a globe, only the Temple of Earth by J.J. Lequeu has been included in the description. It can be said that in more modern structures of this type, the sphere as a metaphor of the globe is a measure that simplifies architectural symbolism to such an extent that it negatively affects the quality of the resulting architecture. Similar structures have not been analysed.

The analysed buildings confirm the thesis that the symbolism of the sphere in architecture is a timeless and unchanging issue. Both in the eighteenth century and today, the sphere symbolises perfection, majesty, infinity and enlightenment. It has been a universal symbol used in many cultures. Its exterior signified a globe, and its interior, by contrast, a heavenly vault

[11] While most of the buildings constructed in spheres so far have a lower height than diameter, the Nur Alem Building is taller than wider, which has been achieved by placing the sphere on an undulating plinth.

(and also the Holy Trinity, life, 'pure presence'). In the second half of the twentieth century, ecological connotations were added to this symbolism. Only cinemas in spheres do not require justification. The round solid corresponds to the entertainment function in a visible way.

## 7. Summary

It is surprising that despite the initial impression of there only being a few structures to analyse, more and more examples of spherical buildings can be found in architecture. Subsequent examples are being designed or appearing as temporary structures as 'artistic interventions'[12].

The structures come from different parts of the world and different cultural backgrounds. They have different purposes, which is rarely indicated by their form. However, some functions seem to be particularly suited to the form of a sphere – cinemas, planetariums and other buildings related to culture or science.

The conciseness and timelessness of the spherical form causes that, deprived of all unnecessary adjacent elements, it does not provide any indication of its time of design and possible construction. A feature that clearly differentiates spherical buildings is their material. Since it is not possible to completely detach the sphere from the ground, architects also resolved access to it and, at the same time, contact with the ground in a variety of ways.

The field for the design and construction of spherical buildings remains vast. In the formal richness of twenty-first century architecture, when orthogonal, biomorphic and expressionist forms are used, the sphere combines two worlds of elementary architecture and signifying forms. It is a primordial and symbolic solid. It is relatively rarely used and, at the same time, it does not require justification. It carries universal content.

[12] An example could be the 'ORB' by Bjarke Ingels and Jakob Lange (2018).

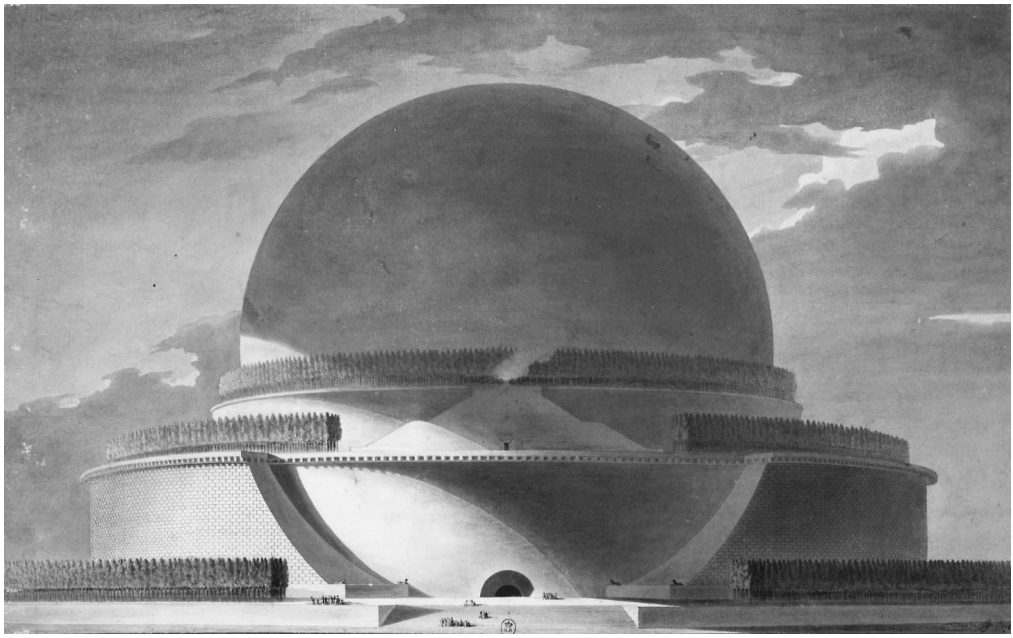

Fig. 1. Cenotaph by Étienne-Louis Boullée (1784), source: Eaton, R., *Ideal Cities: Utopianism and the (Un) Built Environment*, Thames & Hudson, London 2002

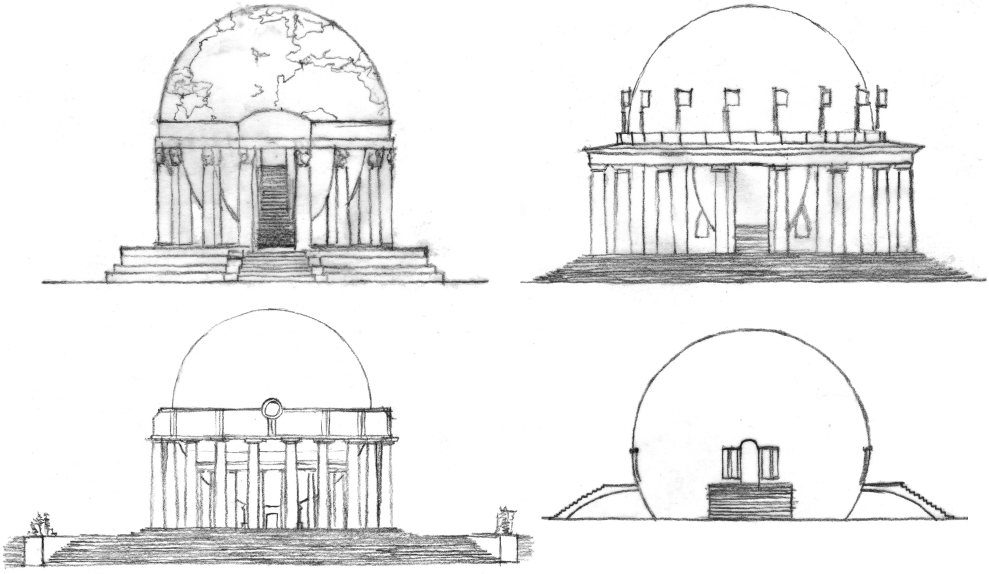

Fig. 2. Top left – Temple of Earth by Jean Jacques Lequeu (1790); top right – Temple of Equality by Jean Jacques Lequeu (1791); bottom top – House for a Cosmopolitan by Antoine Laurent Thomas Vaudoyer (1783); bottom right: House of the Farm Guards by Claude Nicolas Ledoux (ca. 1770), drawing by author

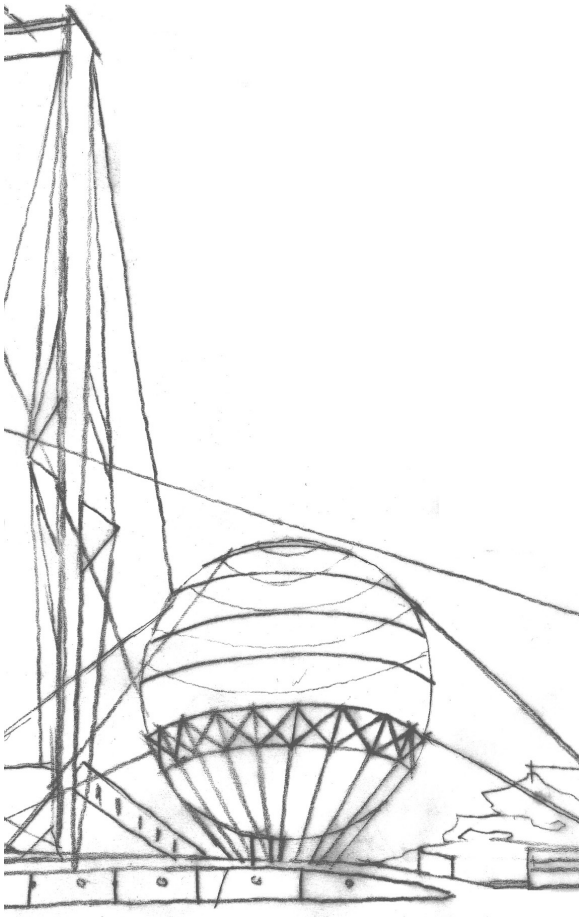

Fig. 3. Lenin Institute by Ivan Leonidov (1927), drawing by author

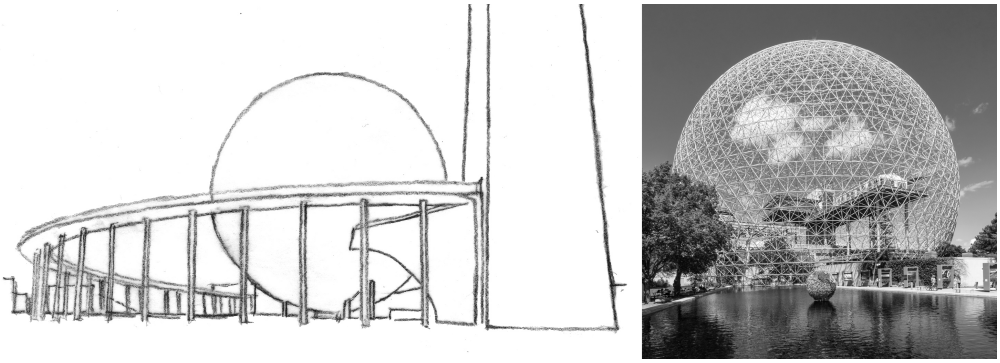

Fig. 4. Left – The Perisphere by Wallace Harrison and J. André Fouilhoux (New York, 1939); right – Biosphere by Buckminster Fuller (Montreal, 1967), drawing by author; photo by Ralf Roletschek, https://en.wikipedia.org/wiki/Montreal_Biosphere (access 23.01.2019)

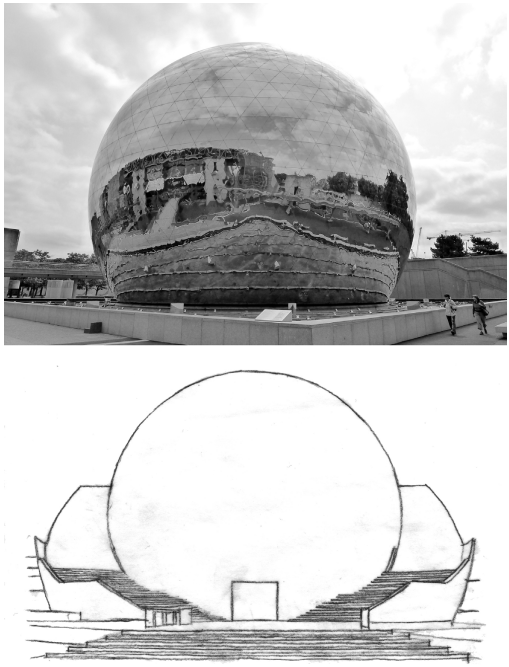

Fig. 5. Top – La Géode by Adrien Fainsilber and Gérard Chamayou (Paris, 1985); bottom – Cultural Centre (CECUT) by Pedro Ramírez Vázquez (Tijuana, 1982), photo and drawing by author

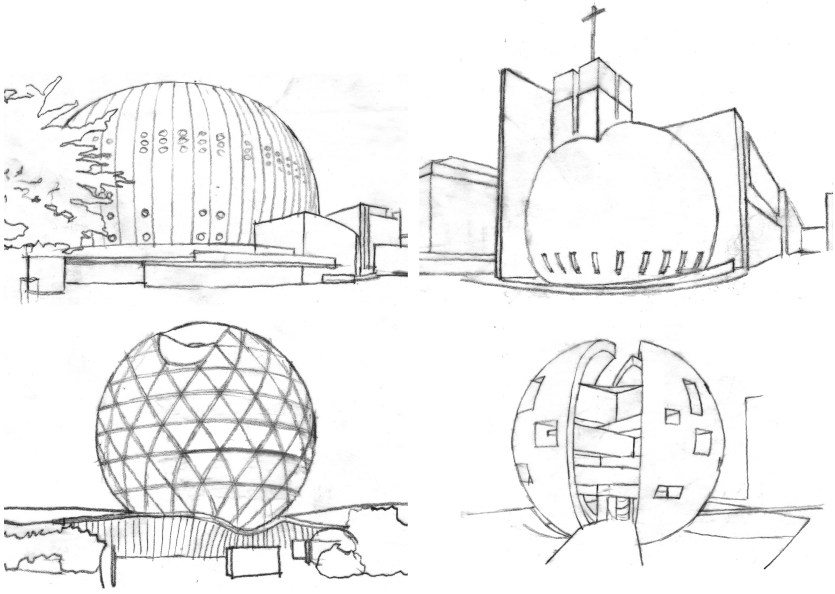

Fig. 6. Top left – Swedish National Arena – Ericsson Globe by Berg Arkitektkontor AB (Stockholm, 1989); top right – Holy Trinity Church by Ugo Brunoni (Geneva, 1994); bottom left – Nur Alem by Adrian Smith + Gordon Gill Architecture (Astana, 2017); bottom right – The Obama Presidential Library by Aras Burak Sen (Chicago, 2015), drawings by author

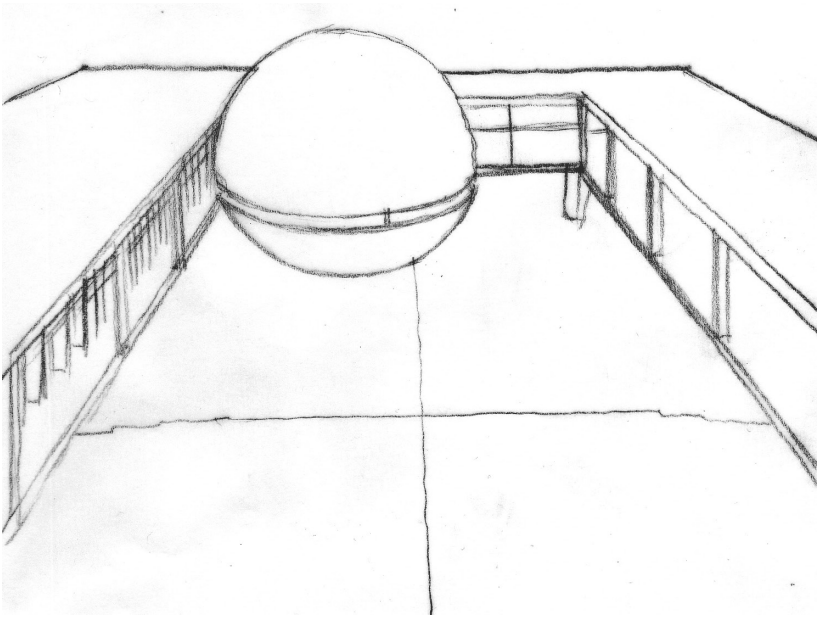

Fig. 7. Berggruen Institute by Herzog & de Meuron (Los Angeles, 2015-), drawing by author

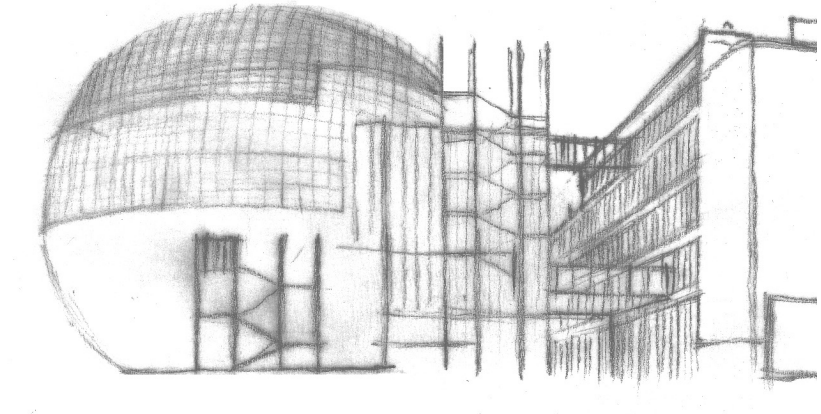

Fig. 8. Academy Museum of Motion Pictures by Renzo Piano (Los Angeles, opening planned for 2019), drawing by author

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If you want to quote this article, its proper bibliographic entry is as follow: Szpakowska-Loranc E., *The sphere in architecture as an example of an elementary form*, Technical Transactions, Vol. 6/2019, pp. 91–106.

TECHNICAL TRANSACTIONS 6/2019
ARCHITECTURE AND URBAN PLANNING
DOI: 10.4467/2353737XCT.19.064.10617
SUBMISSION OF THE FINAL VERSION: 4/06/2019

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# On the European Cultural Heritage Route of Residence of the Radziwiłłs – Castle in Ołyka, Volhynia

## Na europejskim szlaku dziedzictwa kulturowego radziwiłłowskich rezydencji – zamek w Ołyce na Wołyniu

**Abstract**

The European cultural heritage route of residences once belonging to the Radziwiłł family, located in the territories today belonging to Latvia, Lithuania, Belarus, Ukraine, and Poland, is demarcated by ca. fifty sites exhibiting high artistic and historical values. The ongoing research contributes to determining the value of the preserved historical sites, as well as assessing the risk they face. Development of a protection method at the level of the structure of the building, but also increasing the social and ethnic integration, will contribute to the creation of collective memory and identity of Europeans. The castle in Ołyka [Ukrainian: Olyka], one of the three centres of the Radziwiłł family fee tail, is one of the most distinguished examples of residential architecture in Volhynia. It has not been scientifically documented to date, which could constitute a foundation for the development of the building restoration project. Preserved to our time in a very bad technical condition, it awaits protection of its architectural heritage.

**Keywords:** residential architecture, heritage protection, cultural trail, Ołyka

**Streszczenie**

Europejski szlak dziedzictwa kulturowego rezydencji należących do rodu Radziwiłłów na obszarach obecnej Łotwy, Litwy, Białorusi, Ukrainy i Polski wyznacza około pięćdziesięciu obiektów architektonicznych o wysokich walorach artystycznych i historycznych. Prowadzone badania przyczyniają się do określenia wartości zachowanych, jak również stanu zagrożenia cennych zabytków. Wypracowanie metod ochrony na poziomie struktury dzieła, ale też zwiększających integralność społeczną i narodowościową, posłuży tworzeniu zbiorowej pamięci i tożsamości Europejczyków. Zamek w Ołyce, jeden z trzech ośrodków ordynacji radziwiłłowskiej, zaliczany jest do najwybitniejszych dzieł architektury rezydencjonalnej na Wołyniu. Do dziś nie doczekał się dokumentacji naukowej, będącej podstawą do opracowania projektu restauracji obiektu. Zachowany do naszych czasów w bardzo złym stanie technicznym,oczekuje na ochronę architektonicznego dziedzictwa.

**Słowa kluczowe:** architektura rezydencjonalna, ochrona dziedzictwa, szlak kulturowy, Ołyka

## 1. Introduction

The Act on Monument Protection and Preservation from 2003 provides that "a historic monument, as a testimony to a bygone era, being a work of man, should be preserved, as it is in the social interest due to the historic, artistic, or scientific value it exhibits" [9]. The year 2018, announced by the European Commission as the European Year of Cultural Heritage, should constitute a beginning of a path towards stimulation of local communities. The awakening awareness of the architectural heritage of a specific region shall entail measures associated with its protection. Family residences of the Radziwiłłs, dispersed over the territories of the today's Latvia, Lithuania, Belarus, Ukraine, and Poland, have survived to our times in different stages of preservation. The Author carried out a preliminary identification of residences along the European route of cultural heritage of one family in order to categorise the sites in terms of their state of preservation [10]. It is assumed that the artistic, historical, and scientific values of these sites are unquestionable as they are all listed as historic monuments. Therefore, organising a cultural route linking the residences should constitute a social interest of the countries which in the past contributed to the power of Poland and Lithuania. The Author's research allows to determine the extent of preservation, but also the risks faced by individual sites, caused by physical factors and time. Results of the study may initiate social and ethnic integration, contributing to the awareness of common history. The goal of further research will be to develop a method of protection at the level of the structure of a particular architectural work, as well as protection improving the social awareness of the significance of residential cultural heritage of one family. Marking the local heritage of family residences on the map of Europe will allow these valuable historic sites to come into being in a broad context of global and universal values, irrespective of the state of their preservation. The castle in Ołyka, which constitutes the most valuable example of residential architecture within the former territories of the Polish Republic, has not lived to see a scientific study. The monograph of the castle in Ołyka, compiled by Stanisław Tomkowicz in 1923 on the basis of a search query and a description of the existing state as of 1913, should constitute a foundation for the development of the site restoration project. The condition of this monument requires immediate intervention on the part of the local authorities, monument preservation services, and a team of scholars engaged in the protection of architectural heritage.

## 2. Analysis of historical and artistic values of the castle in Ołyka

The history of Ołyka, a little town in Volhynia, was associated with the Radziwiłłs since ca. 1513 through a marriage of Anna née Kiszka with the castellan of Trakai, Jan Radziwiłł, dubbed 'the Bearded'. The son of this union, Mikołaj Radziwiłł dubbed 'the Black', Grand Marshal of Lithuania and Castellan of Vilnius, inherited the estates in Ołyka, marking the beginning of the history of this place, which lasted until 1939 [7, pp. 56–65]. In 1540 he launched the construction of a castle in the place of a former fortress, on wetlands which provided natural protection. In 1547 Mikołaj Radziwiłł 'the Black' received a hereditary title of a prince from

emperor Charles V, approved in 1549 by Sigismund Augustus [2, p. 366]. The probable completion of the construction of the castle in 1564 is determined on the basis of a fragment of a stone slab, found in the ruins of the castle in 1883, on which this very date appears. The relic with the inscription was built into a side wall of the staircase of the 16th-century castle [2, p. 367]. The initial seat, located within the broads of small rivers, the Miłowiczka and the Putyłówka, had the character of a fortress. Roman Aftanazy compiled a description of the Ołyka castle from the 16th century on the basis of a view of the castle located on a preserved copperplate [2, p. 368]. The initial castle was located on quadrangle embankments with four corner bastions. The castle could be reached via a bridge supported by fourteen stone pillars. Inside the quadrangle around the courtyard there was diversified, chaotic development on three sides, which apart from the gate buildings and the palace featured end walls directed towards the courtyard. There were four towers on the site. Two of them were situated on the development frontage facing the bridge, and the other two were inside the bastions. The tallest four-storey tower was integrated with the building of the palace (Fig. 1). According to the inventory of the Ołyka castle from 1686, the brick building of the palace had four rooms and an apothecary on the ground floor and seven rooms on the first floor, with a grand hall dubbed 'the upper hall', and a chapel. The grand hall had seven windows and a wooden gallery for an orchestra, hence it was taller than the other rooms on this floor. Next to the palace there were wooden outbuildings, stables, and two wells [3, pp. 67–70]. In 1640 prince Albrycht Stanisław Radziwiłł, the next head of the Ołyka fee tail, launched the extension of the castle in the Renaissance style. The castle was equipped with surrounding walls erected on a quadrangle plan with four corner bastions, in the place of the former embankments. According to Tomkowicz, the residence in Ołyka belongs to the most distinguished examples of *palazzo in Fortezza* projects in Volhynia. The Ołyka castle combined in itself equivalent defensive functions with those of a stronghold and a representational palace arranged around a large courtyard (*cour d'honneur*), surrounded by buildings featuring rich architectural forms in the façades. In 1640 prince Albrycht Radziwiłł placed a plaque over the entrance gate, featuring a Latin inscription, and a statue of the Lady of Loretto made of white alabaster right above it. There was a chapel above the gateway, and a stone sculpture of St. Michael with wings was placed on the façade facing the courtyard [3, pp. 67–70]. The 1737 inventory suggests that after the death of prince Albrycht in 1656 "the old palace" was still subjected to subsequent transformations. The embankments, "partly made of brick and partly made of soil", were reinforced. The part of the inventory devoted to the residential quarters refers to the two-storey building as "a brick palace, to which round stairs led from both sides" [3, pp. 89–99]. The next inventory from 1755 indicates that Michał Kazimierz Radziwiłł, dubbed 'Rybeńko', conducted construction works here in the years 1737–1755 [3, pp. 115–120]. All the four frontages arranged around the courtyard were rebuilt at the time and the entire complex was given a representational Baroque character, without any features of defensiveness. Michał Kazimierz Radziwiłł, following the custom of landed gentry, was particularly strongly engaged in the transformation of his residence in Ołyka. In cooperation with architects, not only in terms of the functional programme, but also of a new architectural form that was in fashion in Europe at the time, he prepared "drawings outlined with his own hand" [4, pp. 299–306]. Since 1741

Castelli, an Italian architect, cooperated with Michał Radziwiłł 'Rybeńko' [1]. In the years 1720–1766 a German architect and designer of gardens, Johan Georg Knackfus, worked in Ołyka and Żółkiew [*Ukrainian: Zhovkva*] upon a commission of the head of the Ołyka fee tail. In the period 1750–1760 he supervised the reconstruction of the castle in Ołyka. At the same time Jakub Fryczyński contributed to furnishing the interiors of the castle in Ołyka with a Late-Baroque design [6, pp. 52–53, 57]. The spatial layout of the entire castle complex in Ołyka was based on embedding the monumental palace within the perimeter of 17th-century bastion fortifications, which was typical for the model of an Italian *palazzo in fortezza*. 18th-century family residences located within the perimeter of fortifications had only a symbolic character, emphasising the social position of the family. In the palace complex in Ołyka, the group of buildings was combined with curtains referring to the Italian tradition, and the spatial composition was based on an axis along which an entrance tower with a gate building was located, separated from the main body of the palace with a large courtyard. The sides of the quadrangle courtyard flank spacious outbuildings, intended for the more and more numerous court. The earlier two-storey structure of the palace, built on the former vaulted basements, was extended by one more floor, to house the 'grand' hall spanning two floors. In 1741–1745 the hall was transformed by making twelve window openings, six large ones and six smaller ones above them. The new window openings replaced the seven previous windows of the former building. The interiors were designed according to the giant Corinthian order, and large planes of the walls divided by pilasters were filled with paintings on canvas, which were painted in 1745 by the court painter of Nieśwież (*Belarussian: Nyasvizh*), Ksawery Dominik Heski [6, p. 79]. The interiors of the grand hall were furnished with a large fireplace, stuccowork, and wall paintings. A portrait hall, of the same length as the grand hall, was adjacent to it. Behind it there was a chapel, richly ornamented with stuccowork. The façade of the palace building facing the courtyard had two portals on the sides of the arcade driveway and a balcony on the first floor. In the early 19th century fragments of surface frescoes were still visible on the facades of the palace facing the courtyard, the portals and the balcony were still there, only to get completely devastated in this century. The external facade of the palace, composed of a seven-axis projection with a separated three-axis pseudo projection with pilasters, was in a slightly better situation. Within the frames limited by the pilasters there were tall windows from the grand hall. The edifice was covered with a prominent hipped roof covered with tiles, in the projection composition, ornamented with three oval dormers. Behind the edifice of the palace there were residential buildings in the external corners at the level of the embankments, with their longer sides facing a small courtyard [8, p. 11]. In his description of the castle from 1913, Tomkowicz mentions preserved fragments of frescoes in one of the houses, on the first floor. The other two residential houses in the corners of the fortress facing the embankments are preserved only as parts of the foundations. Tomkowicz assumed that most probably the fortifications of the castle in Ołyka were never fully made of brick and stone, which can be confirmed by the existence of fragments of earth embankments [8, pp. 11–12]. In ca. 1760 the residential complex with a palace already had all the elements of development in the side wings and the gates facing the town. The gateway facing Turczyn was not there yet, as only foundations for this structure had been lain [2, p. 373]. The side wings of the palace consisted of two floors, and

they featured a modest composition of pilasters and inter-window panels. They were covered with a gable roof. The wing with the gate buildings was integrated with the side outbuildings by means of quarter circle arcade battens, behind which there were four small courtyards: two of them beside the main body of the building are planned on an irregular hexagon, and the other two are triangular in shape. The gate architecture, monumental in character, was extended with an external, lower part of the gate, crowned with a semi-circular arch, under which there was a chapel [8, pp. 9–10]. A two-storey Baroque clock tower dominated over the internal part of the edifice erected on the plan of an elongated octagon. The gate buildings, erected on a rectangular plan, with seven-axis façades in the composition of panels and pilaster strips, were covered with hipped roofs, whereas the clock tower was crowned with a slender dome (Fig.3). During this rebuilding phase, the castle complex was provided with several dozen rooms and representational halls, and in this functional layout, with only few changes, it was preserved until 1939 [2, p. 375], (Fig.2). During the partitions, the splendour of the Ołyka residence declined, and in the days of Dominik Radziwiłł, the 11th entailer of Nieśwież and Ołyka, the estate was confiscated because of the prince's participation in the warfare against Russia. In 1814, thanks to the efforts of prince Adam Czartoryski, the Ołyka residence returned to the hands of Antoni Radziwiłł, who hailed from the Kleck (*Belarussian: Kletsk*) fee tail. Ever since the beginning of the 19th century the decline of the palace, which in the years 1812–1836 housed a hospital, was progressing. The interior design of the palace rooms was destroyed then. When the hospital was liquidated, the castle was abandoned until ca. 1860, when thanks to the next Ołyka entailer the residence flourished once again. By 1882 prince Ferdynand Fryderyk Radziwiłł conducted restoration and renovation works, adjusting the residence to contemporary needs. The reconstruction was implemented in stages, and at its initial stage the construction works were supervised by a Lvov-based architect, Zygmunt Gorgolewski. Some of the residential premises were renovated, the roof was replaced, and the façades were partially renovated. On the central axis, in the place of the no longer existing balcony, in 1896 an arcade was built, supported by four columns, bearing a terrace covered with a pent roof (Fig.5). The gateway and the main entrance to the castle was furnished with baroque portals [8, pp. 2–3]. In 1882 the Radziwiłłs occupied the castle once again. By 1913 the main body of the edifice, the north-eastern side wing with guest rooms, and the outbuildings were renovated. The second wing of the palace was not inhabited at the time. The gate buildings facing Turczyn housed stables, coach houses, and warehouses. The entrance gate with a tower and the fortress walls remained unrenovated [5]. During the World War I Ołyka was on the frontline for three years. The castle was repeatedly burgled and devastated, and it fell into ruin once again. After 1920 the caste was reconstructed and modernised by the last entailer, prince Janusz Radziwiłł. The former glory of the palace was restored. One wing was fully renovated, whereas only a half of the other one was renovated by 1939. The water supply, electric, and heating installation was modernised inside the palace [2, p. 381]. Ołyka as one of the three fee tails of the Radziwiłł family, was subject to a legally regulated principle of indivisibility and inheritance only within the family. The continuity of lasting and multiplying of the excellent cultural heritage was disturbed only by the outbreak of the World War II, when the castle in Ołyka was devastated and robbed, and the loss of the estate by the Radziwiłłs constituted a beginning of a certain

path to ruin for the castle. In 1945 some of the castle rooms were converted into stables. After 1950 the castle was adapted and converted into a psychiatric hospital, which operates to date. In the 1970s a superficial renovation of the façades of the castle complex was conducted, which did not contribute at all to the plan of saving this monument, in consistence with the conservation philosophy.

## 3. State of preservation of the castle complex in Ołyka

The durability of residences of magnate families was secured by the fact that they were handed down from generation to generation. It was certain then that family residences would be preserved, modernised, or reconstructed in the spirit of the architectural trend prevailing at the time. This historical continuity of generations was sometimes very brutally interrupted by warfare, Russian or Swedish annexation, Tatar invasions. Eventually, the outbreak of the World War II commenced the process of degradation of the material heritage of magnate residences, and their end was eventually brought by the communist rule. These valuable buildings were occupied by random users, who didn't care about the family heritage, which made the residences fall into ruin. The castle complex in Ołyka, as a testimony of the bygone era, but also a testimony of historical events which had their effect on the final form of the complex, awaits rescue. Cultural heritage sites proposed to be entered in the World Heritage List must satisfy the criteria of authenticity and integrity. The criterion of authenticity is not limited to the original form and structure. This notion takes into account subsequent transformations, extensions, and modernisations, carried out in the past and exhibiting artistic and historical values. The residence of the Radziwiłł family in Ołyka has been preserved to our times in a bad technical condition, as a castle complex satisfying all authenticity criteria. The spirit of the place resides there to this day, hidden within the decaying walls of the castle, and *Volumina Legum* reminds us that these places used to belong to Poland. Today, the castle houses a psychiatric hospital. The earth and stone embankments with preserved bastions, surrounded with an old moat, are still legible and can be easily restored, despite their bad technical condition (Fig.7 and 8). The palace complex is accessible through two gates: one leads through the embankments and the main building from the side of the town, and along the same axis, facing Turczyn, there is a gate house with a clock tower (Fig.4). The 100 x 98 m courtyard, once designed as a representational *cour d'honneur* with fountains and a stand of trees, is covered with random trees and shrubs today. There is no arcade with a loggia in the palace building as they were disassembled after 1939. There is no trace of representational portals that used to ornament entrances to the courtyard facing the collegiate (Fig.6). The palace interiors got stripped of their architectural design and of the once rich furnishings. In the corners of the bastion complex there used to be small courtyards on the plan of polygons with tunnels leading outside the embankments. Today the devastated space of these courtyards is difficult to discern. A high level of groundwater in this area causes dampness of the walls and settling of the foundations, and consequently it leads to decomposition of the structure of the buildings. On the other hand, leaking roofs complete the destruction. The castle complex in Ołyka remains in the state of ruin. Degradation and decomposition of matter

progresses, and these processes result in the loss of authenticity of the palace complex with its entire historical legacy. Splintered and crumbling fragments of the bastion walls, leaking roofs of the edifice of the palace, collapsed ceilings, cracked and damp walls – this is a picture that depicts an annihilation of a centuries-long heritage. Current protective repairs carried out by the hospital staff are performed without any supervision of building and conservation services and unfortunately they are not capable of stopping the degradation of this valuable monument of architecture. Architectural heritage of the bygone centuries is slowly sinking into nothingness. The technical condition of the buildings calls for an immediate intervention of building and conservation services. For this purpose, it will be necessary to compile scientific documentation, opinions of experts on monument conservation and construction, as well as architectural studies. Developing in details each phase of transformations of the castle complex will allow to restore the today non-existent architectural design. The documentation compiled this way will constitute a foundation for developing an architectural and conservation project, aiming at the restoration of the former splendour of the residence. Regrettably, local authorities are not interested in the preservation of the cultural heritage of this magnate residence in Volhynia. A centuries-long architectural legacy of one family slowly falls into ruin.

## 4. Conclusion – cultural heritage protection

Since the 16th century Volhynia was becoming the seat of the most powerful magnate families in the Polish Republic. The growing power of the Radziwiłłs with the fee tail in Ołyka left one of the most exquisite cultural achievements in architecture in this area. Artistic, historical, and scientific values of the castle complex are regarded as the most distinguished examples of residential architecture. The cultural heritage deriving from the times of glory of magnate residences was gradually lost already in the 19th century, and the 20th century, marked by world wars, the turmoil of big social transformations, and dominated by the totalitarian communist rule, completed their destruction. The destructive force of the past and the present constitutes a path towards a complete ruin of the residence in Ołyka. Cultural heritage protection, guaranteed in international agreements, refers to protection in every situation, place, and time. The beginning of the 21st century, when appeals to protect cultural heritage are contained in conventions, doctrines, and philosophy of monument preservation, should stop the process of decline of magnate residences on the European cultural heritage route of the Radziwiłł family. The task of the European Commission, which announced the year 2018 as the European Year of Cultural Heritage, appealing for "overcoming borders" and going beyond the territory of a given country or region, is aiming to create a collective memory and identity of Europeans. One of the elements that constitute this process should be active participation of social groups from a given region, which would cooperate with scholars and local authorities, contributing to the process of rescuing and protection of the architectural heritage. It is high time indeed, if we don't want the cultural heritage of one family to be present only on the memory map.

*Translated by Iweta Kulczycka*

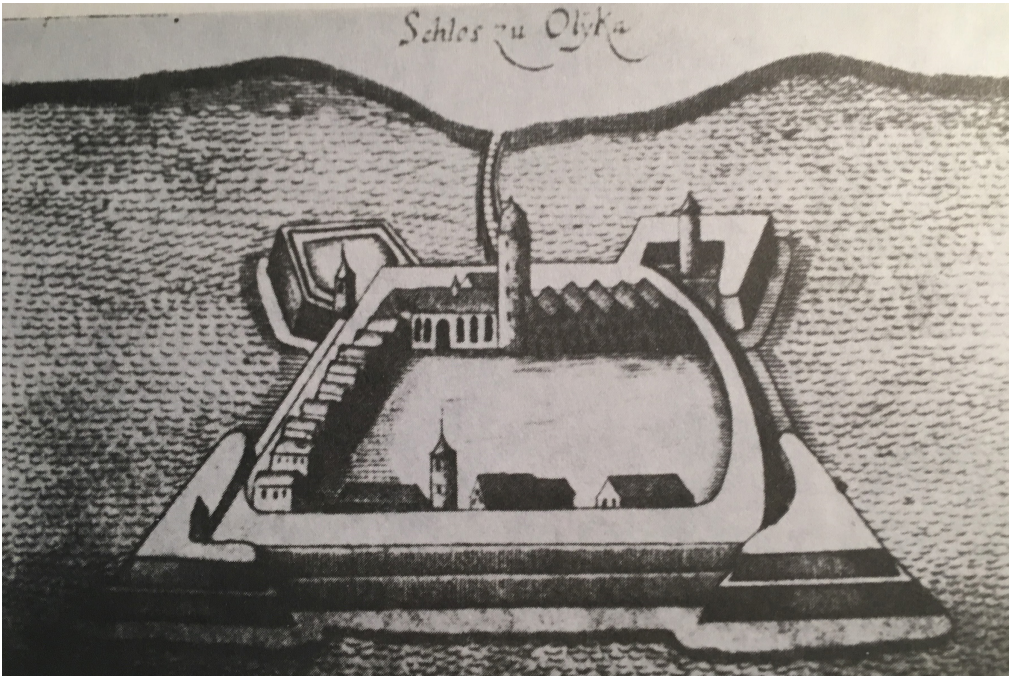


Fig. 1. Castle in Ołyka according to the copperplate from the 17th century (source: [2])

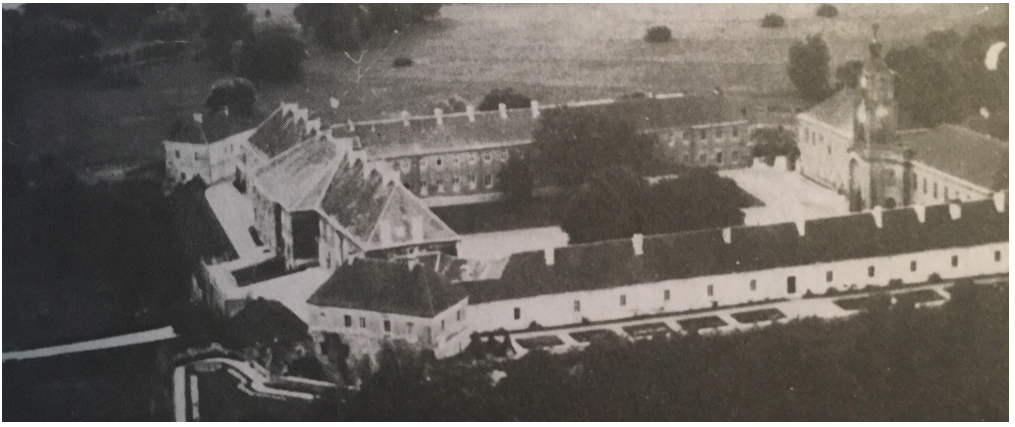

Fig. 2. Ołyka, view of the castle in ca. 1914 (source: [2])

Fig. 3. Castle in Ołyka, entrance gate facing the courtyard, before 1938 (source: [2])

Fig. 4. Castle in Ołyka, entrance gate, condition as of 2019 (photo by B. Zin)

Fig. 5. Castle in Ołyka, view of the wing of the palace facing the courtyard, 1939 (source: [2])

Fig. 6. Castle in Ołyka, view of the wing of the palace facing the courtyard, condition as of 2019 (photo by B. Zin)

Fig. 7. Castle in Ołyka, entrance gate facing the collegiate, condition as of 2019 (photo by B. Zin)

Fig. 8. Castle in Ołyka, entrance gate facing Turczyn, condition as of 2019 (photo by B. Zin)

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If you want to quote this article, its proper bibliographic entry is as follow: Zin B., *On the European Cultural Heritage Route of Residence of the Radziwiłłs – Castle in Ołyka, Volhynia*, Technical Transactions, Vol. 6/2019, pp. 107–118.

TECHNICAL TRANSACTIONS 6/2019
CIVIL ENGINEERING
DOI: 10.4467/2353737XCT.19.065.10618
SUBMISSION OF THE FINAL VERSION: 21/05/2019

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# Sensitivity analysis of the dynamic response of a frame. Part I: Direct differentiation method

# Analiza wrażliwości odpowiedzi dynamicznej ramy. Część I: Metoda bezpośrednia analizy wrażliwości

**Abstract**

This paper presents a sensitivity analysis related to the solution of a stationary, linear system of second order equations of motion obtained by the Finite Element Method. The Direct Differentiation Method was presented in this paper. The essence of this method is the explicit differentiation of the system of equations with respect to parameters. As a result, derivatives of vectors and matrices are obtained. The necessary material derivatives of vectors and matrices associated with the simplest 3D beam element are presented. Sensitivity analysis consists in searching for changes in physical quantities in relation to selected parameters. Ultimately, the sensitivity analysis comes down to calculating derivatives of specific functions with respect to parameters. Real and continuous design variables are considered.

**Keywords:** sensitivity analysis, direct differentiation method, explicit differentiation

**Streszczenie**

Analiza wrażliwości polega na poszukiwaniu zmian wielkości fizycznych względem wybranych parametrów. Sprowadza się ona do obliczania pochodnych określonych funkcji. W pracy przedstawiono analizę wrażliwości rozwiązania stacjonarnego, liniowego układu równań ruchu drugiego rzędu otrzymanego metodą elementów skończonych. Przedstawiono metodę bezpośrednią analizy wrażliwości. Polega ona na bezpośrednim zróżniczkowaniu równań względem parametrów. W rezultacie uzyskano pochodne wektorów i macierzy. Przedstawiono niezbędne pochodne materialne wektorów i macierzy związanych z najprostszym elementem belki 3D. Rozpatrywano rzeczywiste i ciągłe zmienne projektowe.

**Słowa kluczowe:** analiza wrażliwości, bezpośrednia analiza wrażliwości, pochodne równania ruchu

## 1. Introduction

Sensitivity analysis consists in searching for changes in physical quantities in relation to changes in selected parameters, which are called design variables, decision variables or free variables. Ultimately, the sensitivity analysis comes down to calculating derivatives of specific functions with respect to parameters [10]. These parameters can determine the configuration of the structure (i.e. its geometry), properties of materials, dimensions or characteristics of cross-sections, etc. A wide discussion about various types of parameters is contained in [10, 16, 19]. If the parameters depicts the geometry of the structure, then the sensitivity analysis is related to the determination of material derivatives [13].

In this paper, only real and continuous design variables are analysed. These variables can be arranged in the form of the vector **h**:

$$\mathbf{h} = [h_1, \ldots, h_p, \ldots, h_{N_p}], \quad h_p \in \mathcal{R}, \tag{1}$$

where $N_p$ means the number of design variables.

Determination of derivatives of solutions (i.e. sensitivity analysis) is mostly used in the Optimization [16, 15], Identification, in the Structural Health Monitoring [8, 17, 5], Model Updating [18, 12]. Obtaining derivatives of solutions also provides valuable information at the design stage, indicating which parameter has the largest impact on the determined values [6, 10].

The broad literature has been focused on sensitivity analysis (see basic issues eg. [13, 10]). This analysis is commonly implemented in software dedicated to mechanical problems (see eg. [16, 7]) – unfortunately, it is less frequently applied in Civil Engineering software. The classic approach is dominated by two methods: Direct Differentiation Method (DDM) and Adjoint System Method. Numerous papers have been devoted to both methods. Additionally, the Virtual Distortion Method [11] and Virtual Load Method [2, 3] have been developed. All above methods are applied in both linear and nonlinear problems.

This paper presents a sensitivity analysis related to the solution of a stationary, linear system of second order equations of motion obtained by the Finite Element Method (FEM). The DDM will also be presented. The essence of this method is the explicit differentiation of the system of equations with respect to parameters. As a result, derivatives of vectors and matrices are obtained. The necessary material derivatives of vectors and matrices associated with the simplest 3D beam element are presented in this paper.

Presented approach is parallel to [1, 9, 6, 14].

## 2. Second order matrix equation of motion

Movement of the structure with *N* dynamic degrees of freedom can be written using the *N* system of ordinary and stationary differential equations:

$$\begin{cases} \mathbf{M}(\mathbf{h})\ddot{\mathbf{x}}(t,\mathbf{h})+\mathbf{C}(\mathbf{h})\dot{\mathbf{x}}(t,\mathbf{h})+\mathbf{K}(\mathbf{h})\mathbf{x}(t,\mathbf{h})=\mathbf{F}(t,\mathbf{h}), \\ \dot{\mathbf{x}}(0,\mathbf{h})=\mathbf{v}_0(\mathbf{h}), \quad \mathbf{x}(0,\mathbf{h})=\mathbf{u}_0(\mathbf{h}), \end{cases} \tag{2}$$

where matrix **M**, **C** and **K** are symmetric and **K** is positive defined; displacement vector **x** dependent on time and design parameters. Similarly, the right hand side $\mathbf{F}(t,\mathbf{h})$ describes the excitation of the system. The dot above vector means differentiation over time, i.e.:

$$\dot{\mathbf{x}}(t,\mathbf{h})=\frac{\partial \mathbf{x}(t,\mathbf{h})}{\partial t}. \tag{3}$$

In the equation (2) the dependence of the existing matrices on the parameter vector is marked explicitly. In general, the initial conditions may also depend on design parameters. In the analysis of civil structures, it is often assumed that these conditions are zero:

$$\mathbf{v}_0(\mathbf{h})=\mathbf{0}, \quad \mathbf{u}_0(\mathbf{h})=\mathbf{0}. \tag{4}$$

The common used method of obtaining the equation (2) is FEM [4]. The matrices of the system are global matrices expressed in the global coordinate system after the aggregation process. Typically, boundary conditions are also included in the matrices of the (2) system.

One of the method of considering the boundary conditions of the structure and introducing them into the matrix of the system is reorganization of matrices. The key is isolation and ordering those elements of the displacement vector **x** of which absolute displacements are known (equal to zero for fixed supports or non-zero for supports receiving settlements, offsets, etc.). The subvector of known generalized displacements is denoted as $\mathbf{x}_b$. The remaining components are ordered in $\mathbf{x}_s$ subvector, which is associated with unknown displacements of nodes which do not have contact with a boundary. All matrices and vectors are subject to similar division:

$$\begin{bmatrix} \mathbf{M}_{ss} & \mathbf{M}_{sb} \\ \mathbf{M}_{bs} & \mathbf{M}_{bb} \end{bmatrix} \begin{bmatrix} \ddot{\mathbf{x}}_s \\ \ddot{\mathbf{x}}_b \end{bmatrix} + \begin{bmatrix} \mathbf{C}_{ss} & \mathbf{C}_{sb} \\ \mathbf{C}_{bs} & \mathbf{C}_{bb} \end{bmatrix} \begin{bmatrix} \dot{\mathbf{x}}_s \\ \dot{\mathbf{x}}_b \end{bmatrix} + \begin{bmatrix} \mathbf{K}_{ss} & \mathbf{K}_{sb} \\ \mathbf{K}_{bs} & \mathbf{K}_{bb} \end{bmatrix} \begin{bmatrix} \mathbf{x}_s \\ \mathbf{x}_b \end{bmatrix} = \begin{bmatrix} \mathbf{P}_s \\ \mathbf{P}_b - \mathbf{R}_b \end{bmatrix}, \tag{5}$$

where for all matrices there is $(\bullet)_{bs} = (\bullet)_{sb}^T$ (symmetry). Vector $\mathbf{R}_b$ consists of reactions i.e. unknown nodal forces associated with the boundary. By expandig the equation (5) we obtained:

$$\begin{cases} \mathbf{M}_{ss}\ddot{\mathbf{x}}_s+\mathbf{C}_{ss}\dot{\mathbf{x}}_s+\mathbf{K}_{ss}\mathbf{x}_s=\mathbf{P}_s-\mathbf{M}_{sb}\ddot{\mathbf{x}}_b-\mathbf{C}_{sb}\dot{\mathbf{x}}_b-\mathbf{K}_{sb}\mathbf{x}_b, \\ \mathbf{R}_b=\mathbf{P}_b-\mathbf{M}_{bb}\ddot{\mathbf{x}}_b-\mathbf{C}_{bb}\dot{\mathbf{x}}_b-\mathbf{K}_{bb}\mathbf{x}_b-\mathbf{M}_{bs}\ddot{\mathbf{x}}_s-\mathbf{C}_{bs}\dot{\mathbf{x}}_s-\mathbf{K}_{bs}\mathbf{x}_s. \end{cases} \tag{6}$$

The first equation in (6) is a state equation – it allows to calculate unknown displacements $\mathbf{x}_s$ of non-boundary nodes of a model, with known nodal loads and nodal support displacements. The second equation in (6) allows to calculate the unknown reactions $\mathbf{R}_b$ in support nodes with previously determined components of the vector $\mathbf{x}_s$. All occurrences of vectors in (6) are dependent on the **h** vector, which is not written for the clarity.

Equations (6) are the general form of discrete motion equations with any kinematic excitations. Thus, one can solve them, for example, the response of a structure subjected to a seismic excitation to any function $\mathbf{x}_b = \mathbf{x}_b(t)$ (depending only on time) which is theoretically different for each degree of freedom associated with the boundary. The generality of this rule allows to analyse spatially sprawling structures (long bridges, pipelines, dams, geotechnical objects, etc.) subjected to kinematic excitations caused by a moving seismic wave. It is also possible to design buildings subjected to kinematic excitations caused by trains, road traffic (heavy vehicles or trams) or subway etc.

On the other hand the presence of the $\mathbf{P}_s$ component allows to enter any other excitations forces (including harmonics) into free nodes of the mechanical system.

If the boundary conditions are unchanged in time (no movement of supports) and equal to zero (no static settlements), i.e. $\mathbf{x}_b(t, \mathbf{h}) \equiv \mathbf{0}$, then the equations (6) take the form:

$$\begin{cases} \mathbf{M}_{ss}\ddot{\mathbf{x}}_s + \mathbf{C}_{ss}\dot{\mathbf{x}}_s + \mathbf{K}_{ss}\mathbf{x}_s = \mathbf{P}_s, \\ \mathbf{R}_b = \mathbf{P}_b - \mathbf{M}_{bs}\ddot{\mathbf{x}}_s - \mathbf{C}_{bs}\dot{\mathbf{x}}_s - \mathbf{K}_{bs}\mathbf{x}_s. \end{cases} \tag{7}$$

However, if there is no force excitation in the system $\mathbf{P}(t, \mathbf{h}) \equiv \mathbf{0}$ and only kinematic inputs are present, then:

$$\begin{cases} \mathbf{M}_{ss}\ddot{\mathbf{x}}_s + \mathbf{C}_{ss}\dot{\mathbf{x}}_s + \mathbf{K}_{ss}\mathbf{x}_s = -\mathbf{M}_{sb}\ddot{\mathbf{x}}_b - \mathbf{C}_{sb}\dot{\mathbf{x}}_b - \mathbf{K}_{sb}\mathbf{x}_b, \\ \mathbf{R}_b = -\mathbf{M}_{bb}\ddot{\mathbf{x}}_b - \mathbf{C}_{bb}\dot{\mathbf{x}}_b - \mathbf{K}_{bb}\mathbf{x}_b - \mathbf{M}_{bs}\ddot{\mathbf{x}}_s - \mathbf{C}_{bs}\dot{\mathbf{x}}_s - \mathbf{K}_{bs}\mathbf{x}_s. \end{cases} \tag{8}$$

In the analysis of building structures most often a simpler form of kinematic excitations is assumed – this is connected with the assumption that the movement of the base within the foundations can be treated as a movement of a rigid body which usually has three translational degrees of freedom (or six DOFs including rotation of the base). So, it possible to write two dependencies:

$$\mathbf{x}_b(t, \mathbf{h}) = \mathbf{B}(\mathbf{h})\mathbf{u}_b(t), \quad \mathbf{x}_s(t, \mathbf{h}) = \mathbf{A}(\mathbf{h})\mathbf{u}_b(t) + \mathbf{y}_s(t, \mathbf{h}), \tag{9}$$

where: vector $\mathbf{u}_b$ describes the absolute, stiff movement of the base, the matrix $\mathbf{B}$ expresses the purely geometric relationship of motion of nodes of the boundary of the structure with ground movement, vector $\mathbf{y}_s$ expresses relative displacements of the free nodes of the structure, matrix $\mathbf{A}$ expresses the purely geometric relationship of motion of free nodes of structure which is result of the motion of rigid ground and is equal to:

$$\mathbf{A} = -\mathbf{K}_{ss}^{-1}\mathbf{K}_{sb}\mathbf{B}. \tag{10}$$

Assuming that the damping of the structure is defined by the classical proportional

relations $\mathbf{C} = \alpha\mathbf{M} + \beta\mathbf{K}$ and it is small (i.e. $0 \le \beta \ll \alpha \ll 1$) and that low frequencies dominate in excitation, the first equation in (8) takes the form:

$$\mathbf{M}_{ss}\ddot{\mathbf{y}}_s+\mathbf{C}_{ss}\dot{\mathbf{y}}_s+\mathbf{K}_{ss}\mathbf{y}_s=-(\mathbf{M}_{sb}-\mathbf{M}_{ss}\mathbf{K}_{ss}^{-1}\mathbf{K}_{sb})\mathbf{B}\ddot{\mathbf{u}}_b. \tag{11}$$

Further considerations assume zero initial conditions (4) for (2).

## 3. Drect differentiation method

The essence of the DDM is the direct differentiation of the equation (2) with respect to the parameter $h_p$. After differentiation and arrangement, we get:

$$\mathbf{M}\frac{\mathcal{D}\ddot{\mathbf{x}}}{\mathcal{D}h_p}+\mathbf{C}\frac{\mathcal{D}\dot{\mathbf{x}}}{\mathcal{D}h_p}+\mathbf{K}\frac{\mathcal{D}\mathbf{x}}{\mathcal{D}h_p}=\frac{\mathcal{D}\mathbf{F}}{\mathcal{D}h_p}-\left[\frac{\mathcal{D}\mathbf{M}}{\mathcal{D}h_p}\ddot{\mathbf{x}}+\frac{\mathcal{D}\mathbf{C}}{\mathcal{D}h_p}\dot{\mathbf{x}}+\frac{\mathcal{D}\mathbf{K}}{\mathcal{D}h_p}\mathbf{x}\right], \tag{12}$$

where zero initial conditions were assumed and the symbol $\mathcal{D}(\bullet)/\mathcal{D}h_p$ denotes a material derivative of a given quantity.

The introducing of the material derivative [13] is important due to the fact that changing some parameters (e.g. element length) may involve changing the configuration and geometry of the structure, which in turn causes that a material point as a result of this change has a different position in space than before. Thus, the computed spatial derivative would not be expressed as a quantity. From a mathematical point of view, the material derivative of $f=f(t,s(\mathbf{h}),\mathbf{h})$ is a derivative of a composition mapping:

$$\frac{\mathcal{D}f}{\mathcal{D}h_p}=\frac{\partial f}{\partial s}\frac{\partial s}{\partial h_p}+\frac{\partial f}{\partial h_p}, \tag{13}$$

where the first summand of (13) is associated with the change node location (convection) and the second summand expresses the change of function *f* at the fixed node position. Due to the rules of differentiating vectors and matrices, the formula (13) is transferred to the components of these objects. If the parameter does not specify the geometry of the structure and specify of properties of material or the cross-section, then the material derivative is equivalent to a simple derivative (no dependence of *f* on the *s* variable).

Finally, derivatives $\mathcal{D}\mathbf{M}/\mathcal{D}h_p$, $\mathcal{D}\mathbf{C}/\mathcal{D}h_p$, $\mathcal{D}\mathbf{K}/\mathcal{D}h_p$ in (12) means material derivatives of inertia, damping and stiffness matrix; $\mathcal{D}\mathbf{x}/\mathcal{D}h_p$ and $\mathcal{D}\mathbf{F}/\mathcal{D}h_p$ denote material derivatives of system response and excitation. The $\mathcal{D}\mathbf{x}/\mathcal{D}h_p$ and its derivatives with respect to time are unknowns in the equation (12). Thus, by comparing (2) and (12) we can see that in order to determine the material derivatives of the response from the equation (12) we should resolve (2) earlier by designating the **x** vector and its time derivatives.

From a formal point of view, equations (2) and (12) have a similar structure – they differ only in the right hand side. Therefore, known and typical methods of direct integrating second order equations can be used.

The next two sections present vectors and matrices and their derivatives used in (12).

## 4. Vectors and matrices for 3D beam elements

The FEM belongs to the basic numerical methods of solving physical problems. In this section element matrices and their derivatives in relation to beam elements are shown. Beams describes straight frame bars (without shearing) in 3D space. Explicit forms of the stiffness, inertia and damping matrices were presented, without reference to the shape functions. The following text presents only the dependencies necessary to obtain derivatives.

The FEM introduces two types of orthogonal and right coordinate systems: the element's local system for each element and one common global system – Fig. 1. Local system with versors $\vec{\mathbf{i}}_e(\mathbf{h})$, $\vec{\mathbf{j}}_e(\mathbf{h})$, $\vec{\mathbf{k}}_e(\mathbf{h})$ can be generally a system depending on the parameters $\mathbf{h}$.

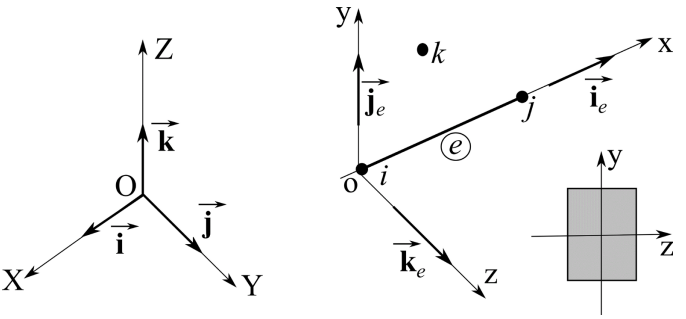


Fig. 1. Coordinate systems: global OXYZ and local 3D beam element oxyz. Orientation of an exemplary cross-section

A typical beam element $e$ is the line segment between nodes $i$, $j$. Vectors $\vec{\mathbf{r}}_i(\mathbf{h})$, $\vec{\mathbf{r}}_j(\mathbf{h})$, specified in the global coordinate system, indicate the location of the nodes. For an unambiguous orientation of the local coordinate system, an additional point $k$ should be introduced with vector $\vec{\mathbf{r}}_k(\mathbf{h})$. Then the versors of the local coordinate system are given the following formulas:

$$\vec{\mathbf{i}}_e(\mathbf{h}) = \frac{\vec{\mathbf{r}}_j(\mathbf{h}) - \vec{\mathbf{r}}_i(\mathbf{h})}{L_e(\mathbf{h})}, \quad \text{where} \quad L_e(\mathbf{h}) = \left\| \vec{\mathbf{r}}_j(\mathbf{h}) - \vec{\mathbf{r}}_i(\mathbf{h}) \right\|, \tag{14}$$

$$\vec{\mathbf{k}}_e(\mathbf{h}) = \frac{\vec{\mathbf{i}}_e(\mathbf{h}) \times [\vec{\mathbf{r}}_k(\mathbf{h}) - \vec{\mathbf{r}}_i(\mathbf{h})]}{\left\| \vec{\mathbf{i}}_e(\mathbf{h}) \times [\vec{\mathbf{r}}_k(\mathbf{h}) - \vec{\mathbf{r}}_i(\mathbf{h})] \right\|}, \tag{15}$$

$$\vec{\mathbf{j}}_e(\mathbf{h}) = \frac{\vec{\mathbf{k}}_e(\mathbf{h}) \times \vec{\mathbf{i}}_e(\mathbf{h})}{\left\| \vec{\mathbf{k}}_e(\mathbf{h}) \times \vec{\mathbf{i}}_e(\mathbf{h}) \right\|}. \tag{16}$$

The cross × means the vector product. As noted above, the vector $\vec{\mathbf{r}}_k(\mathbf{h})$, in general, is dependent on the parameters $\mathbf{h}$ – it means that sensitivity analysis is possible due to the spatial orientation of the element's cross section. This orientation is often associated with parameters defining the geometry of the structure.

The set of vectors $\vec{\mathbf{r}}_l(\mathbf{h})$, where $l$ iterates through all nodes of the FE model, unambiguously defines the geometry of the structure.

Any vector $\vec{\mathbf{r}}_g$ specified in the global coordinate system OXYZ has coordinates in the local system of the $e$ element defined by vector $\vec{\mathbf{r}}_e$. Both vectors are related by geometric transformation:

$$\vec{\mathbf{r}}_e(\mathbf{h}) = \mathbf{t}_e(\mathbf{h})\vec{\mathbf{r}}_g(\mathbf{h}), \tag{17}$$

where the transformation matrix $\mathbf{t}_e(\mathbf{h})$ is given by:

$$\mathbf{t}_e(\mathbf{h}) = \begin{bmatrix} \vec{\mathbf{i}} \circ \vec{\mathbf{i}}_e(\mathbf{h}) & \vec{\mathbf{j}} \circ \vec{\mathbf{i}}_e(\mathbf{h}) & \vec{\mathbf{k}} \circ \vec{\mathbf{i}}_e(\mathbf{h}) \\ \vec{\mathbf{i}} \circ \vec{\mathbf{j}}_e(\mathbf{h}) & \vec{\mathbf{j}} \circ \vec{\mathbf{j}}_e(\mathbf{h}) & \vec{\mathbf{k}} \circ \vec{\mathbf{j}}_e(\mathbf{h}) \\ \vec{\mathbf{i}} \circ \vec{\mathbf{k}}_e(\mathbf{h}) & \vec{\mathbf{j}} \circ \vec{\mathbf{k}}_e(\mathbf{h}) & \vec{\mathbf{k}} \circ \vec{\mathbf{k}}_e(\mathbf{h}) \end{bmatrix}. \tag{18}$$

The circle ∘ means the dot product. Due to the orthogonality of both coordinate systems, the asymmetric matrix $\mathbf{t}_e$ is orthonormal, i.e.:

$$\mathbf{t}_e^T \mathbf{t}_e = \mathbf{t}_e^{-1} \mathbf{t}_e = \mathbf{I}. \tag{19}$$

The nodal forces **f** and the moments **m** acting in nodes $i$, $j$ of the beam element $e$ (Fig. 2), can be arranged in the following columns:

$$\mathbf{f}_i^T = [f_{xi}, f_{yi}, f_{zi}], \quad \mathbf{f}_j^T = [f_{xj}, f_{yj}, f_{zj}], \quad \mathbf{m}_i^T = [m_{xi}, m_{yi}, m_{zi}], \quad \mathbf{m}_j^T = [m_{xj}, m_{yj}, m_{zj}]. \tag{20}$$

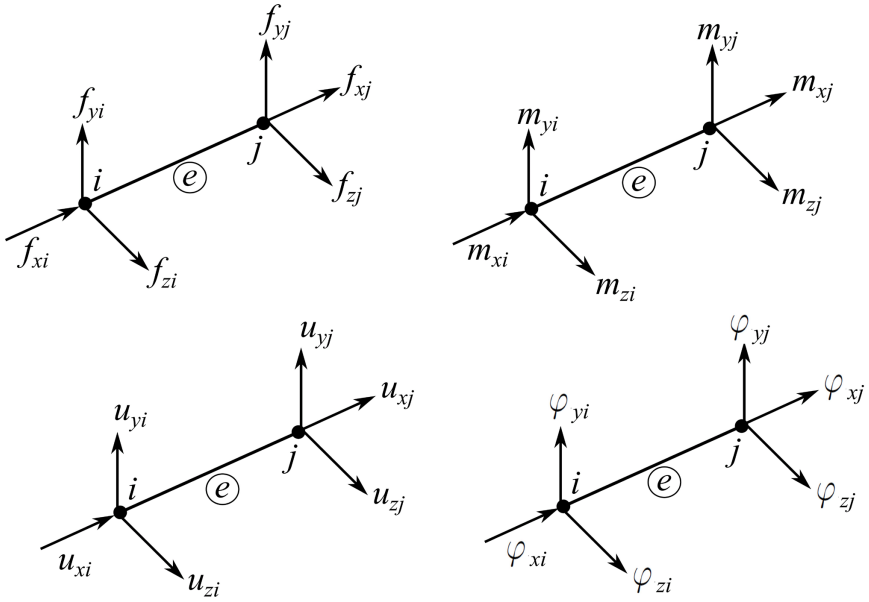


Fig. 2. Presentation of forces **f** and moments **m** and translation **u** and angular φ displacements in nodes $i$ – $j$ of finite element $e$

Between local and global values based on (17) there is:

$$\mathbf{p}_e(\mathbf{h}) = \mathbf{T}_e(\mathbf{h})\mathbf{P}_e(\mathbf{h}), \tag{21}$$

where the dependence of the existing quantities on the **h** parameter vector has been marked. Additionally:

$$\mathbf{p}_e^T = [\mathbf{f}_i, \mathbf{m}_i, \mathbf{f}_j, \mathbf{m}_j], \quad \mathbf{P}_e^T = [\mathbf{F}_i, \mathbf{M}_i, \mathbf{F}_j, \mathbf{M}_j], \quad \mathbf{T}_e = \mathrm{diag}[\mathbf{t}_e, \mathbf{t}_e, \mathbf{t}_e, \mathbf{t}_e]. \tag{22}$$

Vectors of forces $\mathbf{F}_i$, $\mathbf{F}_j$ and nodal moments $\mathbf{M}_i$, $\mathbf{M}_j$ are defined in the global system.

Based on (19), the inverse of the relationship (21) is given by the formula:

$$\mathbf{P}_e(\mathbf{h}) = \mathbf{T}_e^{-1}(\mathbf{h})\mathbf{p}_e(\mathbf{h}) = \mathbf{T}_e^T(\mathbf{h})\mathbf{p}_e(\mathbf{h}). \tag{23}$$

This equation should be used for the aggregation of the node load vector when the $\mathbf{p}_e$ vectors are known.

By analogy to (20), the displacements vectors are defined in the *e* nodes (Fig. 2):

$$\mathbf{u}_i^T = [u_{xi}, u_{yi}, u_{zi}], \quad \mathbf{u}_j^T = [u_{xj}, u_{yj}, u_{zj}], \quad \boldsymbol{\varphi}_i^T = [\varphi_{xi}, \varphi_{yi}, \varphi_{zi}], \quad \boldsymbol{\varphi}_j^T = [\varphi_{xj}, \varphi_{yj}, \varphi_{zj}]. \tag{24}$$

Similarly to (22), an additional arrangement of displacements is introduced:

$$\mathbf{u}_e^T = [\mathbf{u}_i, \boldsymbol{\varphi}_i, \mathbf{u}_j, \boldsymbol{\varphi}_j], \quad \mathbf{x}_e^T = [\mathbf{x}_i, \boldsymbol{\Phi}_i, \mathbf{x}_j, \boldsymbol{\Phi}_j], \tag{25}$$

where $\mathbf{u}_e$ – are generalized nodal displacements of the element in the local system, $\mathbf{x}_e$ – are generalized nodal displacements of the element in the global system. Therefore, for the displacement vectors, the relationship is identical to (21):

$$\mathbf{u}_e(\mathbf{h}) = \mathbf{T}_e(\mathbf{h})\mathbf{x}_e(\mathbf{h}). \tag{26}$$

The physical relation joins the nodal displacement $\mathbf{u}_e$ with the nodal forces $\mathbf{p}_e$ occurs throughout the element stiffness matrix $\mathbf{k}_e$:

$$\mathbf{p}_e(\mathbf{h}) = \mathbf{k}_e(\mathbf{h})\mathbf{u}_e(\mathbf{h}), \tag{27}$$

where matrix $\mathbf{k}_e$ has the following structure:

$$\mathbf{k}_e = \frac{E_e}{L_e^3}\begin{bmatrix} \mathbf{k}_{ii}^e & \mathbf{k}_{ij}^e \\ \mathbf{k}_{ji}^e & \mathbf{k}_{jj}^e \end{bmatrix}, \quad \mathbf{k}_{ij}^e = (\mathbf{k}_{ji}^e)^T. \tag{28}$$

The matrix $\mathbf{k}_e$ was defined in the local system. A sequence of formulas for the submatrices appearing in the (28) is presented below:

$$\mathbf{k}_{ii}^e = \begin{bmatrix} \mathbf{k}_{11}^e & \mathbf{k}_{12}^e \\ \mathbf{k}_{21}^e & \mathbf{k}_{22}^e \end{bmatrix}, \quad \mathbf{k}_{jj}^e = \begin{bmatrix} \mathbf{k}_{11}^e & -\mathbf{k}_{12}^e \\ -\mathbf{k}_{21}^e & \mathbf{k}_{22}^e \end{bmatrix}, \quad \mathbf{k}_{ji}^e = -\begin{bmatrix} \mathbf{k}_{11}^e & \mathbf{k}_{12}^e \\ -\mathbf{k}_{21}^e & -\mathbf{k}_{33}^e \end{bmatrix}, \quad \mathbf{k}_{12}^e = (\mathbf{k}_{21}^e)^T. \tag{29}$$

Also:

$$\mathbf{k}_{11}^{e}=\operatorname{diag}\left[A_e L_e^2, 12J_{ze}, 12J_{ye}\right],\quad \mathbf{k}_{22}^{e}=4L_e^2\operatorname{diag}\left[\frac{J_{xe}}{8(1+\nu_e)}, J_{ye}, J_{ze}\right], \tag{30}$$

$$\mathbf{k}_{21}^{e}=6L_e\begin{bmatrix}0 & 0 & 0\\ 0 & 0 & -J_{ye}\\ 0 & J_{ze} & 0\end{bmatrix},\quad \mathbf{k}_{33}^{e}=2L_e^2\operatorname{diag}\left[\frac{-J_{xe}}{4(1+\nu_e)}, J_{ye}, J_{ze}\right].$$

In the entries of the above formulas the dependence on **h** was omitted, for the sake of simplicity. An analogous relation to (27) occurs at the element level for objects defined in the global system, i.e.:

$$\mathbf{K}_e(\mathbf{h})\mathbf{x}_e(\mathbf{h})=\mathbf{P}_e(\mathbf{h}), \tag{31}$$

where the stiffness matrix $\mathbf{K}_e$ of the element in the global system is related to the matrix $\mathbf{k}_e$ by the known transformation

$$\mathbf{K}_e(\mathbf{h})=\mathbf{T}_e^T(\mathbf{h})\mathbf{k}_e(\mathbf{h})\mathbf{T}_e(\mathbf{h}). \tag{32}$$

The inertia matrix of the element *e* written in the local system has the following structure:

$$\mathbf{m}_e=\rho_e\begin{bmatrix}\mathbf{m}_{ii}^{e} & \mathbf{m}_{ij}^{e}\\ \mathbf{m}_{ji}^{e} & \mathbf{m}_{jj}^{e}\end{bmatrix},\quad \mathbf{m}_{ij}^{e}=(\mathbf{m}_{ji}^{e})^T. \tag{33}$$

The sequence of the formulas containing the submatrices appearing in the (33) is summarized below:

$$\mathbf{m}_{ii}^{e}=\begin{bmatrix}\mathbf{m}_{11}^{e} & \mathbf{m}_{12}^{e}\\ \mathbf{m}_{21}^{e} & \mathbf{m}_{22}^{e}\end{bmatrix},\quad \mathbf{m}_{jj}^{e}=\begin{bmatrix}\mathbf{m}_{11}^{e} & -\mathbf{m}_{12}^{e}\\ -\mathbf{m}_{21}^{e} & \mathbf{m}_{22}^{e}\end{bmatrix}, \tag{34}$$

$$\mathbf{m}_{ij}^{e}=\begin{bmatrix}\mathbf{m}_{33}^{e} & \mathbf{m}_{34}^{e}\\ -\mathbf{m}_{43}^{e} & -\mathbf{m}_{44}^{e}\end{bmatrix},\quad \mathbf{m}_{12}^{e}=(\mathbf{m}_{21}^{e})^T,\quad \mathbf{m}_{34}^{e}=(\mathbf{m}_{43}^{e})^T,$$

where:

$$\mathbf{m}_{11}^{e}=A_e L_e\operatorname{diag}\left[\frac{1}{3},\frac{13}{35},\frac{13}{35}\right]+\frac{6}{5L_e}\operatorname{diag}\left[0, J_{ze}, J_{ye}\right],$$

$$\mathbf{m}_{22}^{e}=\frac{A_e L_e^3}{105}\operatorname{diag}\left[0,1,1\right]+L_e\operatorname{diag}\left[\frac{1}{3}J_{xe},\frac{2}{15}J_{ye},\frac{2}{15}J_{ze}\right], \tag{35}$$

$$\mathbf{m}_{12}^{e}=\frac{11A_e L_e^2}{210}\begin{bmatrix}0 & 0 & 0\\ 0 & 0 & 1\\ 0 & -1 & 0\end{bmatrix}+\frac{1}{10}\begin{bmatrix}0 & 0 & 0\\ 0 & 0 & J_{ze}\\ 0 & -J_{ye} & 0\end{bmatrix},$$

$$\mathbf{m}_{33}^{e} = A_e L_e \operatorname{diag}\left[\frac{1}{6}, \frac{9}{70}, \frac{9}{70}\right] - \frac{6}{5L_e} \operatorname{diag}\left[0, J_{ze}, J_{ye}\right],$$

$$\mathbf{m}_{44}^{e} = \frac{A_e L_e^3}{140} \operatorname{diag}\left[0,1,1\right] + \frac{L_e}{6} \operatorname{diag}\left[-J_{xe}, \frac{1}{5} J_{ye}, \frac{1}{5} J_{ze}\right], \tag{35}$$

$$\mathbf{m}_{34}^{e} = \frac{13 A_e L_e^2}{420} \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & -1 \\ 0 & 1 & 0 \end{bmatrix} + \frac{1}{10} \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & J_{ze} \\ 0 & -J_{ye} & 0 \end{bmatrix},$$

The relation of the inertia matrix $\mathbf{M}_e$ of the element $e$ written in the global system with the matrix $\mathbf{m}_e$ written in the local system of the element is analogous to (32).

The elemental matrices $\mathbf{M}_e$, $\mathbf{K}_e$ and the vector of nodal loads $\mathbf{P}_e$, defined in the global system, constitute the basis for the aggregation of global arrays of the system of equations and global vectors [4]. The general formula of these matrices can be summarized as:

$$\mathbf{M} = \mathop{\mathsf{A}}_{e} \mathbf{M}_e, \quad \mathbf{K} = \mathop{\mathsf{A}}_{e} \mathbf{K}_e, \quad \mathbf{P} = \mathop{\mathsf{A}}_{e} \mathbf{P}_e, \tag{36}$$

where the $\mathsf{A}$ character should be understood in sense of an aggregation operation.

The global damping matrix $\mathbf{C}$ is defined as usual proportional matrix:

$$\mathbf{C}(\mathbf{h}) = \alpha(\mathbf{h})\mathbf{M}(\mathbf{h}) + \beta(\mathbf{h})\mathbf{K}(\mathbf{h}), \quad 0 \le \beta \ll \alpha \ll 1. \tag{37}$$

## 5. Derivatives of vectors and matrices

Length $L_e$ of an element is present in all formulas defining element matrices – hence, it is necessary to derive a derivative of this value with respect to $\mathbf{h}$. The derivative is given by:

$$\frac{\mathcal{D} L_e}{\mathcal{D} h_p} = \vec{\mathbf{i}}_e \circ \left( \frac{\mathcal{D} \vec{\mathbf{r}}_{je}}{\mathcal{D} h_p} - \frac{\mathcal{D} \vec{\mathbf{r}}_{ie}}{\mathcal{D} h_p} \right), \quad h_p = 1, \ldots, N_p. \tag{38}$$

Derivatives $\mathcal{D}\vec{\mathbf{r}}_{je} / \mathcal{D} h_p$ and $\mathcal{D}\vec{\mathbf{r}}_{ie} / \mathcal{D} h_p$ of the coordinates of the ends of the bar element must be known and/or calculated before. These derivatives are obtained with known parametrizations of curves or surfaces on which the FE nodes lie.

Derivatives of the versors of the local coordinate system (14)÷(16) are the next functions to be determined:

$$\frac{\mathcal{D} \vec{\mathbf{i}}_e}{\mathcal{D} h_p} = \frac{1}{L_e} \left( \frac{\mathcal{D} \vec{\mathbf{r}}_{je}}{\mathcal{D} h_p} - \frac{\mathcal{D} \vec{\mathbf{r}}_{ie}}{\mathcal{D} h_p} - \vec{\mathbf{i}}_e \frac{\mathcal{D} L_e}{\mathcal{D} h_p} \right), \tag{39}$$

$$\vec{\mathbf{a}}_e = \frac{\mathcal{D} \vec{\mathbf{i}}_e}{\mathcal{D} h_p} \times (\vec{\mathbf{r}}_{ke} - \vec{\mathbf{r}}_{ie}) + \vec{\mathbf{i}}_e \times \left( \frac{\mathcal{D} \vec{\mathbf{r}}_{ke}}{\mathcal{D} h_p} - \frac{\mathcal{D} \vec{\mathbf{r}}_{ie}}{\mathcal{D} h_p} \right),$$

$$\frac{\mathcal{D}\vec{\mathbf{k}}_e}{\mathcal{D}h_p}=\frac{\vec{\mathbf{a}}_e-\vec{\mathbf{k}}_e(\vec{\mathbf{k}}_e\circ\vec{\mathbf{a}}_e)}{\left\|\vec{\mathbf{i}}_e\times(\vec{\mathbf{r}}_{ke}-\vec{\mathbf{r}}_{ie})\right\|}, \tag{40}$$

$$\vec{\mathbf{b}}_e=\frac{\mathcal{D}\vec{\mathbf{k}}_e}{\mathcal{D}h_p}\times\vec{\mathbf{i}}_e+\vec{\mathbf{k}}_e\times\frac{\mathcal{D}\vec{\mathbf{i}}_e}{\mathcal{D}h_p}, \tag{41}$$

$$\frac{\mathcal{D}\vec{\mathbf{j}}_e}{\mathcal{D}h_p}=\frac{\vec{\mathbf{b}}_e-\vec{\mathbf{j}}_e(\vec{\mathbf{j}}_e\circ\vec{\mathbf{b}}_e)}{\left\|(\vec{\mathbf{k}}_e\times\vec{\mathbf{i}}_e)\right\|}.$$

Now, having derivatives of the versors of the local coordinate system, the derivatives of the transformation matrix $\mathbf{t}_e$ and $\mathbf{T}_e$ should be calculated. The derivative of the matrix $\mathbf{T}_e$ allows to specify the bar stiffness changes in the global coordinate system due to the change of the configuration described by the parameters $h_p$. The derivation of $\mathcal{D}\mathbf{T}_e/Dh_p$ reduced to the calculation of $\mathcal{D}\mathbf{t}_e/\mathcal{D}h_p$ using equations (18) and (22). Thus:

$$\frac{\mathcal{D}\mathbf{t}_e}{\mathcal{D}h_p}=\begin{bmatrix}\vec{\mathbf{i}}\circ\frac{\mathcal{D}\vec{\mathbf{i}}_e}{\mathcal{D}h_p} & \vec{\mathbf{j}}\circ\frac{\mathcal{D}\vec{\mathbf{i}}_e}{\mathcal{D}h_p} & \vec{\mathbf{k}}\circ\frac{\mathcal{D}\vec{\mathbf{i}}_e}{\mathcal{D}h_p}\\ \vec{\mathbf{i}}\circ\frac{\mathcal{D}\vec{\mathbf{j}}_e}{\mathcal{D}h_p} & \vec{\mathbf{j}}\circ\frac{\mathcal{D}\vec{\mathbf{j}}_e}{\mathcal{D}h_p} & \vec{\mathbf{k}}\circ\frac{\mathcal{D}\vec{\mathbf{j}}_e}{\mathcal{D}h_p}\\ \vec{\mathbf{i}}\circ\frac{\mathcal{D}\vec{\mathbf{k}}_e}{\mathcal{D}h_p} & \vec{\mathbf{j}}\circ\frac{\mathcal{D}\vec{\mathbf{k}}_e}{\mathcal{D}h_p} & \vec{\mathbf{k}}\circ\frac{\mathcal{D}\vec{\mathbf{k}}_e}{\mathcal{D}h_p}\end{bmatrix},\quad \frac{\mathcal{D}\mathbf{T}_e}{\mathcal{D}h_p}=\operatorname{diag}\left[\frac{\mathcal{D}\mathbf{t}_e}{\mathcal{D}h_p},\frac{\mathcal{D}\mathbf{t}_e}{\mathcal{D}h_p},\frac{\mathcal{D}\mathbf{t}_e}{\mathcal{D}h_p},\frac{\mathcal{D}\mathbf{t}_e}{\mathcal{D}h_p}\right]. \tag{42}$$

Shown derivatives express that in the most complicated case, when the $h_p$ describes the configuration of the structure, non-zero derivatives remain dependencies indirectly or directly on vectors of the ends of the element $e$, i.e. from $\vec{\mathbf{r}}_{ie}$, $\vec{\mathbf{r}}_{je}$ and $\vec{\mathbf{r}}_{ke}$. Thus, non-zero derivatives remains of transformation matrix $\mathcal{D}\mathbf{t}_e/\mathcal{D}h_p$, $\mathcal{D}\mathbf{T}_e/\mathcal{D}h_p$ and above all $\mathcal{D}L_e/\mathcal{D}h_p$. It is also important that the arrays of derivatives in (42) often lose their orthogonality.

The derivation of the stiffness matrix $\mathbf{k}_e$ in the local system with respect to $h_p$ is defined by the following formulas:

$$\frac{\mathcal{D}\mathbf{k}_e}{\mathcal{D}h_p}=\left[\frac{1}{E_e}\frac{\partial E_e}{\partial h_p}-\frac{3}{L_e}\frac{\mathcal{D}L_e}{\mathcal{D}h_p}\right]\mathbf{k}_e+\frac{E_e}{L_e^3}\begin{bmatrix}\frac{\mathcal{D}\mathbf{k}^e_{ii}}{\mathcal{D}h_p} & \frac{\mathcal{D}\mathbf{k}^e_{ij}}{\mathcal{D}h_p}\\ \frac{\mathcal{D}\mathbf{k}^e_{ji}}{\mathcal{D}h_p} & \frac{\mathcal{D}\mathbf{k}^e_{jj}}{\mathcal{D}h_p}\end{bmatrix},\quad \frac{\mathcal{D}\mathbf{k}^e_{ij}}{\mathcal{D}h_p}=\left(\frac{\mathcal{D}\mathbf{k}^e_{ji}}{\mathcal{D}h_p}\right)^T,\quad h_p=1,\ldots,N_p \tag{43}$$

where:

$$\frac{\mathcal{D}\mathbf{k}_{ii}^{e}}{\mathcal{D}h_p}=\begin{bmatrix}\dfrac{\mathcal{D}\mathbf{k}_{11}}{\mathcal{D}h_p} & \dfrac{\mathcal{D}\mathbf{k}_{12}}{\mathcal{D}h_p}\\ \dfrac{\mathcal{D}\mathbf{k}_{21}}{\mathcal{D}h_p} & \dfrac{\mathcal{D}\mathbf{k}_{22}}{\mathcal{D}h_p}\end{bmatrix},\quad \frac{\mathcal{D}\mathbf{k}_{jj}^{e}}{\mathcal{D}h_p}=\begin{bmatrix}\dfrac{\mathcal{D}\mathbf{k}_{11}}{\mathcal{D}h_p} & -\dfrac{\mathcal{D}\mathbf{k}_{12}}{\mathcal{D}h_p}\\ -\dfrac{\mathcal{D}\mathbf{k}_{21}}{\mathcal{D}h_p} & \dfrac{\mathcal{D}\mathbf{k}_{22}}{\mathcal{D}h_p}\end{bmatrix},$$

$$\frac{\mathcal{D}\mathbf{k}_{ji}^{e}}{\mathcal{D}h_p}=-\begin{bmatrix}\dfrac{\mathcal{D}\mathbf{k}_{11}}{\mathcal{D}h_p} & \dfrac{\mathcal{D}\mathbf{k}_{12}}{\mathcal{D}h_p}\\ -\dfrac{\mathcal{D}\mathbf{k}_{21}}{\mathcal{D}h_p} & \dfrac{\mathcal{D}\mathbf{k}_{33}}{\mathcal{D}h_p}\end{bmatrix},\quad \frac{\mathcal{D}\mathbf{k}_{21}}{\mathcal{D}h_p}=\left(\frac{\mathcal{D}\mathbf{k}_{12}}{\mathcal{D}h_p}\right)^{T}.$$

Additionally:

$$\frac{\mathcal{D}\mathbf{k}_{11}}{\mathcal{D}h_p}=\operatorname{diag}\left[L_e\left(\frac{\partial A_e}{\partial h_p}L_e+2A_e\frac{\mathcal{D}L_e}{\mathcal{D}h_p}\right),12\frac{\partial J_{ze}}{\partial h_p},12\frac{\partial J_{ye}}{\partial h_p}\right],$$

$$\frac{\mathcal{D}\mathbf{k}_{22}}{\mathcal{D}h_p}=\frac{2}{L_e}\frac{\mathcal{D}L_e}{\mathcal{D}h_p}\mathbf{k}_{22}+4L_e^2\operatorname{diag}\left[\frac{1}{8(1+\nu_e)}\frac{\partial J_{xe}}{\partial h_p},\frac{\partial J_{ye}}{\partial h_p},\frac{\partial J_{ze}}{\partial h_p}\right],$$

$$\frac{\mathcal{D}\mathbf{k}_{21}}{\mathcal{D}h_p}=\frac{1}{L_e}\frac{\mathcal{D}L_e}{\mathcal{D}h_p}\mathbf{k}_{21}+6L_e\begin{bmatrix}0 & 0 & 0\\ 0 & 0 & -\dfrac{\partial J_{ye}}{\partial h_p}\\ 0 & \dfrac{\partial J_{ze}}{\partial h_p} & 0\end{bmatrix},$$

$$\frac{\mathcal{D}\mathbf{k}_{33}}{\mathcal{D}h_p}=\frac{2}{L_e}\frac{\mathcal{D}L_e}{\mathcal{D}h_p}\mathbf{k}_{33}+2L_e^2\operatorname{diag}\left[-\frac{1}{4(1+\nu_e)}\frac{\partial J_{xe}}{\partial h_p},\frac{\partial J_{ye}}{\partial h_p},\frac{\partial J_{ze}}{\partial h_p}\right].$$

It was assumed that Poisson's ratio $\nu_e$ does not depend on the $h_p$ which is justified in practices. Matrix of the derivatives $\mathcal{D}\mathbf{k}_e/\mathcal{D}h_p$ is symmetrical, but often it is not positively defined (negative values and zeros may happen on the diagonal).

The derivative of the stiffness matrix of an element in the global system is given by the formula:

$$\frac{\mathcal{D}\mathbf{K}_e}{\mathcal{D}h_p}=\left(\frac{\mathcal{D}\mathbf{T}_e}{\mathcal{D}h_p}\right)^{T}\mathbf{k}_e\mathbf{T}_e+\mathbf{T}_e^{T}\frac{\mathcal{D}\mathbf{k}_e}{\mathcal{D}h_p}\mathbf{T}_e+\mathbf{T}_e^{T}\mathbf{k}_e\frac{\mathcal{D}\mathbf{T}_e}{\mathcal{D}h_p},\quad h_p=1,\ldots,N_p. \qquad (44)$$

where the dependence of (32) and equality

$$\left(\frac{\mathcal{D}\mathbf{T}_e}{\mathcal{D}h_p}\right)^T=\frac{\mathcal{D}\mathbf{T}_e^T}{\mathcal{D}h_p}$$

was utilized.

The derivative of the inertia matrix $\mathbf{m}_e$ of the element $e$ in the local coordinate system with respect to $h_p$ is expressed by the following formulas:

$$\frac{\mathcal{D}\mathbf{m}_e}{\mathcal{D}h_p}=\frac{1}{\rho_e}\frac{\partial\rho_e}{\partial h_p}\mathbf{m}_e+\rho_e\begin{bmatrix}\frac{\mathcal{D}\mathbf{m}_{ii}^e}{\mathcal{D}h_p} & \frac{\mathcal{D}\mathbf{m}_{ij}^e}{\mathcal{D}h_p}\\ \frac{\mathcal{D}\mathbf{m}_{ji}^e}{\mathcal{D}h_p} & \frac{\mathcal{D}\mathbf{m}_{jj}^e}{\mathcal{D}h_p}\end{bmatrix},\quad \frac{\mathcal{D}\mathbf{m}_{ij}^e}{\mathcal{D}h_p}=\left(\frac{\mathcal{D}\mathbf{m}_{ji}^e}{\mathcal{D}h_p}\right)^T,\quad h_p=1,\ldots,N_p. \tag{45}$$

where:

$$\frac{\mathcal{D}\mathbf{m}_{ii}^e}{\mathcal{D}h_p}=\begin{bmatrix}\frac{\mathcal{D}\mathbf{m}_{11}^e}{\mathcal{D}h_p} & \frac{\mathcal{D}\mathbf{m}_{12}^e}{\mathcal{D}h_p}\\ \frac{\mathcal{D}\mathbf{m}_{21}^e}{\mathcal{D}h_p} & \frac{\mathcal{D}\mathbf{m}_{22}^e}{\mathcal{D}h_p}\end{bmatrix},\quad \frac{\mathcal{D}\mathbf{m}_{jj}^e}{\mathcal{D}h_p}=\begin{bmatrix}\frac{\mathcal{D}\mathbf{m}_{11}^e}{\mathcal{D}h_p} & -\frac{\mathcal{D}\mathbf{m}_{12}^e}{\mathcal{D}h_p}\\ -\frac{\mathcal{D}\mathbf{m}_{21}^e}{\mathcal{D}h_p} & \frac{\mathcal{D}\mathbf{m}_{22}^e}{\mathcal{D}h_p}\end{bmatrix},$$

$$\frac{\mathcal{D}\mathbf{m}_{ij}^e}{\mathcal{D}h_p}=\begin{bmatrix}\frac{\mathcal{D}\mathbf{m}_{33}^e}{\mathcal{D}h_p} & \frac{\mathcal{D}\mathbf{m}_{34}^e}{\mathcal{D}h_p}\\ -\frac{\mathcal{D}\mathbf{m}_{43}^e}{\mathcal{D}h_p} & -\frac{\mathcal{D}\mathbf{m}_{44}^e}{\mathcal{D}h_p}\end{bmatrix},\quad \frac{\mathcal{D}\mathbf{m}_{12}^e}{\mathcal{D}h_p}=\left(\frac{\mathcal{D}\mathbf{m}_{21}^e}{\mathcal{D}h_p}\right)^T,\quad \frac{\mathcal{D}\mathbf{m}_{34}^e}{\mathcal{D}h_p}=\left(\frac{\mathcal{D}\mathbf{m}_{43}^e}{\mathcal{D}h_p}\right)^T.$$

Additionally:

$$\frac{\mathcal{D}\mathbf{m}_{11}^e}{\mathcal{D}h_p}=\left(\frac{\partial A_e}{\partial h_p}L_e+A_e\frac{\mathcal{D}L_e}{\mathcal{D}h_p}\right)\operatorname{diag}\left[\frac{1}{3},\frac{13}{35},\frac{13}{35}\right]+$$
$$+\frac{6}{5L_e}\left(\operatorname{diag}\left[0,\frac{\partial J_{ze}}{\partial h_p},\frac{\partial J_{ye}}{\partial h_p}\right]-\frac{1}{L_e}\frac{\mathcal{D}L_e}{\mathcal{D}h_p}\operatorname{diag}\left[0,J_{ze},J_{ye}\right]\right),$$

$$\frac{\mathcal{D}\mathbf{m}_{22}^e}{\mathcal{D}h_p}=\frac{L_e^2}{105}\left(\frac{\partial A_e}{\partial h_p}L_e+3A_e\frac{\mathcal{D}L_e}{\mathcal{D}h_p}\right)\operatorname{diag}\left[0,1,1\right]+\frac{\mathcal{D}L_e}{\mathcal{D}h_p}\operatorname{diag}\left[\frac{1}{3}J_{xe},\frac{2}{15}J_{ye},\frac{2}{15}J_{ze}\right]+$$
$$+L_e\operatorname{diag}\left[\frac{1}{3}\frac{\partial J_{xe}}{\partial h_p},\frac{2}{15}\frac{\partial J_{ye}}{\partial h_p},\frac{2}{15}\frac{\partial J_{ze}}{\partial h_p}\right],$$

$$\frac{\mathcal{D}\mathbf{m}_{12}^{e}}{\mathcal{D}h_p}=\frac{11L_e}{210}\left(\frac{\partial A_e}{\partial h_p}L_e+2A_e\frac{\mathcal{D}L_e}{\mathcal{D}h_p}\right)\begin{bmatrix}0&0&0\\0&0&1\\0&-1&0\end{bmatrix}+\frac{1}{10}\begin{bmatrix}0&0&0\\0&0&\dfrac{\partial J_{ze}}{\partial h_p}\\0&-\dfrac{\partial J_{ye}}{\partial h_p}&0\end{bmatrix},$$

$$\frac{\mathcal{D}\mathbf{m}_{33}^{e}}{\mathcal{D}h_p}=\left(\frac{\partial A_e}{\partial h_p}L_e+A_e\frac{\mathcal{D}L_e}{\mathcal{D}h_p}\right)\operatorname{diag}\left[\frac{1}{6},\frac{9}{70},\frac{9}{70}\right]+$$

$$+\frac{6}{5L_e}\left(\frac{1}{L_e}\frac{\mathcal{D}L_e}{\mathcal{D}h_p}\operatorname{diag}\left[0,J_{ze},J_{ye}\right]-\operatorname{diag}\left[0,\frac{\partial J_{ze}}{\partial h_p},\frac{\partial J_{ye}}{\partial h_p}\right]\right),$$

$$\frac{\mathcal{D}\mathbf{m}_{44}^{e}}{\mathcal{D}h_p}=\frac{L_e^2}{140}\left(\frac{\partial A_e}{\partial h_p}L_e+3A_e\frac{\mathcal{D}L_e}{\mathcal{D}h_p}\right)\operatorname{diag}\left[0,1,1\right]+\frac{1}{6}\left(\frac{\mathcal{D}L_e}{\mathcal{D}h_p}\operatorname{diag}\left[-J_{xe},\frac{1}{5}J_{ye},\frac{1}{5}J_{ze}\right]+\right.$$

$$\left.+L_e\operatorname{diag}\left[-\frac{\partial J_{xe}}{\partial h_p},\frac{1}{5}\frac{\partial J_{ye}}{\partial h_p},\frac{1}{5}\frac{\partial J_{ze}}{\partial h_p}\right]\right),$$

$$\frac{\mathcal{D}\mathbf{m}_{34}^{e}}{\mathcal{D}h_p}=\frac{13L_e}{420}\left(\frac{\partial A_e}{\partial h_p}L_e+2A_e\frac{\mathcal{D}L_e}{\mathcal{D}h_p}\right)\begin{bmatrix}0&0&0\\0&0&-1\\0&1&0\end{bmatrix}+\frac{1}{10}\begin{bmatrix}0&0&0\\0&0&\dfrac{\partial J_{ze}}{\partial h_p}\\0&-\dfrac{\partial J_{ye}}{\partial h_p}&0\end{bmatrix}.$$

The derivative of the inertia matrix of an element in the global system is given by the formula:

$$\frac{\mathcal{D}\mathbf{M}_e}{\mathcal{D}h_p}=\left(\frac{\mathcal{D}\mathbf{T}_e}{\mathcal{D}h_p}\right)^T\mathbf{m}_e\mathbf{T}_e+\mathbf{T}_e^T\frac{\mathcal{D}\mathbf{m}_e}{\mathcal{D}h_p}\mathbf{T}_e+\mathbf{T}_e^T\mathbf{m}_e\frac{\mathcal{D}\mathbf{T}_e}{\mathcal{D}h_p},\quad h_p=1,\ldots,N_p. \tag{46}$$

On the end, the derivative of the global damping matrix **C** is equal to:

$$\frac{\mathcal{D}\mathbf{C}}{\mathcal{D}h_p}=\frac{\partial\alpha}{\partial h_p}\mathbf{M}+\frac{\partial\beta}{\partial h_p}\mathbf{K}+\alpha\frac{\mathcal{D}\mathbf{M}}{\mathcal{D}h_p}+\beta\frac{\mathcal{D}\mathbf{K}}{\mathcal{D}h_p},\quad h_p=1,\ldots,N_p. \tag{47}$$

if that happens $\alpha$, $\beta$ depends on **h**, in general.

For derivatives of elemental matrices the aggregation process of global derivatives arrays is identical as the aggregation process for global matrices (36):

$$\frac{\mathcal{D}\mathbf{M}}{\mathcal{D}h_p}=\mathop{\mathsf{A}}_{e}\frac{\mathcal{D}\mathbf{M}_e}{\mathcal{D}h_p},\quad \frac{\mathcal{D}\mathbf{K}}{\mathcal{D}h_p}=\mathop{\mathsf{A}}_{e}\frac{\mathcal{D}\mathbf{K}_e}{\mathcal{D}h_p},\quad \frac{\mathcal{D}\mathbf{P}}{\mathcal{D}h_p}=\mathop{\mathsf{A}}_{e}\frac{\mathcal{D}\mathbf{P}_e}{\mathcal{D}h_p},\quad h_p=1,\ldots,N_p. \tag{48}$$

## 6. Conclusions

The DDM is simple in its mathematical form as well as in numerical implementation. The basic equation of the (12) has a similar form as the motion equation given in (2). Therefore it is easy to use the known methods of direct integrating of the equation of motion to obtain derivative of displacements, velocities and accelerations.

The algorithm of the DDM reduced to a one-time calculation of the system response via (2) and the need to integrate the equation of derivatives (12) for each parameter separately. This is a fundamental disadvantage of DDM. Because in the case of a huge model with thousands of degrees of freedom and of large number of parameters, the DDM method becomes ineffective. A helpful solution is using parallel algorithms.

In the range of civil engineering problems, where beam models predominate – so in fact with relatively small number of dynamic degrees of freedom, the DDM is attractive because of relative easy of software application.

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If you want to quote this article, its proper bibliographic entry is as follow: Dąbrowska O., Ciurej H., *Sensitivity analysis of the dynamic response of a frame. Part I: Direct differentiation method*, Technical Transactions, Vol. 6/2019, pp. 119–134.

TECHNICAL TRANSACTIONS 6/2019
CIVIL ENGINEERING
DOI: 10.4467/2353737XCT.19.066.10619
SUBMISSION OF THE FINAL VERSION: 21/05/2019

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# Sensitivity analysis of the dynamic response of a frame. Part II: Harmonic and seismic excitations

# Analiza wrażliwości odpowiedzi dynamicznej ramy. Część II: Wymuszenie harmoniczne oraz sejsmiczne

**Abstract**

This paper is a continuation of the first part [7] where basic relations and derivatives related to the sensitivity analysis of the standard 3D beam element have been derived. This part presents the sensitivity analysis of dynamic response of a flat frame using the Direct Differentiation Method for harmonic and seismic excitations separately. Harmonic excitations are typicaly found if some equipment is placed on the stories of industrial buildings. In that case the practical benefit of determining the structure response and its derivatives allows to determine, for example, the vibration comfort of staff and determine the impact of particular structural parameters on the level of comfort. With regard to seismic excitations, determining the response of a structure and its derivatives allows to determine the level of impact of individual parameters on the response.
**Keywords:** sensitivity analysis, direct differentiation method, explicit differentiation

**Streszczenie**

Niniejszy tekst jest kontynuacją części pierwszej [7], w której wyprowadzono podstawowe relacje i pochodne związane z analizą wrażliwości standardowego elementu belkowego 3D. W niniejszym artykule przedstawiono analizę wrażliwości odpowiedzi dynamicznej ramy płaskiej metodą bezpośrednią przy wymuszeniach osobno harmonicznych oraz sejsmicznych. Rozważane zadanie jest liniowe. Wymuszenia harmoniczne są typowe przy lokalizacji rozmaitych urządzeń na stropach budynków przemysłowych. Praktyczna strona wyznaczenia odpowiedzi konstrukcji i jej pochodnych w takich sytuacjach pozawala określić np. komfort wibracyjny osób znajdujących się na konstrukcji oraz określić wpływ poszczególnych parametrów konstrukcyjnych na poziom tego komfortu. W odniesieniu do wymuszeń sejsmicznych wyznaczenie odpowiedzi konstrukcji oraz jej pochodnych pozwala rozstrzygnąć skalę wpływu poszczególnych parametrów na odpowiedź.
**Słowa kluczowe:** analiza wrażliwości, bezpośrednia analiza wrażliwości, pochodne równania ruchu

## 1. Introduction

This paper is a continuation of the first part [7], where basic relations and derivatives related to the sensitivity analysis of the standard 3D beam element have been derived.

Sensitivity analysis consists in searching for changes in physical quantities in relation to changes in selected parameters, which are called design variables, decision variables or free variables. Ultimately, the sensitivity analysis comes down to calculating derivatives of specific functions with respect to parameters [9]. These parameters can determine the configuration of the structure (i.e. its geometry), properties of materials, dimensions or characteristics of cross-sections, etc. If the parameters describe the geometry of the structure, then the sensitivity analysis is related to the determination of material derivatives [10].

This part presents the sensitivity analysis of dynamic response of a flat frame using the Direct Differentiation Method [10] separately for harmonic and seismic excitations. The presented problem is referenced in broad literature (see [1, 11, 8, 5, 6]).

Harmonic excitations are typically found if some equipment are placed on the binders of industrial buildings. In that case the practical benefit of determining the structure response and its derivatives that it allows to determine, for example, the vibration comfort of staff and determine the impact of particular structural parameters on the level of comfort.

With respect to seismic (kinematic) excitations, the equations of motion are expressed in relative displacements, that fact simplifies the right hand side of equation. Determination of structural response and its derivatives for seismic excitation allows to determine how individual parameters influence on the magnitude of the response.

In both cases, optimization problem should be formulated and solved. Solution with gradient method requires providing derivatives with respect to design parameters. Sensitivity analysis make it possible to obtain these derivatives

## 2. The subject of the analysis

Subject frame is shown in the Fig. 1. It is a three-nave flat reinforced concrete frame with perpendicular joints. The figure also depicted parametrisation of the geometry. The material parameters (for concrete) are: elastic modulus $E$ = 32 GPa, density $\rho$ = 2500 kg/m$^3$. The common width of all bar sections is $b$ = 0.3 m.

The vector of design parameters has the form:

$$\mathbf{h} = [l_1, l_2, H, h_z, h_w, h_r], \quad \mathbf{h} \subset \mathcal{R}_+^{N_p}, \quad N_p = 6, \tag{1}$$

where: $l_1$ is the width of the left outer and inner naves, $l_2$ the width of the right nave, $H$ is the height of the stories, $h_z$ is the cross-sections height of the external pillars, $h_w$ is the cross-section height of the inner pillars. The point in the design space $\mathcal{R}_+^6$ for which calculations will be made of both the dynamic frame responses and their derivatives is equal to $h_0$ = [6.0, 6.0, 3.0, 0.4, 0.4, 0.6] m.

Proportional structural dissipation was assumed (see [3]) i.e.

$$\mathbf{C}(\mathbf{h}) = \alpha\mathbf{M}(\mathbf{h}) + \beta\mathbf{K}(\mathbf{h}), \tag{2}$$

where $\alpha = 0.02$, $\beta = 0.003$.

The Fig. 2 shows the division of the frame into finite elements. The pillars were divided into 12 elements, and the binders were divided into 24 elements. Each element has a length of 0.25 m. The lowest nodes are fixed. In this figure, the global coordinate system is marked also.

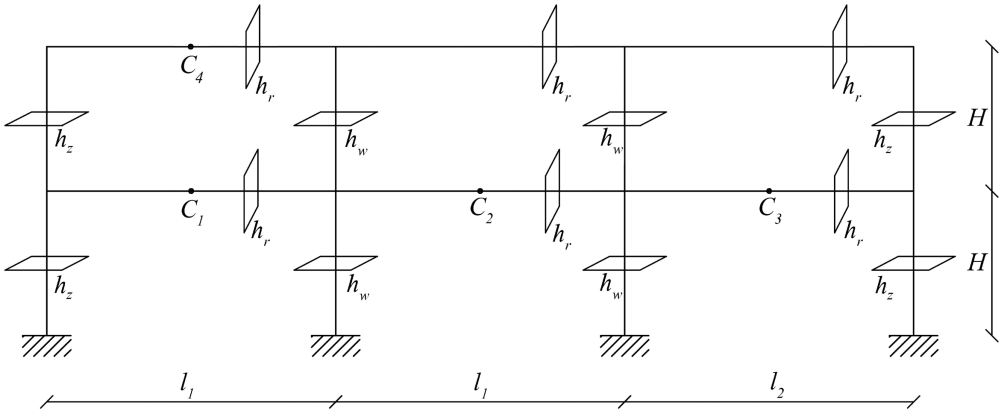


Fig. 1. Flat subject frame. Design parameters are shown. Points $C_1$, $C_2$, $C_3$ represent meanspan of first level binders, point $C_4$ is the meanspan of the upper binder of the left nave

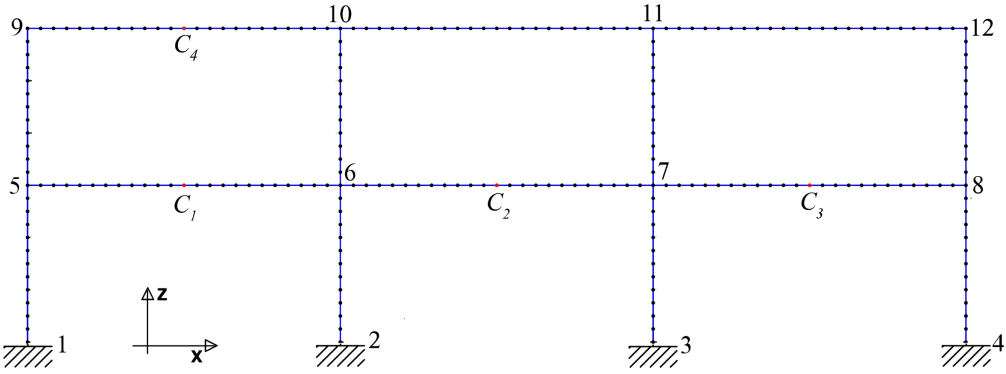


Fig. 2. Boundary conditions and numbering of nodes in the connections of girders and columns

The following Figs. 3, 4, 5 show three of the smallest eigenfrequencies – $f_1 = 7.74$ Hz, $f_2 = 22.7$ Hz, $f_3 = 31.6$ Hz. The first two eigenmodes are related to the horizontal movement of binders (pillar bending), and the third eigenmode express vertical vibrations of the binders. The vertical and horizontal rulers allow to see the proportions of the eigenmodes.

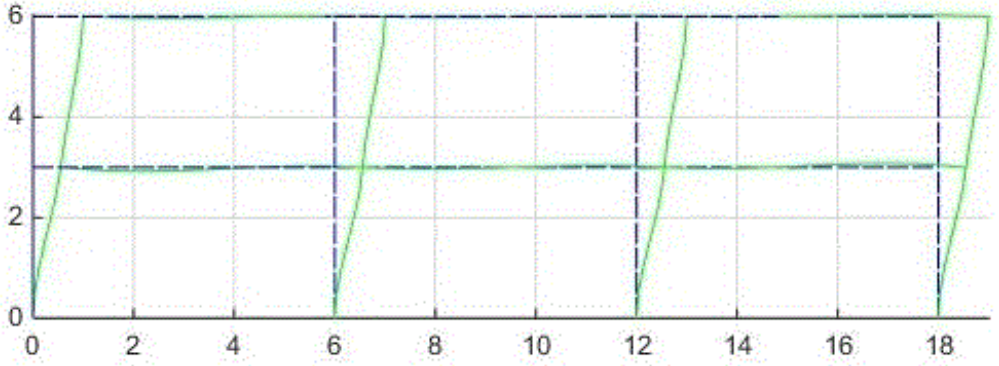


Fig. 3. First eigenmode of the frame $f_1 = 7.74$ Hz

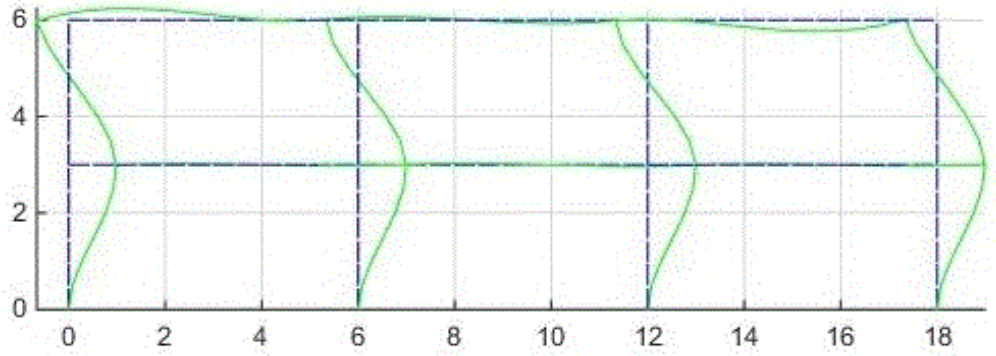


Fig. 4. Second eigenmode of the frame $f_2 = 22.7$ Hz

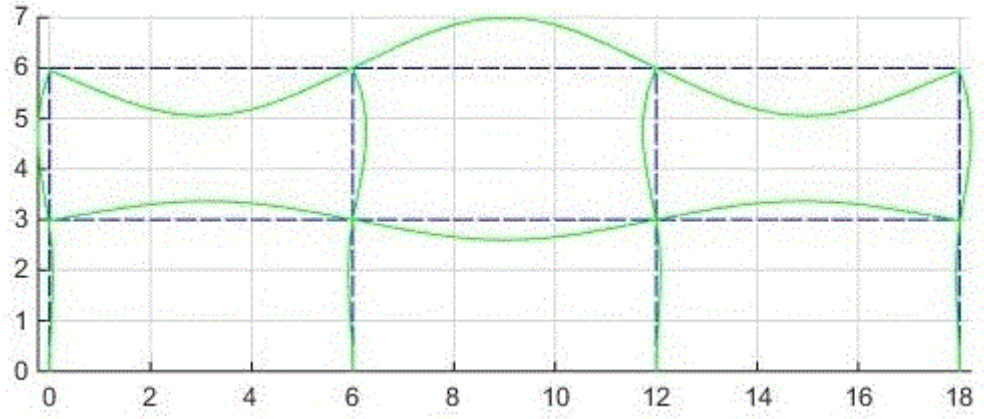


Fig. 5. Third eigenmode of the frame $f_3 = 31.6$ Hz

The aim of the paper is to determine displacements, velocities and accelerations as a function of time at the points: $C_1$, $C_2$, $C_3$ and $C_4$ and derivative of these quantities in relation to the design parameters (1) with two mutually exclusive types of vibration excitation:

1. The periodic excitations located in the points $C_1$ and $C_2$ – Fig. 6. The point $C_1$ is loaded with force $P_1(t) = P_{01}\sin(\omega_1 t)$, while point $C_2$ is loaded with force $P_2(t) = P_{02}\sin(\omega_2 t)$, where $P_{01}$ = 50 kN, $\omega_1$ = 37.5 rad/s ($f_1 \approx 5.97$ Hz), $P_{02}$ = 65 kN, $\omega_2$ = 48.5 rad/s ($f_2 \approx 7.72$ Hz). It means that response of the whole excitation and response of the frame are pseudoperiodic functions.

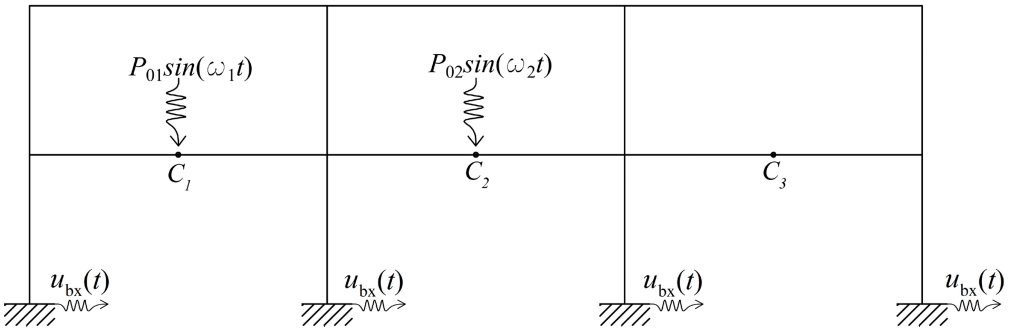


Fig. 6. Localization of excitations of: vertical harmonics $P_1$ i $P_2$ and horizontal seismic $u_{bx}(t)$

2. The horizontal seismic excitation $\ddot{u}_x(t)$ (Fig. 6) registered in El Centro in 1940. The diagram of ground accelerations is shown in Fig. 7. The diagram is taken from [4]. A broad discussion of this earthquake can be found in [12].

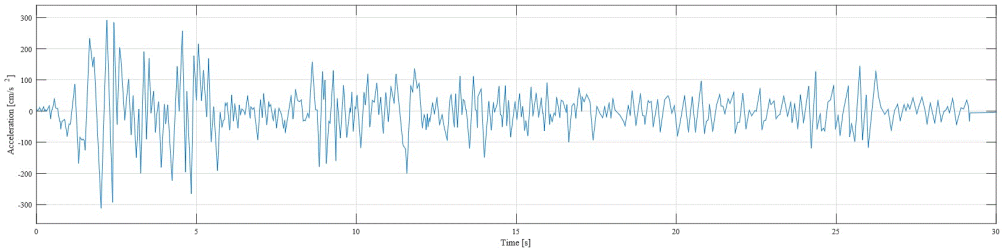


Fig. 7. Recorded diagram of horizontal ground accelerations $\ddot{u}_{bx}(t)$ in El Centro in 1940 [4]

## 3. Case no 1: harmonic excitation

The first example concern the harmonic excitation caused by two forces $P_1(t), P_2(t)$ which are independent of the design parameters **h**. These forces were applied in the middle of the binders at points $C_1$ and $C_2$ respectively. In the beginning the equation of motion (3) (see [7]) should be solved:

$$\mathbf{M}_{ss}(\mathbf{h})\ddot{\mathbf{x}}_s(\mathbf{h}) + \mathbf{C}_{ss}(\mathbf{h})\dot{\mathbf{x}}_s(\mathbf{h}) + \mathbf{K}_{ss}(\mathbf{h})\mathbf{x}_s(\mathbf{h}) = \mathbf{P}_{s1}\sin(\omega_1 t) + \mathbf{P}_{s2}\sin(\boldsymbol{\omega}_2 t), \qquad (3)$$

where the dependencies of vectors and matrices on the parameters **h** are explicitly marked and the loads do not depend on the parameter vector. In matrices with indices $_{ss}$ the boundary

conditions were taken into account; vector $\mathbf{x}_s$ means displacements of nodes unrestrained by the boundary conditions.

According to the DDM procedure the equation (3) should be directly differentiated with (2) taking into account:

$$\mathbf{M}_{ss}\frac{\mathcal{D}\ddot{\mathbf{x}}_s}{\mathcal{D}h_p}+\mathbf{C}_{ss}\frac{\mathcal{D}\dot{\mathbf{x}}_s}{\mathcal{D}h_p}+\mathbf{K}_{ss}\frac{\mathcal{D}\mathbf{x}_s}{\mathcal{D}h_p}=-\left[\frac{\mathcal{D}\mathbf{M}_{ss}}{\mathcal{D}h_p}(\ddot{\mathbf{x}}_s+\alpha\dot{\mathbf{x}}_s)+\frac{\mathcal{D}\mathbf{K}_{ss}}{\mathcal{D}h_p}(\beta\dot{\mathbf{x}}_s+\mathbf{x}_s)\right],\quad p=1,\ldots,N_p. \tag{4}$$

The following algorithm is result of both presented equations:

1. For a given vector of parameters $\mathbf{h}_0$ the equation (3) should be solved once.
2. For each parameter $h_p$, $p = 1, \ldots, N_p$ (loop over index $p$):
   (a) Find the material derivatives $\mathcal{D}\mathbf{M}_{ss}/\mathcal{D}h_p$ and $\mathcal{D}\mathbf{K}_{ss}/\mathcal{D}h_p$ in the equation (4).
   (b) Using the solution from point 1 (i.e. $\ddot{\mathbf{x}}_s$, $\dot{\mathbf{x}}_s$, $\mathbf{x}_s$) aggregate the right hand side vector of the equation (4).
   (c) Solve the equation (4).
3. Stop.

Due to the mathematical similarity of the equations (3) and (4) the same algorithm of time integration is used. In the present work the Newmark procedure [2] with the integration step $\Delta t = 0.001$ sec. is used. The loop in point 2 can be easily parallelized which would radically speed up the calculations.

The vertical displacements and accelerations and their derivatives at points $C_1$, $C_2$, $C_3$ are shown in the following Fig. 8 to Fig. 13. The time interval cover 2.0 sec. i.e. from 1.0 sec. up to 3.0 sec. As you can see after 1.0 sec. observed vibrations and derivatives functions with respect to all parameters are already steady-state.

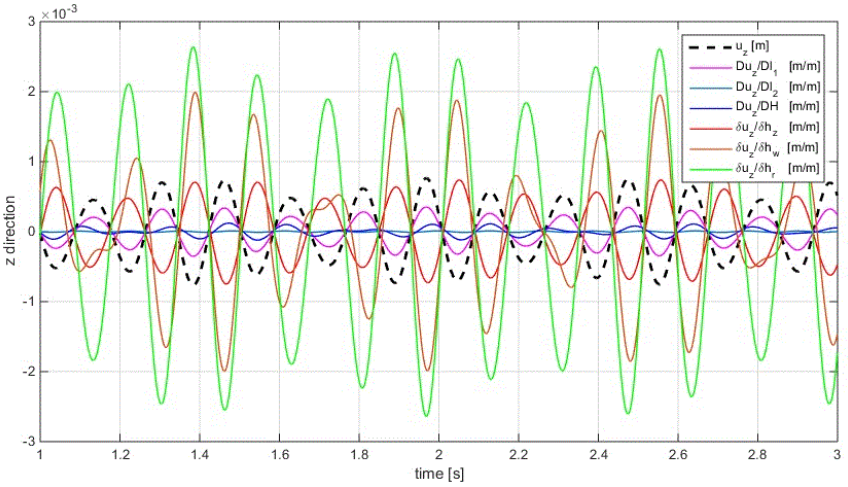


Fig. 8. Vertical displacement $u_z(t)$ at $C_1$ and derivative $\mathcal{D}u_z/\mathcal{D}h_p$

To facilitate the interpretation of the obtained results, let introduce following designation:

$$g_{,h_p}^{\max} = \max_{t\in[1,3]} \left| \frac{\mathcal{D}g}{\mathcal{D}h_p} \right|, \tag{5}$$

which expresses the maximum absolute value of the derivative of $g(t, \mathbf{h})$ with respect to $p$-th parameter, the maximum being calculated over the time interval $t \in [1, 3]$ sec. i.e. in the time of steady-state vibrations

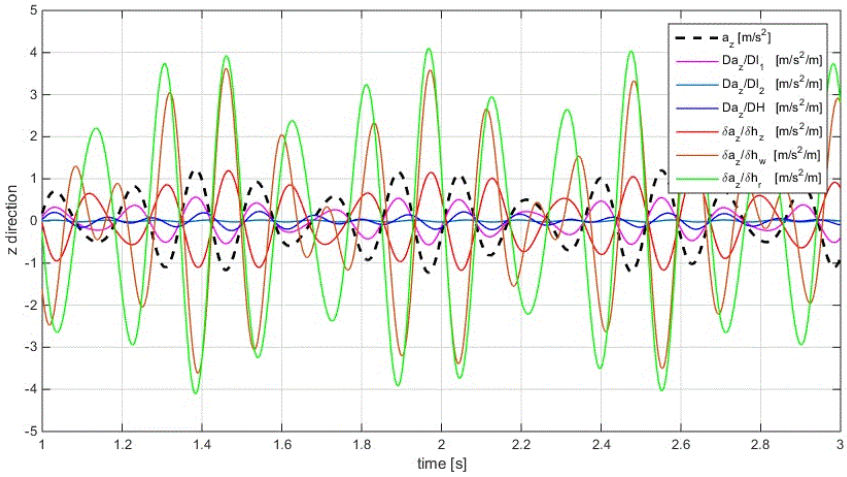


Fig. 9. Vertical acceleration $a_z(t)$ at $C_1$ and derivative $\mathcal{D}a_z/\mathcal{D}h_p$

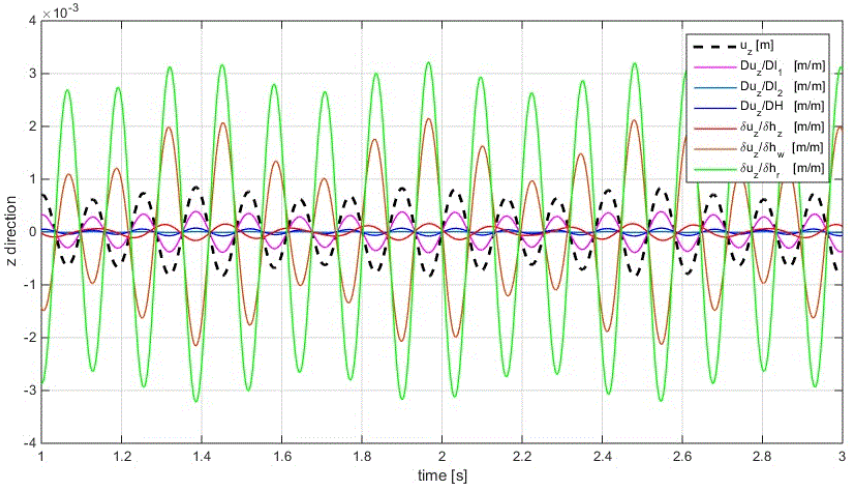


Fig. 10. Vertical displacement $u_z(t)$ at $C_2$ and derivative $\mathcal{D}u_z/\mathcal{D}h_p$

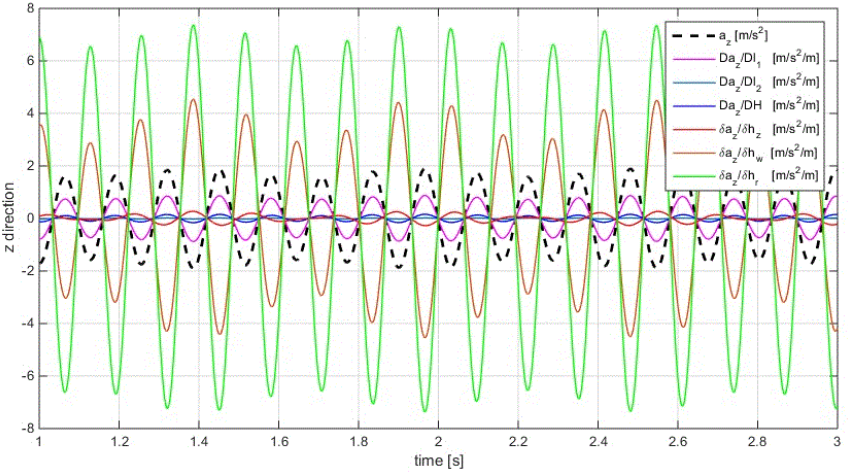


Fig. 11. Vertical acceleration $a_z(t)$ at $C_2$ and derivative $\mathcal{D}a_z/\mathcal{D}h_p$

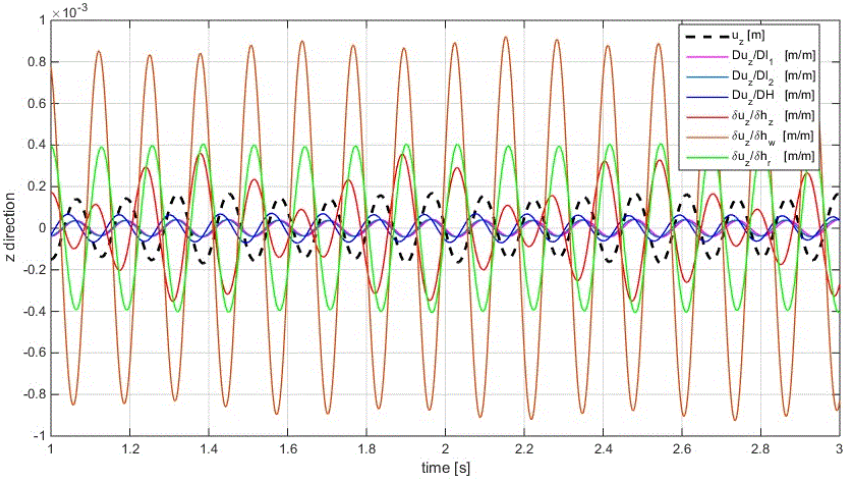


Fig. 12. Vertical displacement $u_z(t)$ at $C_3$ and derivative $\mathcal{D}u_z/\mathcal{D}h_p$

Observation of the results from the Fig. 8 to Fig. 13 allows to formulate the following conclusions:

1. At the point $C_1$ the parameters of $h_r$ (cross-section height of the binders), $h_w$ (cross-section height of the internal pillars) and $h_z$ (cross-section height of the external pillars) have the greatest influence on the displacements and accelerations waveforms. Because there is $u^{\max}_{z,h_r} > u^{\max}_{z,h_w} > u^{\max}_{z,h_z}$ and $a^{\max}_{z,h_r} > a^{\max}_{z,h_w} > a^{\max}_{z,h_z}$. It should be emphasize that the derivatives remain in the counter-phase to the waveforms – thus increasing the stiffness of cross-sections will reduce the amplitudes of displacements and accelerations at point $C_1$.

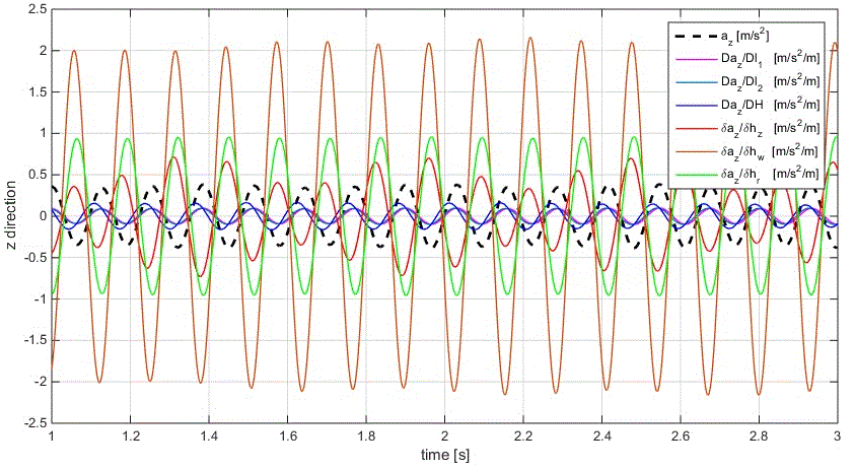


Fig. 13. Vertical acceleration $a_z(t)$ at $C_3$ and derivative $\mathcal{D}a_z/\mathcal{D}h_p$

2. At the point $C_2$ the parameters of $h_r$ (cross-section height of the binders), $h_w$ (cross-section height of the internal pillars) and $l_1$ (width of the naves) have the greatest influence on the displacements and accelerations waveforms. Because there is $u^{\max}_{z,h_r} > u^{\max}_{z,h_w} > u^{\max}_{z,l_1}$ and $a^{\max}_{z,h_r} > a^{\max}_{z,h_w} > a^{\max}_{z,l_1}$. It should be emphasize that the derivatives $\mathcal{D}/\mathcal{D}h_r$ and $\mathcal{D}/\mathcal{D}h_w$ remains in the counter-phase to the waveforms – thus increasing the stiffness of cross-sections will reduce the amplitudes of displacements and accelerations. In the opposition to the above is the derivative with regard to $l_1$ i.e. increase the length of the binders will cause an increase in the displacements or accelerations at the point $C_2$.
3. At the point $C_3$ the parameters of $h_w$ (cross-section height of the internal pillars), $h_r$ (crosssection height of the binders) and $h_z$ (cross-section height of the external pillars) have the greatest influence on the displacements and accelerations waveforms. Because there is $u^{\max}_{z,h_w} > u^{\max}_{z,h_r} > u^{\max}_{z,h_z}$ and $a^{\max}_{z,h_w} > a^{\max}_{z,h_r} > a^{\max}_{z,h_z}$. It should be emphasize that the derivatives remains in the counter-phase to the waveforms – thus increasing the stiffness of cross-sections will reduce the amplitudes of displacements and accelerations at the point $C_3$.

## 4. Case no 2: seismic excitation

The second example concern the seismic excitation of the frame with horizontal ground accelerations recorded during the earthquake in El Centro [4].

The following is the state equation:

$$\mathbf{M}_{ss}(\mathbf{h})\ddot{\mathbf{y}}_s(\mathbf{h}) + \mathbf{C}_{ss}(\mathbf{h})\dot{\mathbf{y}}_s(\mathbf{h}) + \mathbf{K}_{ss}(\mathbf{h})\mathbf{y}_s(\mathbf{h}) = \\ = -[\mathbf{M}_{sb}(\mathbf{h}) - \mathbf{M}_{ss}(\mathbf{h})\mathbf{K}^{-1}_{ss}(\mathbf{h})\mathbf{K}_{sb}(\mathbf{h})]\mathbf{B}\ddot{\mathbf{u}}_b, \tag{6}$$

where $\mathbf{y}$ is the vector of relative displacement. Direct differentiation of (6) lead to relations:

$$\mathbf{M}_{ss}\frac{\mathcal{D}\ddot{\mathbf{y}}_s}{\mathcal{D}h_p}+\mathbf{C}_{ss}\frac{\mathcal{D}\dot{\mathbf{y}}_s}{\mathcal{D}h_p}+\mathbf{K}_{ss}\frac{\mathcal{D}\mathbf{y}_s}{\mathcal{D}h_p}=-\left[\frac{\mathcal{D}\mathbf{M}_{ss}}{\mathcal{D}h_p}(\ddot{\mathbf{y}}_s+\alpha\dot{\mathbf{y}}_s)+\frac{\mathcal{D}\mathbf{K}_{ss}}{\mathcal{D}h_p}(\beta\dot{\mathbf{y}}_s+\mathbf{y}_s)\right]- \tag{7}$$

$$-\left[\frac{\mathcal{D}\mathbf{M}_{sb}}{\mathcal{D}h_p}+\left(\mathbf{M}_{ss}\mathbf{K}_{ss}^{-1}\frac{\mathcal{D}\mathbf{K}_{ss}}{\mathcal{D}h_p}-\frac{\mathcal{D}\mathbf{M}_{ss}}{\mathcal{D}h_p}\right)\mathbf{K}_{ss}^{-1}\mathbf{K}_{sb}-\mathbf{M}_{ss}\mathbf{K}_{ss}^{-1}\frac{\mathcal{D}\mathbf{K}_{sb}}{\mathcal{D}h_p}\right]\mathbf{B}\ddot{\mathbf{u}}_b,\quad p=1,\ldots,N_p,$$

where the equation

$$\frac{\mathcal{D}\mathbf{K}_{ss}^{-1}}{\mathcal{D}h_p}=-\mathbf{K}_{ss}^{-1}\frac{\mathcal{D}\mathbf{K}_{ss}}{\mathcal{D}h_p}\mathbf{K}_{ss}^{-1}$$

is used. In the given dependencies, the matrix $\mathbf{B}$ is a column of ones only in places corresponding to horizontal degrees of freedom fixed in the support nodes (in the considered problem the vector $\mathbf{B}$ is not depend on $\mathbf{h}$) and the vector $\ddot{\mathbf{u}}_b$ turns under these circumstances into a scalar i.e. $\ddot{\mathbf{u}}_b(t)\equiv\ddot{u}_{bx}(t)$ and express the function of acceleration of horizontal soil vibrations.

Both of the presented equations lead to algorithm:

1. For a given vector of parameters $\mathbf{h}_0$ the equation (6) should be solved once.
2. Find matrix $\mathbf{K}_{ss}^{-1}$ once.
3. For each parameter $h_p$, $p = 1, \ldots, N_p$ (loop over index $p$):
   (a) Find the material derivatives $\mathcal{D}\mathbf{M}_{ss}/\mathcal{D}h_p$ and $\mathcal{D}\mathbf{K}_{ss}/\mathcal{D}h_p$ in the equation (7).
   (b) Using the solution from point 1 (i.e. $\ddot{\mathbf{x}}_s$, $\dot{\mathbf{x}}_s$, $\mathbf{x}_s$) aggregate the right hand side vector of the equation (7).
   (c) Solve equation (7).
4. Stop.

Like in previous example, the Newmark procedure [2] with the integration step $\Delta t = 0.001$ sec. is used. The loop in point 3 was parallelized and that fact radically speed up the calculations.

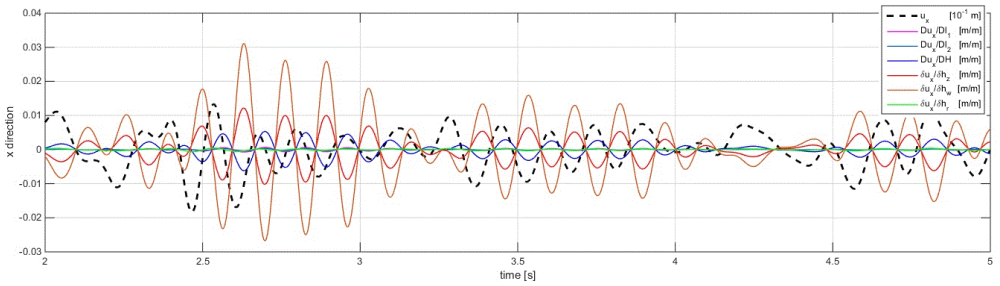


Fig. 14. Diagram of horizontal displacement $u_x(t)$ at $C_1$ and derivative $\mathcal{D}u_x/\mathcal{D}h_p$

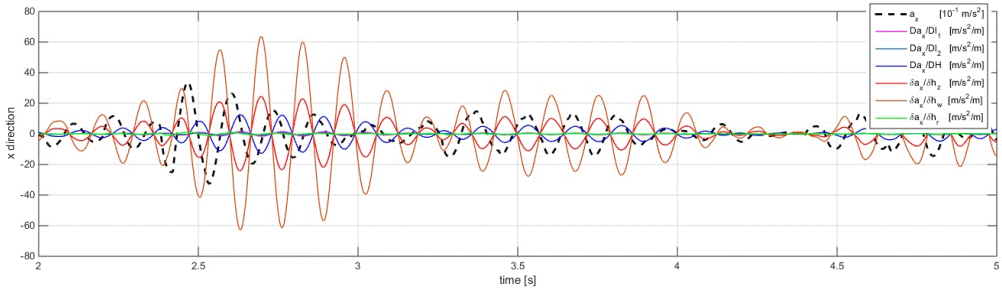


Fig. 15. Diagram of horizontal acceleration $a_x(t)$ at $C_1$ and derivative $\mathcal{D}a_x/\mathcal{D}h_p$

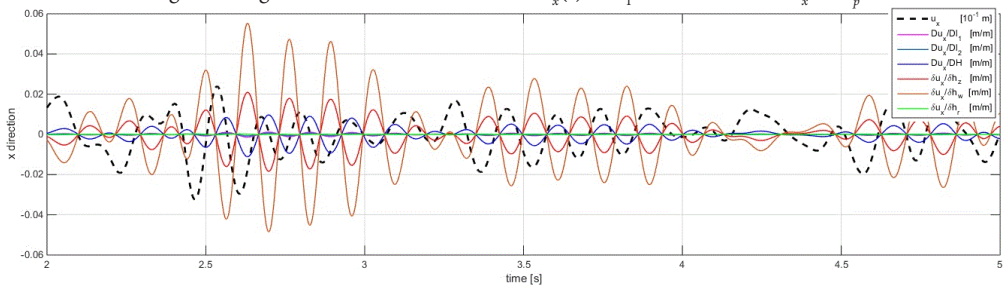


Fig. 16. Diagram of horizontal displacement $u_x(t)$ at $C_4$ and derivative $\mathcal{D}u_x/\mathcal{D}h_p$

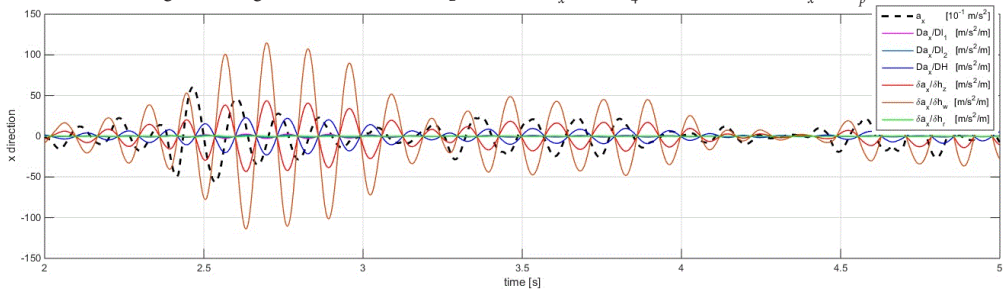


Fig. 17. Diagram of horizontal acceleration $a_x(t)$ at $C_4$ and derivative $\mathcal{D}a_x/\mathcal{D}h_p$

The presented diagram Fig. 7 shows that the most intensive phase of the shock occurs up to 8 sec. and the vibrations are not steady-state. In the Fig. 14 to Fig. 17 the horizontal dynamic responses of the frame at the points $C_1$ and $C_4$ are shown in the time from 2 sec. up to 5 sec. It is obvious that the dominant response is associated with the lowest eigenfrequency $f_1$ of the frame.

Focusing on the most intensive phase of horizontal vibrations of the frame excited by the seismic acceleration between 2.5 sec and 3 sec. the following conclusions could be stated:

1. Amplitudes of maximum horizontal displacements and accelerations at the point $C_4$ (upper binder) are about twice as large as at the point $C_1$ (lower binder). This is related to the shape of the first eigenmode – Fig. 3.
2. In the diagrams of displacements and accelerations derivatives, three derivatives dominate: relative to $h_w$ (cross-section height of internal pillars), $h_z$ (cross-section height of external pillars) and $H$ (storey height). The largest amplitude has derivative with respect to $h_w$. This

amplitude is about three times larger than the amplitude of the derivative with respect to $h_z$ and about four times greater than the amplitude of the derivative with respect to $H$. This is reasonable because the internal pillars are connected in joints with two binders at each level and the increase of stiffness of the inner pillars more stiffens the frame for horizontal movement than increasing the stiffness of external pillars connected only to one binder at each level.

3. The largest amplitudes of derivatives occur in neighbourhood of zero displacement or acceleration, so the influence of the parameters on the responses is very strong in those points. Moreover, zeros of derivative coincide with the maxima of displacements and accelerations – the influence of the parameters on the responses should be deeply explore by higher derivatives in that points.
4. Derivative diagrams with respect to $h_w$ and $h_z$ are in-phase with each other – extreme amplitudes occur at the same time. The derivative with respect to $H$ remains in the counter-phase to above onces. Thus, for example, increasing of the height of the cross-sections of pillars increases horizontal accelerations responses, the increase of the height of the storey causes the reduction of these accelerations at the same time.

## 5. Conclucions

Sensitivity analysis allows to get valuable information about the impact of design parameters on the response of the structure. Obtaining these derivatives could be the starting point in the optimization of the structure, optimal shaping of its geometry and optimization of cross-sections.

The presented sensitivity analysis using the DDM are efficient for models with both a few thousand degrees of freedom and a small number of design parameters. The method is simple in numerical application and gives the possibility of extensive use of parallelization of calculations.

In simpler case, direct inversion of the stiffness matrix $\mathbf{K}_{ss}^{-1}$ and its derivatives can be avoided. The matrix $\mathbf{A}$ (see equation (10) in [7]) must be directly expressed. It has a simple structure but in general is dependent on the parameters $\mathbf{h}$. In those circumstances derivatives $\mathcal{D}\mathbf{A}/\mathcal{D}h_p$ should be explicitly specified.

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