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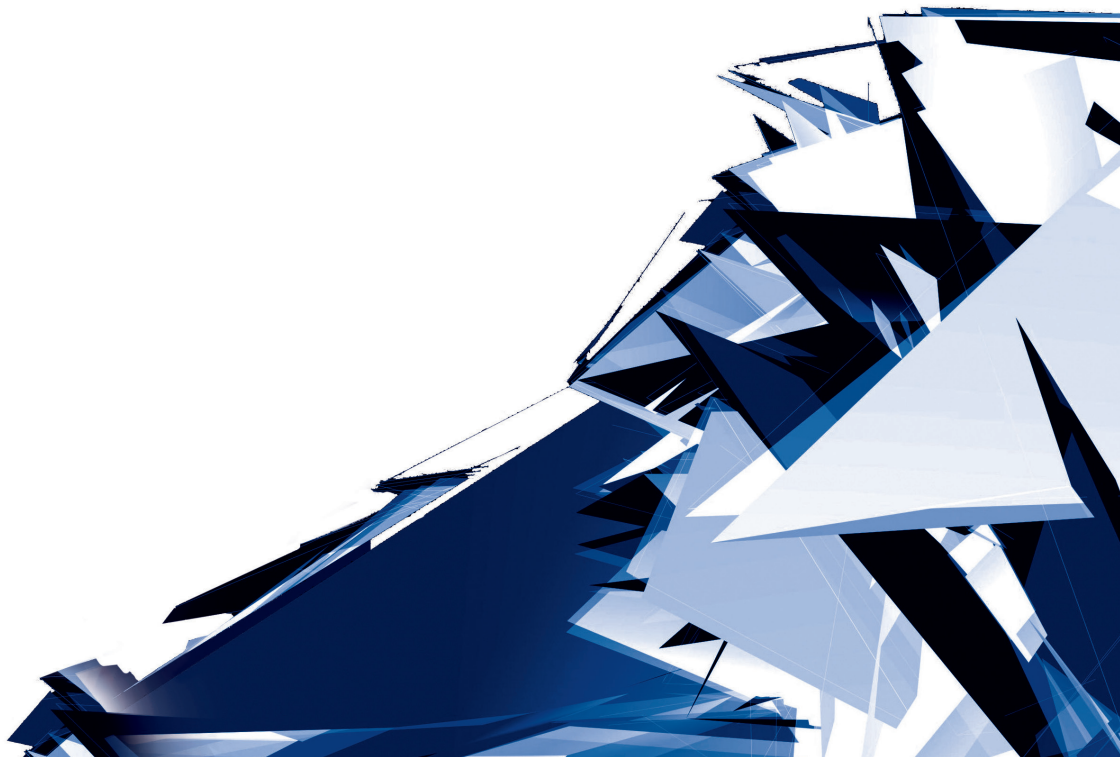

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Sustainable and creative temporary architecture – the activities of the Assemble collective

Zrównoważona i kreatywna architektura tymczasowa – działalność kolektywu Assemble

Abstract

Temporary architecture is not a new phenomenon in architecture, but over the years, both the objects arising as part of this idea as well as the attitude of the designer, the investor and the recipient to them have evolved. Apart from fulfilling a replacement function with regard to an existing building, objects which are created in accordance with the idea are unique in the field of aesthetics, technology and construction. Some of them become the architectural manifestos of the artist, presenting new materials, possibilities and propagating ideas related to ecological thinking.

In the paper, which outlines realizations presented by the Assemble collective, the possibilities of taking advantage of temporary architecture along with its theatrical function in the field of social impact, as well as shaping pro-ecological awareness have been emphasized.

Keywords: Assemble, temporary architecture, mobile architecture, theater, sustainable development

Streszczenie

Architektura tymczasowa nie jest zjawiskiem nowym w architekurze, ale na przestrzeni ewoluowały zarówno powstające w ramach tej idei obiekty, jak i stosunek do nich. Tak projektanta, inwestora, jak i odbiorcy. Obok pełnienia funkcji zastępczej dla istniejącego budynku powstają obiekty, które wyróżniają się na polu estetyki, technologii i konstrukcji. Niektóre z nich stają się architektonicznym manifestami twórcy, prezentując nowe materiały, możliwości techniczne i propagując idee związane z myśleniem proekologicznym.

W pracy poprzez realizacje multidyscyplinarnego kolektywu Assemble pokazano możliwości wykorzystania architektury tymczasowej o funkcji teatralnej na polu oddziaływania społecznego, a także w budowaniu świadomości proekologicznej.

Słowa kluczowe: Assemble, architektura tymczasowa, architektura mobilna, teatr, zrównoważony rozwój

1. Introduction

Architecture in its traditional form is associated with something constant and unchangeable. The urbanization process, even if it can be reversible, is not without impact on the existing landscape and environment. Apart from this, one can also observe continuous technological progress, which translates into specific socio-economic phenomena. Devaluation of what is permanent and unchanging also concerns urban space. In architecture, this is particularly visible in the structure of public buildings, which must constantly adapt to the changing reality, both in terms of their function and design.

Today, temporary architecture plays an increasingly important role in modern construction, gradually ceasing to be a marginal phenomenon. This marginalization resulted from the adopted approach most often focused on the replacement function of objects, i.e. creating objects, which are conceived as temporary, impermanent, existing for a limited time and then removed. Under such an assumption, the emphasis on the form and aesthetics of the object was of secondary importance, and indeed it was neglected. The most important factors to be considered in the implementation of the project were functionality and economic construction. Lack of concern for the aesthetics was often justified by a small budget, because objects devoid of durability were not treated as a so-called investment for years to come. Despite the fact that such objects are still being created, there are other, interesting, intriguing and qualitative objects implemented in line with the idea of a qualitative temporary architecture.

The promotion of qualitative temporary architecture is partly due to the nature of a rapidly changing world. At the turn of the 20th and 21st centuries, rapid civilization progress is noticeable. In the field of architecture, this translates directly into the technological advancement of buildings and the rapid devaluation of some of them in terms of both technology and function. In this field, the existence of a distinctive temporary architecture is gaining importance as it can act selectively to solve the problems of today's world. It can also become a pilot project that introduces technological innovations, constitutes a manifesto of its author, or it can initiate a dialogue with the viewer, posing significant questions concerning the future of architecture, man and the world. The temporary architecture creates great perspectives for creativity and decreases the risk of the creator, as he is aware that his work will not be evaluated in hindsight.

The issue of temporary architecture is particularly important in the area of culture and art. On the one hand, it can offer a substitute place of contact with recipients, while the permanent object is being rebuilt, and on the other hand by enabling the existence of art in a place where it has not been previously present, or for the purpose of organizing individual events. Their sensory reception is of great importance here, as the constructed buildings, in addition to performing their intended function, are to encourage the audience to visit their interiors and interact with them.

2. Mobility

Robert Kronenburg[1] claims that the most important feature of temporary architecture is its ability to be mobile. An example of this is the idea of building tents. Although today they are seen as being temporary; in in traditional Native American culture, tent shelters tent shelters called Tipi served as portable homes and constituted a permanent element of the nomadic life of the people. Tipi tents were supposed to meet the basic criteria specified in the definition of a temporary object, which still remain valid today. Continuing his research, Kronenburg does not treat temporary objects marginally and recognizes the variability of their locations as their advantage and distinguishes several of their groups. This division was made by specifying the method and time of assembly and transport possibilities of the facilities. The author also emphasizes the search for designers for an original and creative approach to the construction and use of new materials [1, p. 29–31].

The largest group consists of mobile objects, in which the ease of their relocation is considered a priority. Another advantage is their compact size. The modern trend in the design of mobile objects highly values their technological advancement, some of them even resemble driving machines. The second group consists of portable objects, created in accordance with the idea that emphasizes the importance of the easiness of folding and unfolding such objects, as well as the comfort of transporting them in parts. The third group are demountable objects, which usually relate to individual events, hence the method of assembly is the key objective here, they also remain the most flexible of all the objects belonging to the aforementioned groups [1, p. 7–8]. The fourth group has become popular in recent years and concerns objects that can be described as "pop-up". In reference to their name, the idea is that such an object is able to be implemented instantly and here the range of the designer's creativity possibilities is wide and the main emphasis is on an ingenious design, using either new technologies and materials or recycled and low-budget materials. Pop-up projects are popular at festivals, where they occasionally become artistic installations. The designs of the Assemble collective can be regarded as pop-up objects.

3. Flexibility

Architecture can be considered in accordance with the dictionary definition, as the art of creating order in a certain environment in order to adapt it to satisfy the multiple physical, material and cultural needs of people through a planned transformation of the natural environment and by creating certain forms and determining specific spaces intended for various purposes [2]. Today, the adaptation of architecture to human needs is called the concept of flexibility. The need for flexible design results from the transformation of civilization that has occurred in recent years. The transformation of

[1] Robert Kronenburg, architect and professor of the Chair of Architecture at the Liverpool School of Architecture. Author of many studies and publications dedicated to the issues of temporary architecture; His most important publications are: Flexible: *Architecture that Responds to Change* (2007), *Architecture in Motion* (2012).

civilization accompanied by technological progress, has influenced the character of human life, which has become much more consumerist. This is particularly visible when we look at how quickly utilitarian objects become devaluated, to what an extent our methods of communication, our organization of work or our eating habits are subject to change. Eventually the same applies to the use of buildings. In architectural terms, it may be defined as susceptibility to change, perceived not only at the functional level, but is also visible in the form of an individual object [3].

In the case of the function of a theater, flexibility is all the more important because the approach to the performance has also been changing over the years. In this field, taking advantage of temporary architecture seems appropriate, since it can offer the most contemporary, individualized and at the same time flexible and multifunctional solutions.

4. Sustainable development

Sustainable development can be defined as the sustainable socio-economic development of contemporary society, which satisfies the needs of the current generation in such a way so as not to reduce the possibility of satisfying the needs of future generations [4].

The idea of sustainable design in recent years is gaining more and more popularity as the negative impact of urbanization processes on the environment becomes noticeable. Often it is irreversible, hence each implementation of a new construction project should be a thought-out action that meets new criteria and fits to new standards. Such type of designs are easier to implement when the architect uses the opportunities offered by the idea of sustainable development, which assumes respect for nature and its diversity as well as for human's well-being and health. The idea should be realized at every stage of the implementation – from the conceptual phase, through to the detailed design, construction and exploitation of the object.

The theory of sustainable design pays special attention to:

- environmental and cultural conditions of the location,
- proper and environmentally friendly use of the area,
- effective use of materials and raw materials, including their recovery,
- energy efficiency and the use of unconventional energy sources,
- application of innovative technological solutions,
- increasing comfort and quality of use.

Temporary buildings designed in a sustainable way by functioning only periodically, may not leave such a negative footprint on the environment, as well as being regarded as an opportunity to promote pro-ecological solutions. Being implemented in degraded areas, they may be considered as the beginning of revitalization and ultimately the recovery of natural values.

Fig. 1. Assemble during the implementation of the Yardhouse project, photo by Assemble / Exhibition – How We Build at The Architekturzentrum Wien in Vienna, photo by L. Rastl (reference: https://www.azw.at/en/event/assemble/)

5. Temporary theater architecture of the Assemble collective

The issue of temporary architecture, which highly values positive social reception and the idea of sustainable development, was repeatedly addressed by the London – based Assemble collective[2]. Their projects are a great example of searching for both a clear and inspiring design idea, an original approach to form and construction, as well as taking advantage of cooperative work and involvement of the local community. References to social initiatives, which are present in the Assemble projects have been visible in many fields since the beginning of their activity in 2010.

The basic assumption of the collective's philosophy is close cooperation between the creators and recipients of the building. The team of people who create the collective consists not only of architects and construction engineers, but also of people associated with theater, scenography, anthropology or philosophy. As early as the design stage, team members work closely with carpenters and other craftsmen who also have a creative contribution to the created work. The project implementation, on the other hand, enables the active participation of volunteers and future recipients of the facility.

The assemble chooses areas requiring architectural and urban intervention, and in their execution, materials which are recycled in a creative way, often widely regarded as useless, are applied. The main objective of this action is education – which means demonstrating that every place, even the most neglected, can be revived and that at the same time, low-budget solutions can be found. The primary premise of the collective philosophy is the proper and effective organization of space, which enables the existence of a community-integration event at the location in question. Many Assemble projects are temporary, but some implement the assumption of a multi-stage process closer to scientific research projects [5].

[2] Assemble – multidisciplinary collective of architects, founded in London in 2010, who work across the fields of art, architecture and design, in 2015 they won Turner prize.

For their activities in 2015, Assemble was awarded the Turner Prize[3], a prize named after J.W. Turner, which is annually awarded to British artists. It was the first time in the history of the prize, that it was granted to people from outside the artistic community who have not created works of art in traditionally understood terms. This is confirmation that the objects implemented by the collective are not only dedicated to art, but in fact themselves create art. [6].

A significant subject of Assemble's activity is related to temporary architecture, because the collective considers it as the area which enables quick and effective introduction of its philosophy into life. Their opening project was the construction of a temporary scene at an abandoned gas station.

Fig. 2. Assemble, The Cineroleum, photo by Assemble [7]

5.1. The Cineroleum, 2010

The architectural transformation of the unused gas station in Clerkenwell into the entertainment hall was invented and implemented by Assemble in 2010. The name "Cineroleum" is an original combination of the words "cinema" and "petroleum". The original name found its reflection in an equally creative design. The motivation of the creators was to draw attention to how many gas stations in the UK remain unused. The introduction of the entertainment function was to be an opportunity for a distinctive transformation of the place and an indication of an alternative to multiplexes. And that's exactly what was carried out and the object became popular among the community and even gained wider publicity in the industry.

The project assumed the use of the existing cubic building as a foyer, and the roofs of the station as roofs for the auditorium. The foyer was made using recycled furniture; a small bar with a traditional popcorn machine was included. The aesthetics aimed to refer to palace interiors full of glamor and refinement. Instead of expensive materials, however, cheap and industrial, often recycled, were used. Each piece of equipment was made on site using

[3] Turner Prize – the prize in the field of visual arts awarded by Tate Britain (formerly Tate Gallery) since 1984. The winners are chosen from artists who are under 50 and live permanently in Great Britain. The prize is named after the English painter, William Turner, one of the greatest British artists, who had a significant influence on European art, and was considered controversial during the his lifetime. https://www.tate.org.uk/art/turner-prize (access: 23.10.2018).

a manual method by the Assemble collective in cooperation with volunteers, starting from scaffolding, through to folding seats constructed from boards to a curtain, which separated the auditorium area. The ruffled, cascaded drapery was created from "tyveka" type roofing and could be associated with the velvet curtains of old palaces, while also attracting the attention of passers-by with its silver glow. The curtain was also a symbolic element of the event taking place. The viewers were led behind the curtain, and after the show was over, the curtains were to be raised so that the viewers could be transferred back outside to the entourage of the so-called everyday street theater [7].

Fig. 3. Assemble, The Cineroleum (work in progress) photo by Assemble [7]

The popularity of the project encouraged its authors to consider another analogical implementation, using another type of unused space. This time it was the space under a viaduct that was selected.

Fig. 4. Assemble, Folly for a Flyover, photo by Assemble [8]

5.2. Folly for a Flyover, 2011

The "Folly" building constructed under a highway viaduct was commissioned by Create London, an organization whose main statutory objective is to offer support to artists. Assemble, apart from carrying out the designer's function, also acted as curators of some

Fig. 5. Assemble, Folly for a Flyover (work in progress), photo by Assemble [8]

events. The public space they have created has become an active cultural site of London's Hackney Wick. Within 9 weeks, many artistic events, performances, cinema shows and workshops were organized there, and the place attracted not only local residents, but artists and guests from around the world. Furthermore, boat trips were organized, and the cafe was operating permanently.

From the very beginning, the creators assumed that on the one hand they would refer to the condition of the existing place, the industrial character of the viaduct, and on the other, they would introduce the element of foolery which would be in accordance with its name. To achieve the desired effect and grant the space a certain identity, the designers decided to introduce a house-like building in-between the construction of the viaduct. Thus, they aimed at creating the impression that this typical English house was enclosed by a viaduct, rather than the other way around. Eventually, the gable roof was located between the highway lanes, which gave the whole object a strange impression. The implementation of the project was carried out using a manual method through the participation and involvement of volunteers who were grouped according to the level of their skills. The authors of the project wanted to take advantage of the help of every person who offered them their support. The facade of the house was carried out according to an original conception referring to the stringing beads. Wooden brick-like elements were threaded onto ropes that went through pre-drilled holes into each formed part. At the end of the period intended for the operation of this temporary space, the object could be easily unfolded and its parts could be used in the playground of the local primary school instead [8].

The popularity of this idea also contributed to its further implementations in subsequent initiatives and has ultimately contributed to the improvement of infrastructure and new development of the entire area.

Fig. 6. Assemble, Theatre on the Fly, exterior and interior, photo by J. Stephenson [9]

5.3. Theatre on the Fly, 2011

The Theater on the Fly, carried out in 2011, was commissioned by the Chichester Festival Theater to serve during the celebration of the 50th anniversary of the theater and is an example that proves that even a small amount of funds is not an obstacle to the creation of an attractive building that will not only meet its proper function, but will also gain a positive reception by the local community. The idea of the designers was to take advantage of the active involvement of the local community, starting from the stage of collecting funds as a part of the promotional activities, through to participation in the conceptual process and the building of the facility with the participation of volunteers.

The facility was located in a derelict area near the existing Chichester Theater and it was supposed to refer, with regard to its function, by means of traditional and innovative elements, both to the latter as well as to history of the theater. A unique detail was, for example, wide double-leaf doors that open the stage to the meadow. The internal space was to reveal theatrical technology to the viewer, by exposing technical mechanisms that usually remain invisible, e.g. by exposing the machine room of the stage tower.

Fig. 7. Assemble, Theatre on the Fly, building at night and interior during the play, photo by J. Stephenson [9]

An important element of the idea of sustainable design was the use of recycled materials or the use of such materials that could be processed easily. Some of them were donated to the authors of the project for the purposes of construction. One example is of a material that covers the wooden frame of the construction. It turned out that the semi-transparent fabric, which is usually used in the construction of ponds or as a foundation for road surfaces, ensures great sound insulation, even in the case of the wind blowing [9].

Fig. 8. Assemble, The Big Slide, photo by Assemble [10]

5.4. The Big Slide, 2013

"The Big Slide" was a temporary structure built in 2013 as the central object of the Stratford Rising Festival. The leitmotif of the festival was the word "Play", which Assemble interpreted in an architectural way, creating a variation on the subject of a typical slide for children.

A large wooden structure was established vis-á-vis the Theater Royal. The construction was two-sided. On one side there was a wide ramp of slides, and on the other, stairs were built, which apart from providing access to the slides, served as the auditorium for theatrical performances. The surface of the slide was covered with plywood with a laminate imitating marble, giving the whole piece a light-hearted effect [10].

Fig. 9. Assemble, The Playing Field, exterior and interior during the play, photo by J. Stephenson [11]

5.5. The Playing Field, 2014

The project "The Playing Field" was part of an art festival organized in 2014 by the Nuffield Theater. Assemble creatively used the fact that they were given free choice to decide on both the function and the form of the object. The temporary wooden structure was to combine the classic idea of the Tudor Theater[4] and the sports arena. The creators depicted the analogy between theater performance and football matches. As far as the architecture is concerned, they selected a form which is typical of the stadium, with a two-sided arrangement of the auditorium, giving the feel of a stage placed on the platform. The stage they designed had an oblong shape, was established at the ground level and was marked out by lines that brought associations of the playing field. Such a field was not only intended for use during theatrical performances, but it was also designed to encourage people to be active after the artistic events ended. The facility was adapted to performances by applying professional electro-acoustic and lighting solutions managed from the position of a technical gallery. The construction, typical of Assemble projects, was made using wooden elements and classic carpentry joinery. While preparing the project documentation, the creators established a cooperation with engineers from the Structure Workshop[5]. Their goal was to display the structure of the object, but the additional objective was simple assembly, which made it possible to build the object without using heavy machinery [11].

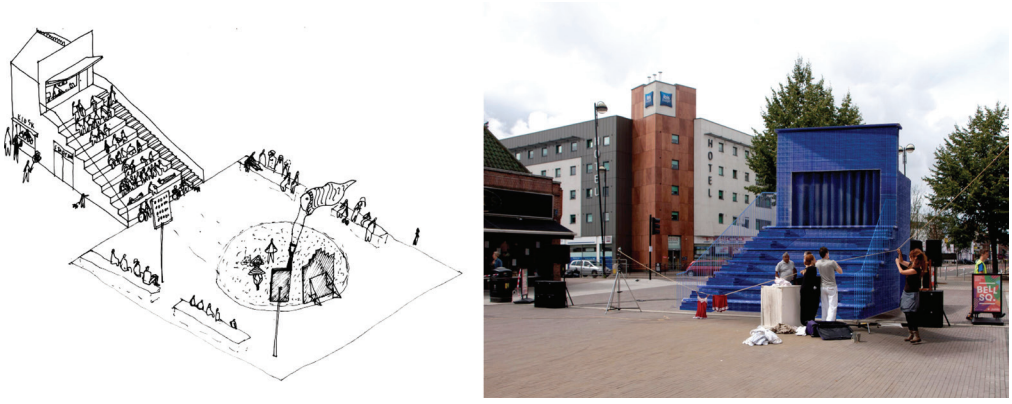

Fig. 10. Assemble, Bell Square Pavilion, sketch by Assemble, photo by Assemble [12]

[4] The idea of the theater originated in the reign of Elizabeth I, when together with sport and entertainment, theaters provided employees with a certain form of rest from their work – objects that were created used to be open and accessible to everyone. https://www.historylearningsite.co.uk/tudor-england/theatres-in-tudor-england/ (access: 23.10.2018).

[5] Structure Workshop – consulting company dealing with engineering design, founded in 2004 in London. The scope of its activities applies both to constructions as well as to artistic installations and industrial design, carried out in Great Britain and other places in the world. http://structureworkshop.co.uk/profile/ (access: 23.10.2018).

5.6. Bell Square Pavilion, 2014

The pavilion was designed by Assemble as an outdoor stage for cultural events that took place in 2014 at the Hounslow Town Center. The compact, two-story structure combined the technical functions, the base of the Watermans production company and the auditorium. The auditorium's levels fulfilled their function during the performances, and were also supposed to provide a functional extension of the public square, which the creators called the so-called theater of everyday life.

All structural elements were prepared earlier in order to enable easy assembly. For the architects, it was essential that the economical and at the same time durable – in terms of their use – materials were used in the construction of the building The basic structure was made using acid-etched concrete technology, and the facade of the building was decorated with glazed, porcelain tiles with a characteristic ultramarine color [12].

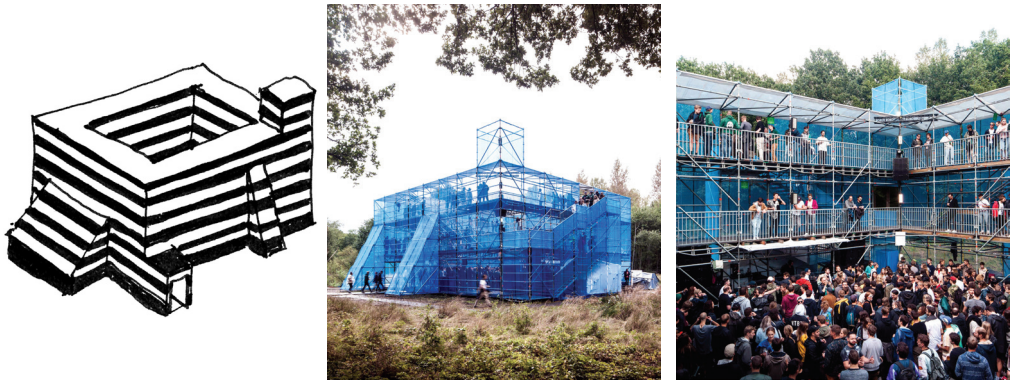

Fig. 11. Assemble, New Castle for Horst Festival, sketch by Assemble, photo by J. Verrecht [13]

5.7. New Castle for Horst Festival, 2017

The temporary pavilion "New Castle" was constructed by Assemble, commissioned by Horst Festival – the festival of music and art that took place in 2017 in Belgium. Here, the context of the place was also the inspiration for the creators, especially the location of the object in the forest meadow near the lake and the 14th century castle.

The iconic form of the castle with a characteristic facade of dark and light stripes of stone has been reinterpreted in a creative way by Assemble. In order to achieve the effect, which is typical for the architecture of fortifications, the new building was constructed using systemic steel scaffoldings. Hidden in the thicket of greenery, the skeleton was covered with a transparent grid with a blue color, enhancing the abstract impression of the whole. Perception of the object changed, depending on the time of day; it had the most attractive look at night, when it was illuminated by extra lights. It not only fulfills the role of the background for theatrical performances during the events, but it becomes itself a source of new experiences for the recipient [13].

6. Summary

This article presents the characteristics of the temporary architecture along with the aspects of mobility, flexibility and sustainability, which are associated with it. At the same time, the significance of its role in the field of theater function was emphasized, since it can be taken advantage of in order to promote culture and art as well as to integrate the local community. This integration is possible not only through the created object, but also through the creative cooperation of all parties in the investment process at all stages of its design and implementation. The contemporary temporary architecture provides great opportunities for the creative activity of the designer, and the implementation of its projects can significantly change the perception of urban space and even stimulate its economic development.

Analysis of selected complete projects by the Assemble collective, illustrates contemporary tendencies in the design of temporary architecture and indicates the direction of its future development. The presented examples allow us to see the impact of the idea of sustainable development on construction and the role of the designer in the proper and original use of the means of expression and technological solutions, so that a positive reception of the object in the community is achieved and at the same time its negative impact on the environment is reduced.

Positive reception in the industry and the rewards that have been granted to the above projects, as well as the visible attachment of recipients to individual objects, confirm that temporary architecture does not remain less valuable than permanent architecture.

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Art installations as an idea of *interference theatre* in the landscape of urban space

Instalacja artystyczna jako idea *teatru interferencji* w krajobrazie przestrzeni miejskiej

Abstract

According to a common belief from ancient times, theatre is happening all around us while we, the actors, keep playing out our roles in the surrounding existential space. An analysis of the phenomenon of theatricalisation of public space must not disregard the role of art installations as performances which serve as the background and medial tool to evoke the interaction of the viewer and stir his/her imagination, fluctuating between the spatial form and the content – the "spirit of the place"; installations of art are symbols embedded into the contemporary cultural space of cities, which restore the memory of the past.

Keywords: multi-appearance, performance, sculpture, theatre, opera, scenography

Streszczenie

Teatr dzieje się wokół nas, a my jesteśmy aktorami grającymi swoje role w naszej przestrzeni egzystencjonalnej. Analizując zjawisko teatralizacji przestrzeni publicznej, nie można pominąć roli instalacji artystycznej jako inscenizacji stanowiącej z jednej strony tło, ale także narzędzie medialne wywołujące interakcję widza i uruchamiające jego wyobraźnię interpolującą pomiędzy formą przestrzenną i jej treścią „ducha miejsca", instalacji będącej zarazem znakiem we współczesnej przestrzeni kulturowej miasta, restytuującym pamięć o przeszłości.

Słowa kluczowe: wielozadaniowość, performance, rzeźba, teatr, opera, scenografia

In an architectural and urban context, public space is understood to mean a generally accessible area of particular significance to both individuals and the community, whose primary purpose is to satisfy their elementary needs and higher aspirations, including social contacts, and ensure multidimensional communication. A definition of the concept is also provided in the Polish Act on Urban Planning and Development [1], which, however, does not restrict it to an exclusive domain of planners working on the distribution or redistribution of resources of the natural and cultural space. This process, of distribution and redistribution of space, is not a phenomenon unique to our civilisation; it has been observed since the earliest days of human activity on Earth. An outstanding Polish art critic and historian, Mieczysław Porębski, described space as material in the hands of architects and urban planners; a medium which has been continuously used in man's creative activity for thousands of years. He did not see space as an unchanging "matter" given once and for all, but maintained that it is "…being constructed and reconstructed over and over again, each time differently…" [2].

These struggles of man with the "matter" of space are not only the problem of our epoch, since, as rightly stated by Małgorzata Dymnicka. The genealogical table of public space dates back to ancient [3], or even pre-ancient times and public space management efforts have always been accompanied by art [4].

The oldest known form of public space is the Greek "agora", which originally denoted a gathering of citizens with the right to vote, held in a suitable place, and subsequently transformed into the central public space in ancient Greek city-states and became the heart of public, political, religious and commercial life where the necessary edifices were built side by side with autonomous spatial creations (statues, obelisks, wells or altars). For instance, the gigantic bronze and iron statue of the Greek sun-god Helios, erected at the turn of the 2nd and 3rd century before Christ, towered over the entrance to the Rhodes Harbour. The monolithic ritual human figures found on Easter Island, each weighing an average of over 20 tons and measuring 6 metres in height, are in turn thought to have been carved around the years 1,000–1,100 AD and made very special creations within the public space of the island's indigenous people. The presence of art in public space was not alien to Polish ancestors either, which is proved by the cult granite sculptures carved around year 700 BC, i.e. the representations of bears, a monk, a human figure carrying a fish and other forms marked with a slant cross, distributed along the pathway towards the top of Mount Ślęża.

Today the focus of public space studies tends to gravitate towards sociology or, strictly speaking, social communication [5, p. 56], with works of art created in such spaces assuming the role of mediumistic measures adjunctive to that of communication. In this context, let me present a few thoughts about works of art, which an art installation becomes in public space, having regard to the historical aspects of that space; the object of creation drawing from traditions of the site's setting; i.e. the expression or interpretation of "genius loci".

As I have already given a wider overview of the art installation in the public space of Technical Transactions [6, p. 190], I will only briefly outline the definition of an art installation which, "as a multi-component art performance, occurring in the existing space or constructing the space, utilises, to this end, the available media (materials) which in their essence constitute a means of expression…" [6, p. 190]. Viewed in this light, an art installation is a game, an intermedial spectacle and a theatre aiming to pass certain contents onto the

audience, evoke emotions among viewers, engage them in dialogue or, finally, to provoke a reaction or deep reflection.

Historical architectural and urban complexes, both in Poland and across Europe, are protected by law. This entails the unavoidable creative confrontation of the value of "new" art with historical values and, consequently, imposes limitations on the unrestrained, unhindered artistic expression which, in the context of the existing public space, triggers the phenomenon of urban "acupuncture" [7]. An art installation in the public space of a historical city thus becomes an experiment seeking to establish a platform for dialogue between the artist and the place, a dialogue allowing the shaping of artistic awareness and, possibly also, adoption of the paradigm of an "orthodox" art installation [8, p. 9–17], i.e. one that poses the problem of conceptual art. The programmatic mediality and communicativeness of contemporary art represents victory over social and cultural limitations but also assumes the art's subsidiary role towards the local recipient (a recipient attached to his/her place), which also applies to the planned duration of the artistic experiment. "The degree of complexity of the task of constructing a work of art within the confines of a city, i.e. of a multidimensionally complex work, requires from the artist awareness of the contents communicated and the unveiling of hidden senses, but also responsible choices with reference to the specific place, the history of its architecture and the well-being of its residents. In traditional elements of the public space (squares, plazas, streets, parks), artistic interventions are at risk of being misunderstood and, subsequently, rejected by the recipients" [8, p. 9–17].

This is what happened to the "unfortunate" art installation in the French Carcassonne by an outstanding Swiss artist Felice Varini, hired to execute a project to celebrate the 20th anniversary of the city's inscription on the world heritage list at UNESCO.

Fig. 1. Felice Varini, "The Castle from Carcassonne"

Spread on the fortifications and towers of the Carcassconne castle complex, vivid thin aluminium yellow strips come together to form concentric circles resembling a giant shooting range. The project evoked inhomogeneous social opinions, oscillating between being perceived as art, irony, an illegible message and vandalism. The vast majority of the 4 million tourists visiting the city each year were amazed that the municipal authorities would approve an installation like this, while the citizens wrote a petition demanding its removal. Purely from the perspective of an art restorer and painter, I believe the social reaction was an exaggerated one, and probably rooted in ignorance, absence of education or promotion of visual activities within historic cities and a lack of competence on the part of the municipal authorities, obligated (in my opinion) to duly prepare the society to the oncoming change in the city's everyday life. It would have been enough to publicly explain the technique and duration of the experiment before the artistic activity at the unique site of Carcassconne commenced. I am convinced that no self-respecting conceptual artist would dare to 'commit a crime' on any monument (we must not confuse the key notions and classifications of visual arts; the art installation does not fall into the category of "shock art"). What we are dealing with here is engaged, critical and thoughtful art, assuming, obviously, that a medial action like this satisfies the criteria below. Firstly, it should be deeply contextual, i.e. dependent on time and location. Only then is it raised to the status of a work of art which, in the historical space, should assume a temporary nature and offer reversibility of the technique. The art installation in Carcassone was, in fact, a momentary and elusive action. The artist used a non-invasive technique which did not produce permanent effects and, therefore, could not be classified as devastation of the monument. This is a typical performance of the artist on architectural facilities, where he generally uses all kinds of figures, shapes, lines and geometrical solids to create transparent images on huge spatial plains. All his images are decipherable only from a specific perspective. In the example described above, the regular pattern and concentric circles scatter into distorted forms if the object is being viewed from the 'wrong' position. The artist is famed for using simple shapes, i.e. circles, squares, triangles joined together at a single perspective from which the right configuration can be viewed. A configuration that is not accidental, but larded with universal symbolism. The existence of his works is only possible owing to the space in which they are created, as without it they have no *raison d'être*. For this reason, the art practised by Varini is called "in situ art" (a Latin phrase that translates literally as *on site* or *in position*).

For Felice Varini, a painter by education, constituent elements of landscape, whether urban or natural, make a background to painting. This sensual reliance between contemporary and historical forms introduced by the artist finds its rationale in Gadamer's concept of a "game", "play" or "fun" with reference to works of art [9]. Through his symbolic art, the author gives the audience a controversial lesson on the perception of reality, referring to weaknesses of the human mind, individual registers and records and the ability to differentiate between memory and historical truth. Contrary to appearances, what we receive is a deep message, a theatre or spectacle which, if looked at from a completely different angle, will turn into nothing but a chaotic mix-up of different graphic forms.

An art installation can, and should, not only evoke positive emotions but also provoke deeper reflections and thoughts triggering a quest for true meanings and intellectual links with civilisational and cultural symbols as well as tradition.

One example of such an approach is the historical installation in the German Kassel, a monument and memory site questioning the Nazi censorship imposed on the freedom of speech in 1933. The installation, known as "The Parthenon of Books", was built using more than 170 book titles banned worldwide by the Nazis. It is a life-size replica of the Athens monument made up of nearly 100,000 once-banned books created by an Argentinian artist, 74 year-old Marta Minujín. This time the "temple" was designed not to worship Athena Parthenos, but to express her attributes as the goddess of wisdom, art and just warfare, and the patron of cities, all associated with freedom, the highest value of man. This imposing work, an expression of intellectual freedom, was presented during the Documenta 14 festival (organised as a sign of resistance against political repression) and erected at the site where Nazi sympathisers burned an estimated 2,000 prohibited books in 1933 in a "book burning campaign" within the 3rd Reich and Austria. The action was conducted by students' unions gathered around the German Association of Students (orig. *Deutsche Studentenschaft*; DSt). The contemporary installation is a 'temple' of imperishable memory of what is lost – the Nazis destroyed mainly Jewish and pacifist literature or books representing classical liberalism, anarchism or socialism or touching on religious themes. Documenta is a prestigious international exhibition of art founded by German artist and professor Arnold Bode in 1955. The first Documenta featured works of art banned by the Nazis, but the event has transformed over time into a major exhibition of modern and contemporary art globally.

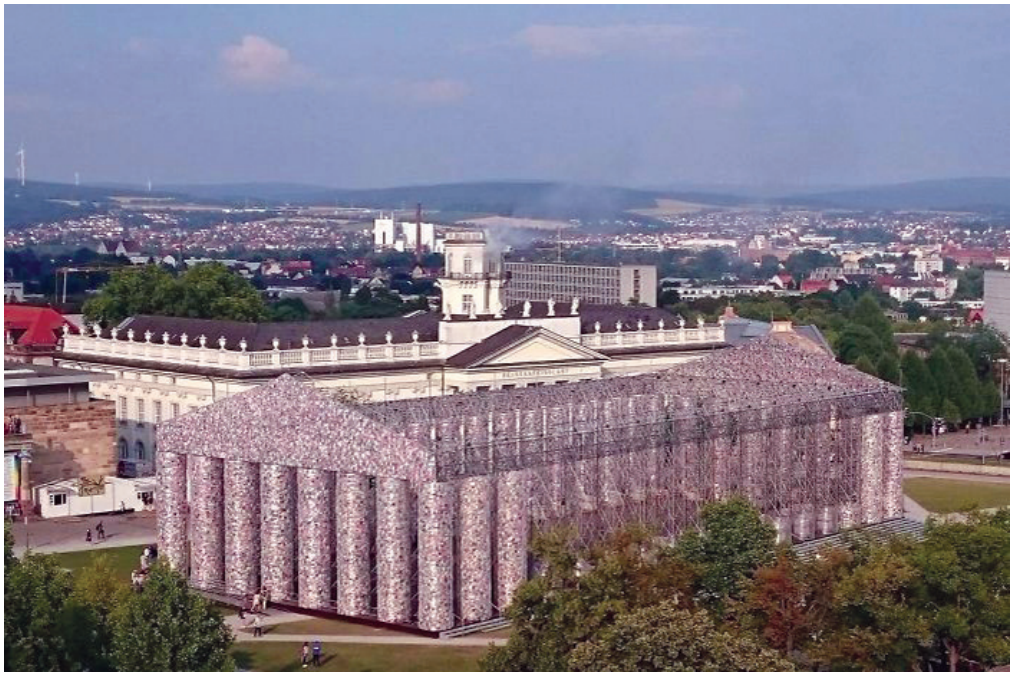


Fig. 2. Marta Minujín, "The Parthenon of Books"

Fig. 3. Marta Minujín, "The Parthenon of Books"

Another installation set within theatrical space is "The Cloud" by Natalia Romik, a Warsaw-based artist and PhD student at the Bartlett School of Architecture, University College London. It is a project based in a converted pre-burial house that is now the Museum of Upper Silesian Jews in Gliwice

Fig. 4. Natalia Romik, "The Cloud"

Through her work, "floating" in the existing public space, the artist transforms the space into a light, metaphysical scene whilst additionally highlighting the austere context of the place.

The public space allows social activity and becomes an area of overlapping and interfering creation, musealisation as well as theatricalisation. As M. Dymnicka puts it: "spatial, social and cultural concepts, transformations and reconstructions" [11] that occur in the public space shape the city's identity anew or become an inherent part of its *genius loci*.

The notion of the creation of art installations in urban public space has already been mentioned above. In recent years, sociological research has shed some light on the phenomenon of the musealisation of public space. As emphasised in sociological [12] and philosophical [13] studies, the musealisation of public space is the outcome of the continual filling of the space with more or less valuable "novelties", the quantity and quality of which accelerates their ageing and thus expands the collection of obsolete novelties, which, when combined with the imperfect tools used to evaluate objects "inhabiting" such space, leads it towards progressive musealisation, i.e. the process of gathering and expanding collections of items from the past. The phenomenon also reflects nostalgia for the past which is inherent to the human condition since, as noted by H. Gadamer, even an avant-garde artist, manifesting a break with past experiences and apotheosis of the experiment, is unable to free his own "self" from the burden of the past which lays deep in his subconsciousness.

On the other hand, it is worth noting that objects from the past, whose material authenticity gives them supreme value, are delivered by creative undertakings that modernise the public space which, through the efforts of archaeologists, shed light on artefacts from the past and on their expositional, scientific, educational, semantic and symbolic meaning, thus considerably identifying the space and defining the certificate of its cultural identity. In this way, the community using the space obtains attractive tools to consolidate memory of past days, which is perceived as a timeless value. Building on Lubbe's thinking about the musealisation of cultural space, Bartosz Korzeniowski noted that "the quicker the transformations in late-modern societies, the bigger the function assigned to objects of the past" [14].

An art installation is also a tool used by the institution called theatre which, regardless of the avant-garde forms of contemporary performance and refined staging technologies, remains a "hybrid" creation in contemporary public space (like the city), connecting "objects" from the past with new practical needs [15].

According to a common belief from ancient times, theatre is happening all around us while we, the actors, keep playing out our roles in the surrounding existential space. Epictetus believed that "a true sage should sit among the audience rather than participate in the tragicomic performance which life is", while Saint Paul teaches Christians to accept this "global performance", directed and staged by God, who writes the scripts of our lives. Finally, a famous poem by Stanisław Wyspiański, one of Poland's iconic artists, starts with the words: "I see my huge theatre".

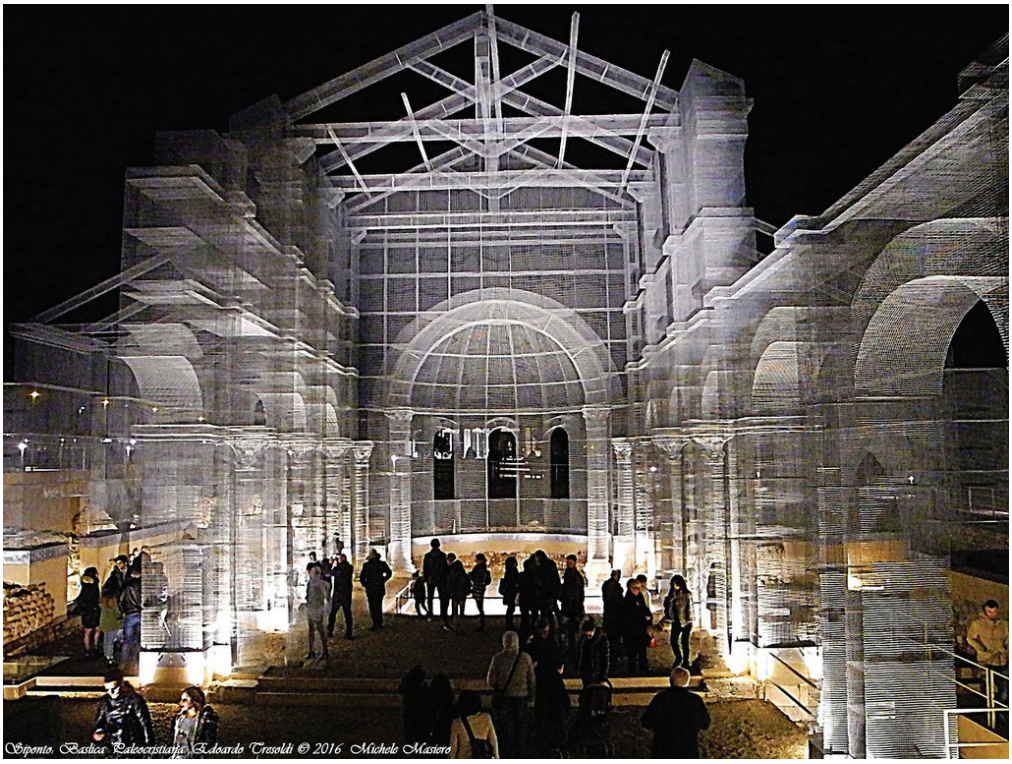
This "huge theatre" is nothing but a specific public space to which Wyspiański brings a sense of patriotic pathos, sketching the vision of the Wawel Hill's Acropolis. The poet embedded artistic initiation into the national cultural landscape and searched through it, looking for inspiration for "new" art which he could use to theatricalise the public space.

When following in the footsteps of Magdalena Kozień-Woźniak's research on the informal space of the urban theatre, which exceeds far beyond the confines of a building and its

traditionally defined substance, focused on theatre which may be happening anywhere and anytime, where anything can be discussed, which has "opened up to diverse expressions and functions of life" and whose mission has the integrated target of offering non-theatrical "other events organised to gather, activate and assemble the citizens" [16, p. 87], it can be observed that contemporary art installations become a form of participation in diverse manifestations, events and functions of public life, thus serving as attributes of interference between the different layers of public, cultural and theatrical space.

An analysis of the phenomenon of theatricalisation of public space must not disregard the role of art installations as performances which serve as the background and a medial tool to evoke the interaction of the viewer and stir his/her imagination, fluctuating between the spatial form and content – the "spirit of the place"; installations of art are symbols embedded into the contemporary cultural space of cities, which restore the memory of the past and, through the situational and semantic context, consolidate the viewers' (recipients') awareness of being a part of the theatre, i.e. the "large air spaces, [where] the people they serve and shadows".

The idea was perfectly illustrated by the expressive and deeply emotional work by Edoardo Tresoldi, who resurrected the "spirit" of the Ed Christian basilica in Siponto without the typical reconstruction of an old building or the outmoded language of social communication. The installation represents a large open air space of interferential theatre, where the people and shadows serve the "virtual architecture".



Il. 5. Edoardo Tresoldi, "Basilica from Siponto"

To sum up, it can be said that an art installation is a phenomenon existing within the area of interference of creation, musealisation and theatricalisation of public space, which can be used as a carrier of ideas, knowledge, symbolism, education and social communication (dialogue) on which the contemporary and historical "genius loci" are fixed.

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The social value of space around the theatre in the latest Polish built projects

Społeczna wartość publicznych przestrzeni wokółteatralnych w najnowszych realizacjach polskich

Abstract

Values generated by art and culture usually almost automatically generate social values that appear around the source of the said art, and thus around theatre buildings or concert halls as well. They help to shape the sense of identity of a place, which is important both to local residents and to those from further afield who are interested in cultural events. The experience of social values created around a source of culture is, however, not always as obvious. Can social values be built in public spaces surrounding theatre or concert hall buildings independently of the cultural events that take place inside them?

Three Polish built projects featuring theatre and entertainment buildings built over the past five years in Gdańsk, Warsaw and Katowice were selected in order to analyse this problem. They have won numerous distinctions and awards, including for their innovative solutions in terms of the public spaces created in their immediate vicinity.

Keywords: social values, public spaces, Shakespearean Theatre, NOSPR, Teatr Nowy

Streszczenie

Wartości generowane przez sztukę i kulturę tworzą zazwyczaj niemal automatycznie wartości społeczne, powstające wokół źródła tej sztuki, a więc i budynków teatralnych lub koncertowych. Pomagają one kształtować poczucie tożsamości miejsca, ważne zarówno dla lokalnych mieszkańców, jak i zainteresowanych osób z zewnątrz. Odczuwanie wartości społecznych, tworzonych wokół źródła kultury, nie zawsze jest jednak tak oczywiste. Czy w przestrzeniach publicznych, otaczających budynki widowiskowo-teatralne można budować wartości społeczne, niezależne od rozgrywających się w nich wydarzeń kulturalnych?

Do analizy problemu wybrano trzy polskie realizacje budynków widowiskowo-teatralnych powstałe w ciągu ostatnich pięciu latach w Gdańsku, w Warszawie i w Katowicach. Zdobyły one wiele wyróżnień i nagród, między innymi za nowatorskie rozwiązania przestrzeni publicznych, stworzonych w najbliższym otoczeniu obiektu.

Słowa kluczowe: wartości społeczne, przestrzeń publiczna, Teatr Szekspirowski, NOSPR, Teatr Nowy

1. Introduction

Public spaces associated with theatre buildings, concert and entertainment halls have a specific character due to the strong dominance of the basic function that is housed within them. According to the Spatial Planning and Development Act from the 10th of October 2018 [6] "an area of public space" is defined as: "an area of particular significance to satisfying the needs of residents, improving their quality of life and conducive to social contact because of its location as well as its functional and spatial qualities…" [6, Art. 2, pt. 6]. Its shape and organisation scheme should provide people not only with open physical access to a place, but also with the possibility of multi-level circulation and interactions that play out between those who gather there, as well as the events that are organised in entertainment buildings.

Widespread globalisation, commercialisation and occupation of public spaces by private entities that accompany the current development of cities have led to a gradual transformation of theatre buildings, concert and entertainment halls into a type of cultural hybrid that attempts to house, alongside the stage proper, widely accessible gastronomic establishments, shopping spaces, and sometimes even entertainment centres associated with recreation [8]. These additional functions, which are meant to increase the attractiveness of the public reception of a place, nonetheless introduce limitations as to its accessibility due to the proper functionality of a space that is enriched in this manner. Public space is thus becoming limited by places occupied by coffee shop tables, with numerous prohibitions being introduced, such as bans on running, roller-skating, stepping on meticulously landscaped lawns, consuming one's own food, etc. As a result, this leads to the partial social exclusion of certain groups of people from a given space and, as a consequence, a negative reception of a given place.

Insofar as the subject of public spaces organised within urban layouts (squares, parks, streets) is often analysed by specialists; public spaces associated with culture-forming buildings are presented somewhat as an afterthought to the discussion of the architecture of a theatre building itself or a report on events that take place in these spaces. Such spaces are also rarely assessed in terms of their social value, although the need to generate values of this type is inseparably associated with creating a place's genetic code [1] based on the culture being represented, in this case by a building which is an evidently functional, formal and dominant element of this space. We can distinguish three basic types of broadly accessible public space around theatre and entertainment venue architecture. The social values of a place that are generated within them often take a completely different character.

2. Values resulting from theatre space functional division plans

In theatres and historical concert halls, a building's architectural form and the character of its immediate vicinity were strictly regulated by rules of hierarchical divisions that have been developed over entire centuries, ones that were the result of not only the production direction of a given play (audience – curtain/stage frame – stage), but also from the class-based division

Fig. 1. Shakespearean Theatre in Gdańsk – interior of an Elizabethan-type layout (photo by Linkowski)

of society. Social values of public spaces associated with such buildings formed around two main notions: the "meeting" and the "event". The "meeting" took place in the sphere directly adjacent to the building, enforcing certain types of behaviours and an appropriately designed entrance zone. Starting with the location of parking spaces, through to an official approach to the main entrance, an appropriate entrance portal with space reserved for people awaiting entrance, to a hall making it possible to observe those who enter – all of this created the social value of the place, which was a result of the visual manifestation that was commented on by its participants on the spot. It was dominated by a public space of a social character, which stretched not only to the immediate surroundings of the theatre, but also within its interior (hall, foyer, audience). A theatre, as an institution, hosted people in its spaces so that they could experience not only art, but each other's company as well.

The "event", or spectacle – uncovered over the course of its performance by the lifting of the curtain – featured values that could only be fully read by the most well-educated members of the audience. The remainder of the audience were satisfied by the sensory experience of the performance, consumed in accordance with each viewer's personal sensitivity. An event's value could also be high despite the spectacle not being understood, as many people were satisfied simply by being present in such a place and enjoying even a fleeting experience of something elite. The decoration of the place in which these "events" and "meetings" took place has been and still is carefully prepared as a "clear sign that makes it possible to directly identify a place and a space" [7, p. 173]. Theatres and concert halls currently being built which repeat the classical scheme of relationships between the stage and the audience in their layout,

attempt to democratise these divisions, offering new compositional and formal solutions which maintain the capacity for the generation of social values within such a place.

The Shakespearean Theatre in Gdańsk, designed in 2005 by Renato Rizzi, was built as late as in 2014. It was built at the site of the former Fencing School building (1600–1612), in which theatre plays were also staged in the seventeenth century [15, p. 41]. Its conceptual scheme and form almost symbolically repeats the historical divisions of space used around this type of stage. The massive brick massing of the current theatre hides a light timber structure of the reconstructed stage and balconies for the audience. The entire lot on which the theatre is placed is surrounded by a thick wall which constitutes a type of visual barrier that demarcates the sphere of the *sacrum* of theatrical space from the *profanum* of urban space. This wall isolates the space that directly surrounds the theatre from the hustle and bustle of the city, whilst simultaneously constituting an element of a cleverly composed public space in which various cultural events such as open-air exhibitions or open theatrical workshops are organised. It also constitutes a sort of tourist observation trail, as we can marvel at the panorama of the city and the massing of the theatre itself from its top. The interior of the stage and the audience section is, in terms of technical and functional solutions, a layout that is fully modern and flexibly modified, making it possible to arrange three basic types of stage: an Elizabethan, Italian or experimental one. This makes it possible to stage plays that utilise various methods of the audience's access to events, during which the stage-audience space can be shared at one of the levels, thus keeping the distance between the participants of an event to a minimum.

The limitations that have been introduced by the reconstructed stage and galleries typical of an Elizabethan-type theatre forced the management of the theatre to introduce zones in the audience that differ in terms of the comfort of observing a play. Zone C (the cheapest) covers

Fig. 2. Shakespearean Theatre in Gdańsk – view of the walking trail along the top of the wall (photo by Panek)

Fig. 3. NOSPR in Katowice, footbridge along the axis of the Centre alongside a fountain and amphitheatre (photo by J. Sroczyńska)

the galleries of the first and second floors and while it does offer members of the audience the freedom to choose the place from which they view a play, it is unfortunately associated with having to stand during performances in order to be able to see the actors on stage. The galleries of the third floor, due to the poor quality of reception and visibility, have been closed entirely. The space around the theatre, delineated by a wall with stairs, narrow passages and irregular courtyards, forms a sort of a puzzle that one needs a significant amount of time to decipher. By allowing a visitor to identify and name it, makes it possible to generate the social values of the place. The layout, inspired by the narrow streets of historical old towns, makes it possible to shorten the walking distance required to meet one another and get to know other people, as well as to develop one's individual imagination, based on a contemporary interpretation of the past. As can be seen, such strict solutions of the classical layout of the division of theatrical spaces and the limitations associated with them, make it possible to evaluate and appreciate selected social values that are generated by and even thanks to these limitations.

3. Values that are the result of the open external spaces of theatres

The evolution of theatre that over the centuries has finally led to a departure from the strict division of space and changes in fundamental relations between the audience and actors, has also resulted in a new approach to the social values of a place that are generated within

theatrical and entertainment space. Contemporary theatres have become a place of public debate, clashes and discussions about everyday life philosophy and aesthetics, a source of new cultural forms, political representations or socio-cultural manifestoes. In a period of the pauperisation of art, the form of the massing of a theatre or concert and entertainment hall is meant to symbolically manifest a place as special, unique and significant to people.

In 2015 the Polish Association of Town Planners, along with the Association of Polish Cities, acknowledged the area surrounding the new building of the Polish Radio National Symphony Orchestra (NOSPR) in Katowice as the best public space in the "newly-created public space" category. The design of the surroundings of the building, which houses a concert hall that is amongst the world's most modern and best in terms of acoustics (in addition to that of the building itself) was prepared by architects from Konior Studio. It is one of the more important elements of the regenerated part of the city which once belonged to the "Katowice" mine and is at present called the Sphere of Culture. This sphere is currently composed of: the "Spodek" multi-arena, the Silesian Museum International Congress Centre and the previously mentioned NOSPR building.

The surroundings of the concert hall that has been awarded this prestigious distinction is located at the site of a former mine lumber yard, right near the shafts of the former mine [12]. Due to the character and function of the main building, it was decided to create an urban garden at the site, with a living and multi-threaded character, one that is, however, based on elements that reinforce and prepare visitors for musical experiences. The space was meant to play the role of a sort of foreground in which, through learning and gradually using various devices that have been placed in this garden, visitors could experience various sounds as they come closer to the core of the design – the concert hall, where they will be able to directly come into contact with the purest and fullest form of auditory sensation that is music. Elements characteristic of music, such as changing rhythm and fluidity, were used both in the facades of the building and in the functional and formal variation of its surroundings. The four-hectare gardens feature such elements as a music fountain, an amphitheatre, a labyrinth of hornbeam trees and numerous sculptures in the form of toys that produce sounds upon interaction. The labyrinth enables people to learn about the historical urban layout of Katowice's city centre from 1926.

Fig. 4. NOSPR in Katowice – hornbeam labyrinth with details reclaimed from a demolished mine (photo by J. Sroczyńska)

With the local community in mind, it was possible to fully employ this space by using materials typical of the region in its creation (brick, timber, steel, cast iron), as well as blending details obtained from the former mine into the decoration of garden furniture. Indeed, this place, despite being somewhat distant from nearby residential block complexes, is rarely empty. The space of the gardens became connected with other elements of the Sphere of Culture through a concrete footbridge that safely binds all of the basic elements of the complex together. The footbridge is currently the most frequently used place by people who want to take a commemorative photograph or wedding photo with the NOSPR building and its gardens in the background. The design, featuring a publically accessible Hall foyer by the inclusion of a music book store, has made it possible for an intermediary zone to be established, one that binds the external space of the public *profanum* (a zone that patiently educates people using elements that constitute an attraction to the average person) with the sphere of the *sacrum* embodied by the concerts' musical culture of the highest order.

The social value of this place lies precisely in this combination of an "event" that provokes a forced interest in the place of a potential "meeting". Preparing people for interaction with high culture is based on participation in play, which slowly introduces the still-unaware audience to the temple of classical sound. Experiencing sensations registered by the senses and reflection upon them are stimulated by the emergence of images and cognitive emotions

Fig. 5. Teatr Nowy in Warsaw – view of the theatre's courtyard (photo by J. Sroczyńska)

within the human mind, which, as a result, generate the individual social values of a given place. This space was also awarded the second prize in the prestigious international European Garden Award competition, whose jury acknowledged the garden as "an important element of the city's new identity" [10].

4. Values of a democratised new type of space around theatres

In Poland, stage spaces of this type are increasing in number every year. They are characterised by the lack of a classical stage and a place for the audience. Both the audience and the actor are meant to take their own place in order to complete their mission. Such a space makes it possible to facilitate many types of stage performances and the lack of scenic framework makes it possible to introduce a reinterpretation of semantics in plays, used by the director of a play and the audience's reception. The audience, along with actors, jointly establish the fundamental semantics and meanings of the values that they distinguish and the spectacle itself becomes "a sort of debate, whose result is never predetermined" [13]. A democratised theatrical space can come into existence not only inside the theatre building itself, but also within its immediate vicinity. It is supported as a perception of art not only by the direction, but also by the simplicity of the stage design, shaped independently of rows of

Fig. 6. Teatr Nowy in Warsaw – interior of the foyer with a bookstore, coffee shop and reading room (photo by J. Sroczyńska)

audience seats. This procedure also makes it possible to do away with the procedure that is typical of historical theatres that causes members of the audience who are just entering the world of art to be intimidated, as well as with all the divisions that support social stratification. The departure of the spectacle beyond the framework of the stage/frame/audience scheme is also accompanied by a different philosophy of shaping the character of the immediate surroundings of the theatre building, which is a type of extended arena for discussion initiated by the spectacle and at the same time a public space of the city in which the events that play out are commented on during the spectacle.

There is an increasing number of such spaces, with the new building of Teatr Stary in Warsaw's Mokotów district being particularly noteworthy in the context of this discussion. Its initiator and current artistic director – Krzysztof Warlikowski – had long searched for a place in which to create his own theatre as a multi-disciplinary space, open to many disciplines of art, making it possible to "engage in an in-depth dialogue with the audience" [13]. This outstanding and world-famous director wanted to establish an institution that would primarily interfere with the lives of the residents of the city in order to, over time, alter human perception of his city by revealing "the structure of its memory, repression or oblivion" [14].

Through dialogue with society, he also wanted to build a social understanding of European culture, showing the characteristics that are similar despite there being many differences arising from a distinct experience of history. In order to implement his project, he decided to procure an abandoned lot that had belonged to MPO, located in Warsaw's Stary Mokotów district, at 10/16 Madalińskiego Street. A design by Kozień Architekci, which won an international competition organised in 2008, was selected for construction. Unfortunately, the design was not executed due to a lack of much-needed funds. The programme had to be significantly reduced and cheaper solutions had to be found while still maintaining the idea behind the project. It was decided to only use the existing buildings of the complex, designed in 1927 by T. Emmel and which have been placed on the protected heritage sites list as the city's post-industrial heritage.

The design of the modernisation and adaptation of the historical complex of buildings of the former garage hall along with the MPO's storehouses and workshops for the purposes of a theatre was developed in 2014 by Piotr Fortuna Architekci from Gdynia. In 2016 Warlikowski began his work in the new building [4]. The stage space of the Grand Stage was organised in the main hall of the former MPO garage and features 4 independent mobile audience modules for 400 people. The space can be freely partitioned using folded curtains, which makes it possible to move the audience segments anywhere within the space. The sides of the Grand Stage, in the spaces of the former workshops and storage areas, were adapted to feature a foyer on one side and theatre facilities on the other. The foyer also houses a coffee shop and a bookstore, which operate all day long, independently of the events hosted at the theatre. A portion of the facilities section, near the changing rooms for artists, was appropriated for a rehearsal room, which, being adjacent to the Grand Stage, can also be used for purposes associated with spectacles or exhibitions. It can also be fully accessible to the public as a space for cameral artistic events thanks to being open from the side of the courtyard.

The interior design was the work of stage designers M. Szczęśniak and Ł. Kwietniewski. Their design is dominated by a spirit of conceptualism and constructivism, which is why both the stage space and the foyer appear to be makeshift, temporary spaces; however, they are anything but random. Their design causes everybody who enters to feel free. It is an everyday space of the city, and is thus used by the local community that meets here in the coffee shop or in the reading room adjacent to the bookstore when its members take a break from their everyday tasks.

The courtyard, designed by Ł. Kowalski and K. Samborska of Pracownia La.Wa is a particularly significant element of the Teatr Nowy International Culture Centre. It is an open area, although separated from the pavements of streets with openwork segments of partitions and benches. It plays the role of a cultural agora, "a place of social interaction, a public space that aids in sharing experiences, but also a place of casual rest on one's route through the city"[4]. It is here that invited artists are meant to test various forms of using urban public space. It constitutes a sort of ecotone, a transitory space between the world of theatre and the city, understood as a separate ecosystem of the city's biocenosis [3]. The elderly and children were also taken into consideration here, as a large lawn and a playground for children have been placed near the courtyard.

One of the freestanding single-storey storage buildings of the former MPO was assigned to act as a so-called dayroom. It is currently a centre that features educational events for children, youth and seniors. It hosts lectures and workshops that support social initiatives associated with improving the standard of living of the district's residents and skills concerned with engaging in social dialogue based on a diversity of human attitudes and cultures. The operational activity of the Centre's dayroom is created and directly regulated by the residents of the neighbourhood who participate in it.

The public space designed around and partially inside the theatre complex is a place that fully generates measurable social values that appear at the point of contact between so-called "high culture" and the true, everyday life of the city, whose pulse is clearly felt in this place, built as a democratic platform for dialogue. It does not lessen the rank of the "events" that play out here, and "meetings" that constantly take place here take on a supralocal significance. They thus constitute a public domain, a common good that is created by local social activity. The authors of a theatrical performance are but an element of the meeting that takes place here, commenting on the values of a democratised space of the city by interpreting a play.

5. Conclusion

The perception of space around theatres is associated with identifying, classifying and ascribing meaning to elements that shape this space as a public place. In order to generate social values within it, each member of the community who visits this place must first identify and then assess this space themselves. Opinions about such a place are undoubtedly affected by its composition, which makes it easier to perceive its assets, as well as enabling people to actively participate in this space, while providing stimuli to human senses which, when processed by

the human mind, build positive connotations [1]. The increasing number of anonymous public spaces is growing uncontrollably, which significantly waters down the idea of the city.

The unification of solutions and the uniformity of public spaces is a result of a stance focused on directionally satisfying the needs of residents. As Michel de Certeau suggested, it is currently necessary to "invent everyday life" [5], in order for the receiver to have a chance to discover and create values that will enable them to form true roots in a given place. Places associated with art, particularly with theatre and music, can, like no other public spaces, help people to form these roots, as the character of a theatre or concert hall is their inseparable trait.

The social values of space around the theatre are suspended between three fundamental layers, namely: the semantic, formal and cultural layer. The semantic layer generates values arising from such determinants like location, the history of the place, the function and manner of the organisation of the central building. The formal layer can generate values thanks to the aesthetic of the compositional and spatial layout, the harmony of employed colours and greenery as a factor that aids relaxation.

The cultural layer (the most dominant one in this space) can provide people with satisfaction resulting from a feeling of experiencing so-called high culture and the possibility of using the prestige that surrounds a place. Values generated within these layers ensure social integration thanks to the ability to engage in dialogue with people on the subject either of assets or a lack thereof on each of the abovementioned layers. And it will always be a dialogue of a transcendental nature, as it is not really about discussing an element of reality, but thanks to people that we get to know and who come to this space and the mutual communication of said people, these values that have the character of spiritual traits – that are so important to the development of humanity – are generated [2]. This is why the postulate of M. Kozień-Woźniak [9] concerning the need to create theatres of interference, whose cultural spaces will be appropriately superimposed upon the surrounding everyday reality, appears to be applicable to all newly built buildings of culture.

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The location of art in the urban space as a goal of contemporary theatre architecture

Umiejscowienie sztuki w przestrzeni miasta jako cel współczesnej architektury teatralnej

Abstract

The response of art to the social needs of the environment requires a reference to the relevant public place. Theatre architecture can regain the power to create a proper place for the art of theatre by responding to the demand for public space in the city. The ancient Greek theatre did this by opening to the surrounding urban or natural landscape. Also the medieval theatre did this, when mobile wagons called mansions stood in city squares. It is the same as the phenomenon of street theatre, when the whole city becomes a theatre. Undoubtedly, since Teatro Oficina is based on the idea of street theatre, a place belonging to the city and its inhabitants should be mentioned. Centro Cultural de São Paulo is still a current example of the architects' striving to build a special relationship, based on the unity of the stage, the audience and the world. Teatro La Lira in Ripoll is a pure synthesis of urban public space sometimes becoming a theatre. It is a return to the very sources of European theatre.

Key words: theatre architecture, Teatro Oficina, Centro Cultural de São Paulo, Teatro La Lira

Streszczenie

Odpowiedź sztuki na społeczne potrzeby środowiska wymaga odniesienia się do miejsca. Architektura teatralna może odzyskać moc tworzenia odpowiedniego miejsca teatralnego poprzez zaspokojenie zapotrzebowania na przestrzeń publiczną w mieście. Tak jak czynił to teatr grecki, otwarty na otaczający krajobraz miejski czy naturalny. Tak jak było w średniowiecznym teatrze, gdy mobilne wozy zwane mansjonami stawały na placach miejskich. Tak jak w fenomenie teatru ulicznego, dla którego całe miasto stawało się teatrem. Teatrem takim niewątpliwie jest Teatro Oficina, osadzony na idei teatru-ulicy, miejsca przynależnego miastu i jego mieszkańcom. Centro Cultural de São Paulo to wciąż aktualny przykład poszukiwań architektów dążących do zbudowania takiej szczególnej relacji, opartej na jedności sceny, widowni, świata. Natomiast Teatro La Lira w Ripoll to czysta synteza tego, czym jest miejska przestrzeń publiczna, która czasem tym teatrem się staje. To powrót do samych źródeł teatru europejskiego.

Słowa kluczowe: architektura teatralna, Teatro Oficina, Centro Cultural de São Paulo, Teatro La Lira

1. Introduction

Contemporaneity is associated with continuous change. Nothing is fixed or defined. Rapid technological progress affects the pace and lifestyle of cities. From the beginning of the twentieth century, architecture responding to this particular feature of modern times is looking for references and ways to express change in architecture. Architecture cannot escape the social and political responsibility of responding to contemporary problems either. The dynamic and expressive architecture of futurism referred to technological progress and the beauty of speed. The total negation of tradition was associated with the revolutionary slogans of the struggle for change. However, Pedro Gadanho noticed the difference between this futuristic vision of the ephemeral architecture of motion and destruction as a result of the state of war, and the architecture as a contemporary critical response to the volatility of values and needs in a world of consumption [3]. It is no longer about architecture as a static utility or even about the beauty of speed, but it is about a performative (efficient) response to the changing needs of modern society. However, performativity is not limited to economic efficiency, but also refers to the cultural dimension. By adopting architecture as a cultural product, its performative dimension should also contribute to an important role, which is the ability to make comments on ongoing changes in culture and society. As such, architecture as a performance often combines the artistic *modus operandi* with a deep sense of social responsibility. Pedro Gadanho recalls the artistic intervention "The Homeless Vehicle" (1988–1989), a work of Krzysztof Wodiczko. The artist designed a multifunctional machine for sleeping, eating, collecting and segregating

Fig. 1. Krzysztof Wodiczko, The Homeless Vehicle, 1988–1989, 5th Avenue New York 1988, www.culture.pl

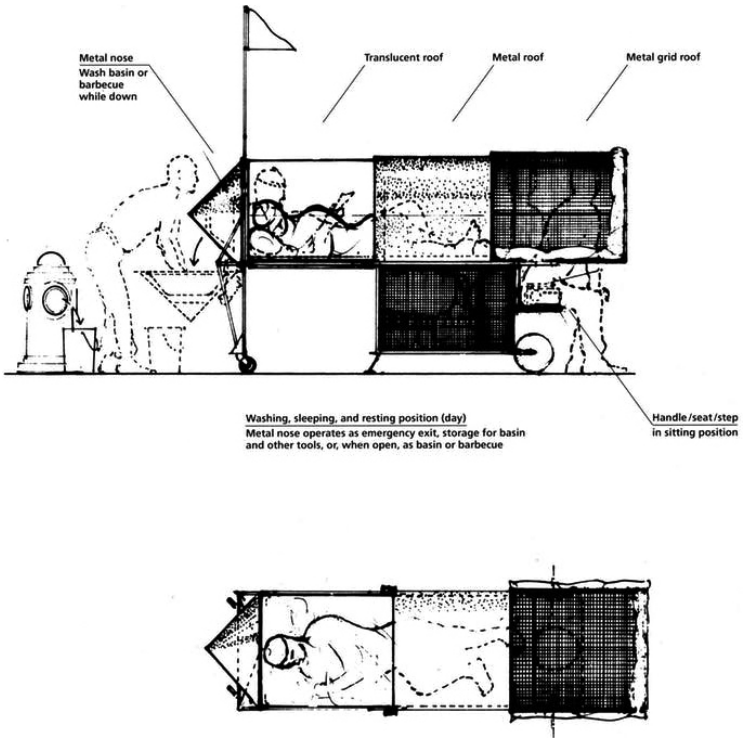

Fig. 2. Krzysztof Wodiczko, The Homeless Vehicle, 1988–1989, preliminary sketches, www.walkerart.org

waste. A shopping cart machine, equipped with wheels, is pushed by the owner. It becomes their mobile and changeable fortress and treasury. At the same time, it still remains a trolley and its owner is homeless. Krzysztof Wodiczko himself described the work as such: "This vehicle is not a solution to the crisis of homelessness, it is an emergency rescue service for people who have no way out and an ambulance because it articulates the complex situation of the homeless, does not show them as crows collecting garbage and waste, only as people using a device for specific purposes – which should not exist in a civilized world. The vehicle has a rescue and didactic function, finding a form for what nobody wants to know or see" [12]. At the same time, this work can be considered a work of architecture, a multifunctional, mobile home. It is giving the vehicle the status of an architectural work – a home as a useful artistic manifestation of a social nature. This manifestation does not refer to stable values of durability, but to the instability of the individual's position in the social structure.

2. Location of Art in the Urban Space

An inherent feature of the *performance* is the location of the work in public space. The performance manifests itself in the streets, stadiums and screens and can no longer be contained in "hermetically sealed cultural vessels", as Dorita Hannah noticed [4, p. 328].

The response of art to the social needs of the environment requires reference to a place not only on the formal level of scale and visibility, but also to the atmosphere, spirit and significance of this place for its inhabitants [8, p. 38]. The location of art in the public space is not only meant to be the message itself, but the dialogue, commitment and creative activity of the recipient.

The theatre location is created both by the theatre and the public space. A mutual, inseparable relationship between the city and the theatre is built by social or even political involvement. Thus, this bond consists not only in the placement of art in the public space, but also in the operation of art in the public interest [9]. The social mission of the theatre can no longer be limited to theatrical performances only. Other events that aim to gather, activate and bring together residents of the city become its integral element. This way of understanding the theatre's mission should also include an architectural contribution. Theatre architecture can regain the power to create a proper place for the art of theatre by meeting the demand for public space in the city. It is worth paying attention to the fact that contemporary architecture operates not only with two, but three types of theatre space. Auditoriums and black-box interiors are no longer the only types considered. The space that is closely related to its location; always unique, exceptional, site-specific, is the third one. Theatre architecture enters the informal theatre space, previously associated mainly with street theatre. It is worth mentioning the notion of *theatres of interference* here [5]. It was proposed in the search of a theatre building that gives the possibility of penetrating public space through theatre space, in an unexpected and unique way, exceptional for a given place. The ancient Greek theatre did this, by opening up to the surrounding urban or natural landscape. Medieval theatres did this, when mobile wagons called mansions stood in city squares, gathering a spontaneous crowd around them. It is the same as the phenomenon of street theatre, where a theatre is created of the whole city. This is in contrast to traditional theatres, which isolate the theatrical space from the surrounding space, giving them an intimate character. Theatres of isolation are protected inside city quarters, behind the walls of fortresses. Theatres of interference are not buildings dominating cities, symbols of social order, where the building is an expression of the hidden theatre. Theatres of emanation announce their presence by setting the boundary between theatre and the outside world that is built like a caesura between *sacrum* and *profanum*, a holy day and a regular day. Building a theatre, called the interference theatre, takes on the principles of the surrounding urban structure, transforms them and introduces them into the principle of creating the theatre area. The Brazilian Teatro Oficina is undoubtedly this kind of theatre, being a place based on the idea of street theatre and belonging to the city and its inhabitants. To illustrate this idea, it is also worth recalling Centro Cultural de São Paulo (CCSP), a building almost fifty years old. It is still a valid example of the search of architects striving to embrace that special relationship, based on the unity of the stage, the audience and the world. It is also an example of the social involvement of the creators in building a space of dialogue and participation. On the other hand, Teatro La Lira in Ripoll is a pure synthesis of the public space recalling to mind the former theatre.

3. Teatro Oficina – a theatre-street

The first, unrealised project of Teatro Oficina in São Paulo by Lina Bo Bardi, Marcelo Suzuki and Edson Elito was ready in 1982. It was a combination of pathways from Jaceguay to Japurá streets and the opening of a plaza to Santo Amaro Street. Two gates that terminate the long interior of the theatre building lead to a large free space with ramps, pavements and a roofed grandstand, thus creating an open theatre space. The project referred to the vision of José Celso Martinez Corrêa (Zé Celso) – one of the main figures of the Brazilian theatre – who dreamt of an area without borders between the stage and the audience. As Edson Elito recalled, it was a complex process of integrating cultural and aesthetic differences: on one hand architects and their modernist education, formal concepts, purity, constructive rationalism and asceticism, and on the other, the Zé Celso theatre, growing out of symbolism, baroque, meanings, emotions and the desire for physical contact between actors and the public [13]. The reconstruction project involved the demolishment of all internal elements, including the slabs above the basement. Only the brick case from the 1920s was preserved, with Roman arches at the base and roof. The result was a large open corridor measuring 9 x 50 m, with high side walls, up to 13 m high, hidden behind a still grey and neglected facade, allowing the viewer a real "rite of passage" while crossing the street to the magical interior. The difference in levels was equalised by a 25 m long ramp, running along the entire theatre, from the entrance door to the rear door. A 1.5-metre strip of land covered with folded wooden planks was also introduced, more strongly emphasising the sense of street and passage. As a constructional intervention, concrete poles were used on high brick walls to strengthen and stiffen them. For the cover, a metal structure that supports the sliding dome was proposed. An interior garden with a waterfall was also designed. Gas was fed from the gas network that powers the theatre. A large opening was introduced in one of the walls with a movable cover that allows connection with the green area. These elements – water, fire and air – appear in architecture, taking part in theatre performances, being part of the scenery. Metal constructions of galleries, catwalks and landings are demountable and can be dismantled and rearranged, if necessary, to achieve the "scaffolding architecture" effect. Nothing in the architecture of the Teatro Oficina is permanent because everything is part of the changing scene. Technical stage equipment, such as stage lighting, equipment and electronic control remains visible. Capturing and distributing video images in the theatre allows simultaneous action in various areas of the stage space. On the ground level of the theatre there is a ramp / crossing / stage, an internal garden and a water mirror with a waterfall, as well as toilets to the entrance to the theatre. On the first level, the galleries / stage / wardrobe give continuity to the space. And on the second level, 7.3 m high, there are dressing rooms. The project consists of the open plan and flexible space. There is a total transparency of space, you can see the actors preparing in the locker rooms – catwalks – mixing the viewing space with the service space. The window in the theatre wall, located in front of one of the stands, reveals the Minhocão viaduct, allowing the viewer to watch the performance at the same time as the view of the city, prompting the viewer to interact with these two realities simultaneously.

Fig. 3. Teatro Oficina, São Paulo, Brazil, L. Bo Bardi, E. Elito, J.M. Corrêa, 1980–84 (photo by M. Twardowski)

Fig. 4. Centro Cultural de São Paulo (CCSP), Eurico Prado Lopes and Luiz Benedito de Castro Telles, 1976 (photo by Thomas Hobbs, www.flickr.com)

4. Centro Cultural de São Paulo (CCSP) – a connector

In 1976, architects Eurico Prado Lopes and Luiz Benedito de Castro Telles won a competition for the design of the city library in the areas located above the Vergueiro metro station built in São Paulo two years earlier [7]. It was already the second architectural competition for this space. The first, carried out by the authorities two years earlier, envisaged setting up an office district there. When construction of the facility was already underway in 1979, the new authorities ordered a change of its function from a library to a cultural centre. They wanted to have a space that would not divide users into age groups or social classes, will have as few doors and divisions as possible, that will combine and integrate people as much as possible, bringing together the interior of the centre with the landscape, using glazed walls instead of full partitions. Centro Cultural de São Paulo (CCSP) is composed of two internal streets. It is a low and long horizontal form, integrated with existing trees. In this way, the everyday life of the street and the artistic life of the cultural centre are permeated in one body. The architects claimed that the building was a democratic act, referring to the equality of the "low" or "popular" street culture (outside) and the "high", "organized" centre of culture (inside). Apart from separate administration zones, gates to enter the library and the possibility of separating the space for performances and rehearsals; the circulation areas in the building form a kind of a street. The building is reminiscent of a low-rise building, stretching along a curved street of 400 metres. The entrances remind one of alternative streets, rather than of representative doors to public facilities. The four floors of the object begin to be visible in places where paths intersect and cross at different levels, with different functions. Places for formal events and performances are set up between the streets. There are also places for less formal meetings and social activities. An open arena called Adoniran Barbosa Hall is accessible through glazed doors at the entry level with a void in the floor showing the black box studio below. Passers-by may gather around this opening, sit by the balustrade, and participate in events, both planned and spontaneous. Different paths can lead to the same place. "You can censor theatre, music and literature. But (dictatorship) could not censor architecture, because it is difficult to understand the intentions contained in the project. We have built a space that connects people, a democratic building was created during the dictatorship", as Luiz Benedito de Castro Telles recalled [7].

5. Teatro La Lira in Ripoll – the void

After the demolition of the Teatro La Lira, a vacant plot remained for many years in the centre of Ripoll in northern Catalonia. The theatre was located within one of the town's quarters, on a plot between the street and the river. Finally, the authorities announced an international architectural competition for a theatre as a multi-purpose space that could serve residents on a daily basis. The footbridge was an important element of the project to improve the circulation system of the town but also enabling residents to access the river. The competition was won by Joana Puigcorbé together with the architectural group RCR Arquitectes (Rafael Aranda, Carme

Pigem and Ramon Vilalta). The architects proposed to conceal the multifunctional hall entirely underground. The terrestrial space has been designed as an urban city square, which was led by a new footbridge connecting the river banks. The porch and the footbridge made of weathering steel shaped a frame to view the mountains, conquered by the dynamic variation of the shadows thrown by the rails forming the frame. The square became a symbolic stage, and the people passing through could be watched from both the riverside gallery and the bridge where the seats were placed. The people within the frame could change their role of actors to spectators sitting on the benches of the riverside gallery at any time. "All this imposes on the subconscious of the observer the reception of the place through the prism of the theatre spirit from the past and memories about the performances played here", as Jolanta Sroczyńska noticed [11]. The internal walls of the frame filling the tightly broken space of neighbouring buildings, provide an opportunity to hide both the evacuation staircase leading to the underground theatre room and a narrow back room, normally used as a cafe. Due to this, the frame has also been useful for additional behind-the-scenes activity, for example in arranging decorations for various urban events organized on the square. The square also serves as a foyer for the multi-use hall. The ceiling lets light through by means of parallel strips that fold on both sides to cover the side walls. The hall can accommodate up to 800 spectators, with different arrangements of the seats and stage.

Fig. 5. Teatro La Lira, Ripoll, Spain, 2011, RCR Arquitectes (photo by J. Sroczyńska)

Fig. 6. Teatro La Lira, Ripoll, Spain, 2011, RCR Arquitectes (competition drawing)

6. Conclusions

Theatre architecture, as an expression of socially engaged theatre art, itself becomes an expression of this commitment. It can also be said that this is another stage in the search of European modernists, returning to the sources of Western theatre. Wagner strengthened the *theatron* to accommodate his new audience. He replaced the balconies and the lodges arranged in the horseshoe shape with a fan-shaped arrangement of the auditorium referring to the ancient Greek theatre. All viewers gathered in the theatre were turned towards the stage portal and seated in long rows. They were focused only on art having its place behind the stage frame. Craig, on the other hand, strengthened the *skene* to emphasize the universal landscape. Appia came back to *choros* to repeat the theatrical ritual of participation. Theatrical constructivists focused on *deus ex machina* to replace god in the machine with the idea of the machine itself as a liberating and productive force [4, p. 225]. This time it is also a return to our sources - to link the theatre with the surrounding space, nature, the world and the cosmos. As it was in Epidaurus, where the hills were a natural continuation of the theatre, or in Acropolis, where the theatre was open to the city spread out at its feet. "People set the circle themselves and were in it (and they did not surround it and they were not outside). They were inside" [1, p. 49]. The presented examples of theatrical spaces are a natural continuation of the public space of the city, which is the street. At Teatro Oficina, the spectacle begins on the street, then actors and spectators march through the theatre building and end up back on the street. The border between the street and the theatre disappears in the CCSP.

Everyone can come and stay or go out, be a participant or observer of art. In Ripoll, the passerby stops under the roof, in a place that was once a theatre and now it can become one again. Each of these spaces is a part of the city, a street that can become a theatre, and theatres that are streets.

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Theatre architecture. A synthesis of arts in theatre

Architektura teatralna. Synteza sztuk w teatrze

Abstract

The 16th century brought changes in the European theatre. The Teatro Olimpico which was erected in Vicenza continued in the formation of the seventeenth-century theatre built in Parma. It initiated the Italian Baroque Theatre, adopted throughout Europe and later throughout the world. The All'Antica arrangement of stage-auditorium that preceded Teatro Farnese was developed in Sabbioneta, and it was the first attempt to create a theatre of the viewer and the actor. A Baroque theatre hall in Mantua, with its functional capabilities, was ahead of its time.

The artists of the Great Theatre Reform were looking for a space that would allow the viewer and the actor to be treated as the subject of performance. The beginning of this approach to theatre was demonstrated by Richard Wagner. Theatre became a place that saw a synthesis of all arts, and Peter Brook most clearly showed it in his performances, notably *Mahabharata*.

Keywords: theatre space, stage and audience relation, Renaissance theatre, Baroque theatre, multiple use form

Streszczenie

Wiek XVI zapoczątkował zmiany w teatrze europejskim. Kontynuacją Teatro Olimpico wzniesionego w Vicenzie był XVII-wieczny teatr w Parmie. Zapoczątkował on przyjętą w całej Europie, później na świecie, formę Włoskiego Teatru Barokowego. Poprzedzająca Teatro Farnese forma sceno-widowni All'Antica zrealizowana w Sabbionecie była pierwszą próbą wykreowania teatru widza i aktora. Zachowująca barokowe pryncypia sala teatru w Mantui swoimi możliwościami funkcjonalnymi wyprzedziła epokę.

Artyści doby Wielkiej Reformy Teatralnej poszukiwali przestrzeni, które pozwoliłaby traktować widza i aktora podmiotowo. Przecząc sztywnemu podziałowi na świat realny i iluzji, początek takiego myślenia o teatrze dał Ryszard Wagner. Teatr stawał się miejscem, gdzie następowała synteza sztuk wszelkich, co Peter Brook najdobitniej wyraził swoimi spektaklami, w tym inscenizacją *Mahabharaty*.

Słowa kluczowe: przestrzeń teatralna, relacja sceny i widowni, teatr renesansowy, teatr barokowy, przestrzeń zmienna

1. Introduction

A breakthrough in the European theatre, initiated by the Teatro Olimpico in Vicenza, shortly afterwards led to the construction of venues that did not prove the value of the idea for creating stage productions. However, the Teatro Olimpico caused a completely unexpected evolution of space in theatre in the direction of a clear division into viewer's and actor's zones. Andrea Palladio could not expect the extent to which Vincenzo Scamozzi would change his assumptions in relation to the stage and the audience. For today's historiography, both parameters of the orchestral zone and *pulpitum*, as well as the entire "backstage" with streets in a weird perspective, will remain an unresolved mystery. The illusionist space behind *Porta Regalis* and the other four door openings does not improve stage possibilities due to limited visibility [1; 2; 3, pp. 43–46, 198–199] (Fig. 1).

Joseph Furttenbach was reluctant to describe the stage in Vicenza as an illusionist one. Yet, one can doubt the stability of his beliefs. Furttenbach, author of a multifaceted study published several times in Poland, titled *On the construction of theatres*, quotes false data on the number of seats for viewers, similarly interprets the space. His work was widespread in the 18th century, practically from the moment of its creation or the first print. In various editions of articles, their selection is diverse. However, in every collection one can find transformations of *Scene Frons*, relating to the Olimpico, the Teatro Farnese in Parma and the Teatro San Carlo in Naples. Furttenbach notes that the richness of the interior proves that both architects, Palladio and Scamozzi, have seen the classics and perhaps a bit of subsequent drama, including the imperial period on the Olimpico's stage. Probably not entirely consciously, with no meaningful stage effect, the streets are entirely inspired by the architecture of the Roman Empire. But this rich decoration of the stage bears a resemblance to the illusionist theatre [4, 5].

2. Palladio and his followers

It is possible that Palladio did not see the stage in this way. The evidence for it would be his numerous studies on Roman performance venues, which he did for his patron, Daniele Barbaro. He prepared drawings for the renaissance edition of *Ten Books on Architecture* by Vitruvius. The way he perceived the architect's role in the contemporary world is visible in his works. A learned stonemason with solid foundations of a mastered craft building, he may not have reached beyond the *a priori* adopted classical repertoire and the physical and dramatic formula of spectacles imposed by the Olympic Academy. He had expressed his conviction to Roman form and detail in his work earlier. His search for a pure form of projection, based on a rectangular composition, contradicted the Mannerist trend, parallel at that time in Italy, based on the art of Michelangelo Buonarroti. Therefore, the attitude of the author of the first indoor Renaissance theatre in Europe towards architectural material was contained in fairly rigid canons and did not create the foundations for the already emerging Baroque. Hence, Palladio also cannot be considered a versatile creator. However, aesthetic qualities make the Teatro Olimpico one of the most renowned works of the late Italian Renaissance. The venue

Fig. 1. Vicenza, Teatro Olimpico. The streets of Vincenzo Scamozzi are visible fragmentarily from certain places in the auditorium. Is it just an enrichment of the richly decorated Scenae Frons? (photo by P. Obracaj)

impresses visitors and it has become the showcase of Vicenza, undoubtedly providing an impetus for the evolution of world scenes at later times. The interior is an example of the emerging theatre that would bind many fields of art.

A few years after the premiere of *Oedipus the King*, Vinzenco Scamozzi constructed the Teatro All'Antica in Sabbioneta. One can assume that the venue was created on the basis of negative experiences from Vicenza. Undoubtedly, the designer saw theatre differently at that time. A small building commissioned by the Gonzaga family contains a deepened and elevated, single rectangular space of auditorium and the stage. It is preceded by a proscenium placed at the level of the first row of seats, and is far from replicating the arrangement of the orchestra and *pulpitum* of Vicenza. This setup offers a wider range of possibilities and is limited only by the size of the room. There are no streets on the background of the stage, and the extended proscenium suggests that several dozens of seats were placed there. The interior of the room is modest, the walls are decorated with a series of polychrome frescoes. At first glance, it makes

a completely different impression than the interior of the Olimpico. By chance, Scamozzi was close to the arrangements that the artists of the Great Theatre Reform had expected. One can only suppose what repertoire he saw in the space he designed. Plautus and Terentius are usually named in this respect today. Kazimierz Braun mentioned Seneca, which seems unlikely. The bloody and realistic dramas of Nero's teacher were not played at all at that time, at least such performances are unheard of. But what follows from that unverified information is that the creator of the theatre in Sabbioneta had a broader vision of using the stage than Palladio. Several decades had passed since the performance of *Oedipus the King* in Vicenza, and the experienced architect now focused on the theatre of viewer and actor. These are the beginnings of a theatrical formula in which viewer and actor were to be the subjects. Thus, Scamozzi saw performances in the All'Antica in a broader context than those which were performed in the other venue, after Palladio's death. A different approach to decorations designed for specific performances, and often inherently their background, meant that theatre was becoming the Temple of All the Arts. The role of the All'Antica is not fully appreciated, it is often ignored, yet from the point of view of a barrier-free stage, it gave the storyteller great freedom of activity [3, p. 189] (Fig. 2).

Fig. 2. Sabbioneta, Teatro All'Antica. Scamozzi suggests an open form of the spectacle area. Orchestra could be predicted a priori also for viewers (photo by P. Obracaj)

World historiography indicates the Teatro Farnese in Parma as the next place in the evolution of theatre, with ideological roots originating in Vicenza. Giovanni Battista Aleotti undertook an extremely difficult project. The Farnese family commissioned him to adapt the 2nd level (or the first floor) of the Palazzo della Pilotta for a theatre space with an audience exceeding 1,400 people. It was only an initial number, because the vast proscenium could accommodate the same number of standing audience, or as many as 1,000 seated audience. In 1628, *Mercurio y Marte* of the Achillini and Monteverdi duo was staged there in grand style. Ten years after the completion of construction work, the stage was prepared for a performance of a show described as a form of opera. After creating a portal frame and a clear division between the stage box and the curved audience, the proscenium was arranged to facilitate viewers. But the essence of this development was the portal frame, behind which the show operating machinery was

placed. These were the beginnings of technologically advanced stage operating technology. The machinery, which has been modified many times since, has become necessary equipment for every opera theatre, arrived in the dramatic theatre, and wasn't opposed until the era of the Great Theatre Reform. It enhanced the development of opera as a form of spectacle and facilitated significant changes in the perception of the role of graphics in theatre. In addition, music joined the combined arts that constituted theatre [3, pp. 43–46, 198–199; 6; 7] (Fig. 3).

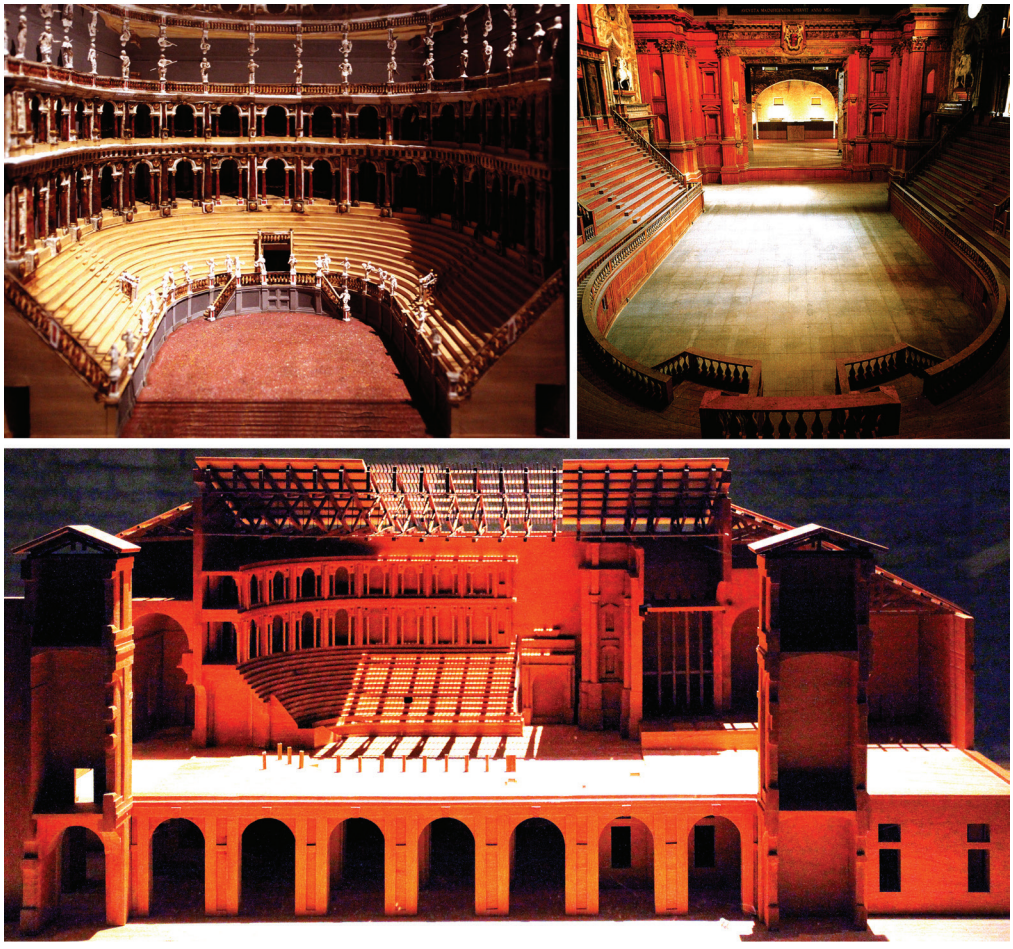

Fig. 3. Parma, Teatro Farnese. Portal frame divides the world of illusion and real (photo by P. Obracaj)

3. Richard Wagner's idea of the theatre

In the 18th century, opera gained a very high social status. It was already associated with a form of a building that had to meet certain functional conditions. By analysing the form of the spatial layout and equipment of the Teatro Farnese, you can easily turn to venues that

were created in the last decades of the 17th and later in the 18th and 19th centuries. In each development from this period there is a part originating from the spatial and technological arrangement of the theatre in Parma. In short, Aleotti originated the triumph of the stage later described as a boxed stage. Broader, these are the beginnings of the Italian Baroque Theatre. This distinction is important because the division into the world of illusion and the real world has been transferred from opera to dramatic theatre. As already mentioned, in the middle of the nineteenth century, this formula was renounced by artists of theatre, which resulted in different arrangements of the stage, often scarcely relating to the baroque model from Parma. Richard Wagner's arrangement can also be described as the box stage. The Festspielhaus Bayreuth built in the second half of the 19th century is a "milestone" of departure from the early-Baroque standard from Parma. The history of the Bayreuth opera house is a complex one, and Richard Wagner stands as a dominant figure among its creators. Inspired by Gottfried Semper's abandoned project in Munich, the master hired two architects, Otto Brückwald and Karl Brandt, commissioning them to "merge" their stage-auditorium vision with the Munich building. That concept was certainly Wagner's original idea. It shows not only the fact that the performances fitted so perfectly in the stage space, but also in his opinions as expressed in theoretical writings. He was inspired by German literature where he found his heroes (often group heroes). He wanted to give them special emphasis and he used the stage to achieve this. But not only the stage. In *Das Kunstwerk der Zukunft* (*The Artwork of the Future*), Valkyrie often runs out in front of the stage and, as in this case, in front of the "disappearing" portal. The bridge separating the first rows of seats probably never really existed. It remained only in the imagination of this outstanding theatre artist, but it was realised later in various performances. Importantly, it was neither the goal nor principle to move away from the Italian stage. The directors were guided (and this is still the case) by dramaturgical considerations.

Richard Wagner perceived human existence as a tragic condition. He was influenced by Jean-Jacques Rousseau and Friedrich Nietzsche, and such was also the reception of his art. However, considering it as a whole, one can see its multi-faceted perception and the effect on the recipient as a result of the symbiosis of many arts. This is an important theme that comes out in Wagner's theatre concept. The stage in Bayreuth from the very beginning, even before it existed, had its receiver, namely the audience. The relationship between the stage and the audience was formed along Wagner's idea and answered the needs of his performances. In contrast to the Parisian scene, his venue has never been the subject of admiration for connoisseurs of art or viewers. Theatregoers do not notice the aesthetics of the room or the exteriors. Still, the art that is performed on that stage is vivid and wonderful. But those who clearly cannot see its concealed beauty nevertheless appreciate what is most important: it is a temple, a temple of art [8, 9].

4. Wagner and Bibiena; two ideas of the baroque stage

Bayreuth is also associated with an Italian architect Giuseppe Galli Bibiena, who built the Margravial Opera House there between 1745 and 1750. A curved auditorium, surrounded by boxes, was separated from the stage box by a deep, richly ornamented portal frame.

Fig. 4. Bayreuth, Margravial Opera House. The auditorium formed as horseshoe was a baroque standard, the visibility from the lodges was limited (photo by P. Obracaj)
Bayreuth, Festspielhaus. The fan-shaped auditorium provides a full view of the scene (fisheye, photo by P. Obracaj)

Baroque details were dominant. It is a court theatre that can be contrasted with Wagner's concept of the opera house. The division into illusion and reality zones is not only distinct but highlighted. The period between the construction of these two buildings is a little more than a century. They were intended for opera, a form of performance that had evolved since the 1820s. Bibiena's venue could not meet the needs of Richard Wagner. The orchestra pit, fenced off with a decorative rail supported by balusters at the level of the first row of seats, can hardly accommodate a Mozart orchestra of only 35 to 40 musicians. What is certain today is that this opera of the margraves could not meet the requirements of Richard Wagner simply because there are up to 105 musicians in his orchestra. Other, less evident limitations are the depth of the portal frame and a narrow stage, confined by the backstage.

One can look at the Bayreuth venues yet from another perspective. The Festspielhaus was created as a theatre that met the creator's needs, the artist knew exactly what these needs were and what space he needed to fulfill his ideas. The relationship between the stage, the orchestra pit and the auditorium was meticulously thought out. Also, the auditorium in the shape of a fan, as well as being a novelty, was designed to allow for an expanded area of creation on the protruding platform. In short, the stage together with the auditorium was a single space, while in Bibiena's venue these two functions are clearly separated. There are some similarities between this arrangement and the theatre in Sabbioneta, however these two are quite different as far as scale is concerned. Still, despite Bibiena's conservative views on opera space, a spirit of theatre reigns in the venue he designed. The architecture, with its sensitivity and craftsmanship, in its form and detail matches the canons of the Baroque.

Giuseppe Galli Bibiena came from an artistic family in Parma. He was considered the most talented and most versatile creator, like his brother Antonio and father Ferdinando. He carried out conservation and design projects. He created set designs for performances in his own venues, as well as for other stages. Giuseppe Bibiena practiced easel and wall painting (*al fresco, al Secco*). In the history of theatre, he was the first creator who embraced the whole integrated theatre art which culminated on stage [3, pp. 73–81, 221–2; 7] (Fig. 4).

Giuseppe's older brother, Antonio, had a similar professional career, though he lived in Giuseppe's shadow. Between 1767 and 1769, Antonio constructed a unique venue in Mantua. The Teatro Dell'Academia, also called the Teatro Scientifico, was intended to serve several functions. In the latest descriptions of the place there is no agreement on whether drama or opera were to dominate there. The moderate style of the hall suggests an academic function, although it might also be seen as a concert hall. The auditorium pointed in one direction adjoins the stage and is surrounded by a three-level gallery of boxes, which is quite unusual for that period. The creator deliberately did not separate the auditorium from the stage using a portal bridge because of the layout of the hall, which is a single space only expanded by shallow pockets. It is a single and stylistically homogeneous space. As he created the object, the creator reached far to imagine all kinds of cultural events there, not only those for which the venue was designed. History does not mention any significant theatrical performances there, but it was nevertheless a place where several opera performances by Baroque composer Luigi Gatti were staged. It is a unique theatre in which a thirteen-year old musician named

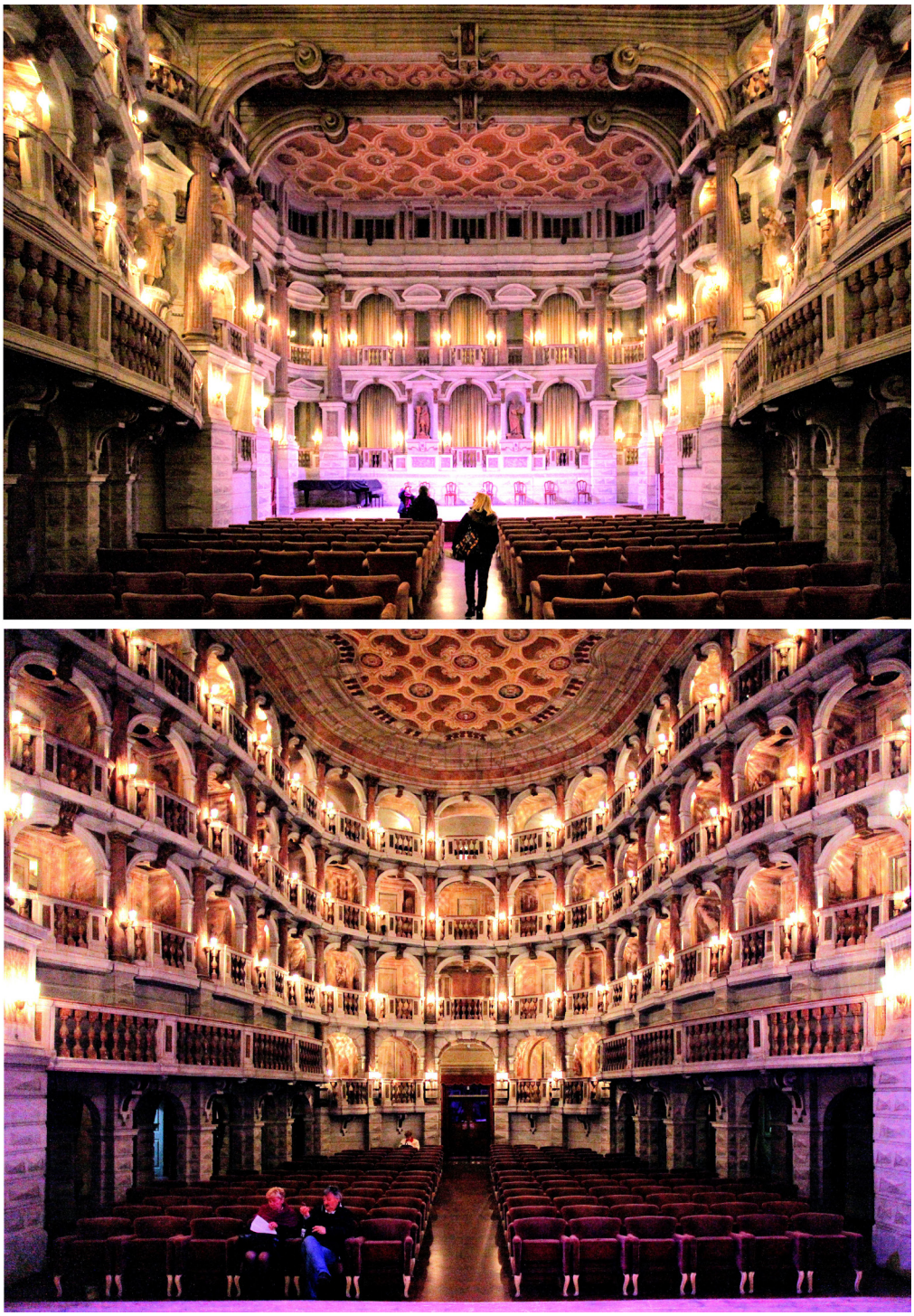

Fig. 5. Mantova, Teatro Scientifico. Baroque space as a multiple use form (photo by P. Obracaj)

Wolfgang Amadeus Mozart debuted. The versatility of the venue was also confirmed by the academic meetings that took place there [3, pp. 47–50].

Antonio, like his brother Giuseppe, was a skilled painter; details of the theatre's interior are covered with frescoes. This facility is considered to be one of the most significant achievements of the Bibiena family. As a part of the Virgilian Academy of Science and Art, the place has been associated mainly with its academic function for centuries. Despite the fact that chamber performances with covered stage background could have been performed there, no one really appreciated the theatrical function of the place. Adolphe Appia, before he met Dalcroze, had been looking for a stage that would combine "history and modernity". His concept was not yet completely defined, but at the time when he was still developing his creative ideas, Bibiena's place could inspire him. He made the best known performances in an austere rectangular hall in Hellerau, spatial analogies are visible though (Fig. 5).

Bibiena's work in Mantua seems not to be very much appreciated. The spatial layout suggests great flexibility, and the boxes surrounding the stage can be associated with the Elizabethan theatre. You can hang a curtain between two illusory portal frames. By covering galleries at the backstage, you can achieve the open stage. So for chamber performances, the creation area can be arranged as an arena, an open stage or a standard proscenium stage. And these are all fundamental relations between the stage and the audience. Bibiena accidentally designed a theatre with flexible space, and the best version of it, because he was able to realize the different options without the use of technology, only by simple variable relations between the stage and the auditorium. Such places were in demand among the leading artists of the Great Theatre Reform. Despite technological progress and inventions which supposedly allow for any form and any show to be performed on stage, theatres where alternative forms could be achieved thanks to architectural features, will continue to be in demand among those in search for a flexible theatre space [10].

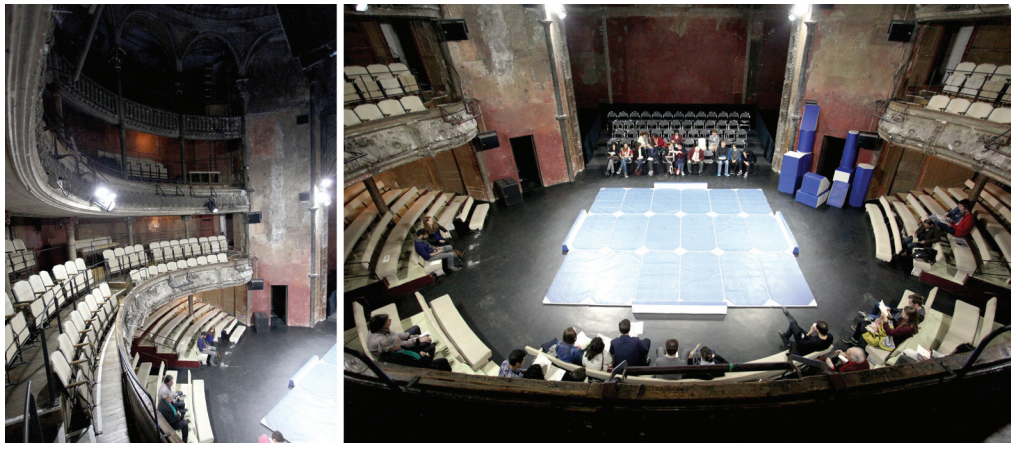

Fig. 6. Paris, Les Bouffes du Nord theatre. Multiple use space results from the idea of staging (photo by P. Obracaj)

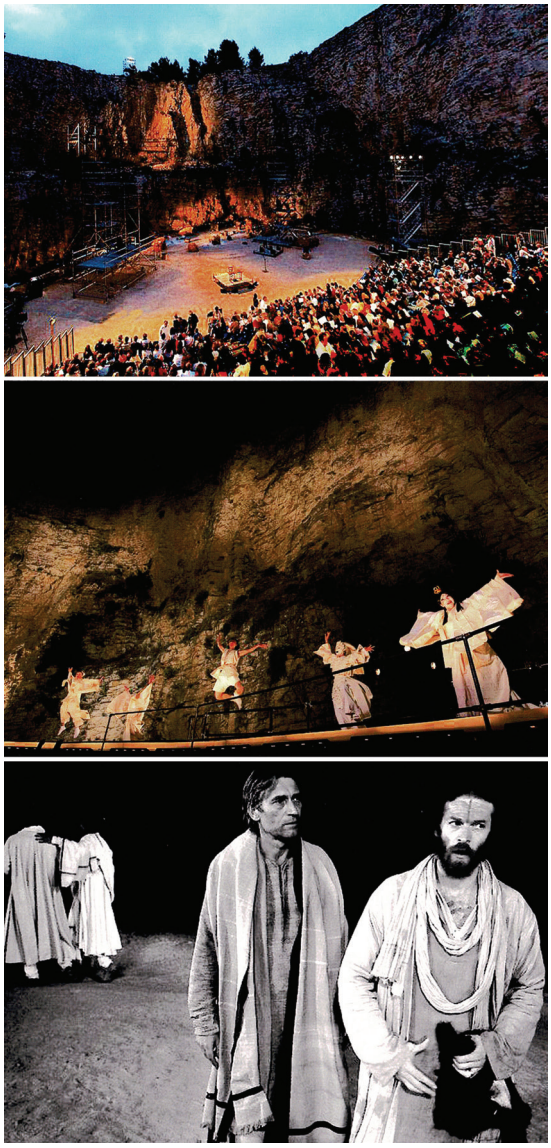

Fig. 7. Avignon, Carrière de Boulbon. The world of illusion is interwoven with the real, open form of the game area, meaningfully integrating the whole theatrical space (photo by P. Obracaj)

5. Conclusions: looking to the 21st century theatre

Such diversity is distinctive for a Parisian venue Les Bouffes du Nord theatre, which appeared as an alternative "theatrical place" for Peter Brook's staging of *Mahabharata*, considered a great synthesis of theatre art. A dynamic action, at times seemingly slowed down, merges with what is physically permanent and fits into the existing spatial conditions

whatever they would be. *Mahabharata* takes place in a space that should be described as open, without barriers and as such coherent with a drama. Thus, the staging does not impose any spatial dogma. With this principle of arrangement, it can take place anywhere. Seeing a performance, whether in a quarry at Avignon, in Athen's Petra, or in Les Bouffes du Nord theatre, one is open to multi vocal interpretations of a show, while intentions of the director are always clear. He explains what is "unexplainable" using artistic means. The role of theatre in the modern world could be summarized similarly [11, 12, 13, 14] (Fig. 6, 7).

It appears that theatre is distinguished by three basic aspirations. First of all – defining a new psychology, a new type of interpersonal relations true for people and societies of the 21st century. Secondly – defining a new type of interpersonal conflicts. Thirdly – finding new creative and artistic means. Considering the above, the integration of all arts in theatre will become even more expressive.

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Spatial development of Mielec in the medieval period compared to the then tendencies to form urban layouts in Lesser Poland

Rozwój przestrzenny Mielca w okresie średniowiecza na tle ówczesnych tendencji w kształtowaniu się układów urbanistycznych na terenie Małopolski

Abstract

This article addresses the issue of the medieval spatial development of the town of Mielec, located in today's Podkarpackie Voivodeship, and in the Middle Ages in the area of historic Lesser Poland. An important element of the presented research is a discussion of the issue of the typology of the urban models applied in the discussed period. One should pay attention to the fact that studying the origins of the founding and development of the town is important from the viewpoint of the current urban planning and conservation policy in this town. It also has an educational dimension and contributes to popularising knowledge about the town's history and cultural heritage.

Keywords: Mielec, spatial development of Mielec in the Middle Ages, urban model

Streszczenie

Niniejszy artykuł dotyczy problematyki rozwoju przestrzennego miasta Mielec w okresie średniowiecza. Ośrodek ten położony jest obecnie na terenie województwa podkarpackiego. W okresie średniowiecza należał zaś do Małopolski. Ważnym elementem prezentowanych badań jest także omówienie typologii modeli urbanistycznych, jakie stosowano w przedmiotowym okresie. Należy zwrócić uwagę na fakt, że podjęcie studiów z zakresu genezy powstania i rozwoju miasta jest istotne z punktu widzenia bieżącej polityki planistycznej i konserwatorskiej na terenie Mielca. Ma także wymiar edukacyjny oraz przyczynia się do popularyzacji wiedzy z zakresu historii tego zabytkowego ośrodka i jego dziedzictwa kulturowego.

Słowa kluczowe: Mielec, rozwój przestrzenny Mielca w średniowieczu, model urbanistyczny

1. Introduction

This article addresses the history of the spatial development of the town of Mielec in the medieval period against the background of the urban models that crystallised in other towns in Lesser Poland at that time. The subject will be outlined on the basis of research that has been conducted by the Authors for several years. This involved preliminary research in archives (e.g. in the Main Archive of Old Records, where one can find the Archive of the Crown Treasury I, Conscription Records, as well as inspection surveys of Sandomierz Voivodeship, and in the Diocesan Archive in Tarnow, which contains documents entitled *Mielec Documenta. Documenta Proventus Mansionaria Demonstrentia* from the years 1599, 1630, 1736 and 1899, respectively), field research, and an analysis of the literature available on the subject. So far, several scientific works have been written on the topic discussed in this article. These are the most important publications: F. Kiryk, *Towns of the Mielec Region Until the mid-17th Century. Mielec, Przecław, Radomyśl Wielki, Rzochów* [1] and the *Royal Permit for the Foundation of Mielec* [2]; a study by S. Brekiesza, *Foundation of Mielec in the Light of the Town Charter from 1470* [3]; M. Maciąg, *A Geographical–Historical Outline of the Mielec Region* [4]; M. Dobrowolska, *Settlement in the Sandomierz Forest Between the Vistula and the San* [5]; J. Malczewska, *Towns Along the Lower Wisłoka River in the Sandomierz Voivodeship with Medieval Origin until the mid-17th c.*, which was published in 2017 [6].

Administratively, modern-day Mielec is in Podkarpackie Voivodeship. It is located in a valley of the Wisłoka River – the Sandomierz Valley. Previously, this area was in historic Lesser Poland. Currently, the town has a population of around 61 thousand and is an important industrial centre of the voivodeship. It should be mentioned that the town has a very eventful history which has not been very thoroughly studied so far, particularly with regard to spatial development.

The authors hope that the presented studies concerning the origins of the town and its functional-spatial structure will contribute to broadening the knowledge about the origins of Mielec, popularising historical knowledge about the town, as well as supporting the issue of protecting the architectural and urban monuments in this culturally valuable centre.

2. Urban models of towns in medieval Lesser Poland

When writing about the spatial development of Mielec, including the urban model which was used to lay out the town, one should briefly describe the typological classification of urban layouts occurring in Lesser Poland during the discussed period. The classification was prepared by a team of research workers from the Chair of History of Architecture, Urban Design and Popular Art at the Faculty of Architecture, Cracow University of Technology, whose research focused on the origins and development of urban layouts. The described classification was created as a result of lengthy studies on the medieval history of urban layouts in Polish towns carried out by M. Ksiażek, M. Wójcikiewicz, K. Kuśnierz, and currently continued by R. Malik and D. Kuśnierz-Krupa.

When characterising the aforementioned classification, one should assume (to simplify matters) that during the high Middle Ages (in the 2nd half of the 13th, and in the 14th and 15th centuries) two basic groups of towns could be found in Poland.

The first group comprises towns that adapted previously existing elements to form a trade settlement [7] which, according to Mieczysław Książek, was a structure that could be found in Poland from the second half of the 11th century until the 13th century. Its growth was related to the disappearance of service settlements and the development of the manufacturing sector. Trade settlements were located along vital trade routes, at their junctions, or at the border of economic regions with diverse production profiles. They became a significant factor in the development of medieval towns and cities [7, p. 49]. Their structure can be discerned even today in the spatial planning of towns which evolved by adapting them, or grew in their direct vicinity [8].

The second group consists of new towns that were orthogonal structures with market squares. Their spatial planning was an effect of the developing economic, political, and social relations, and was shaped by the influence of the urban planning tendencies that were predominant in Europe at the time [7, p. 49]. In this group one should distinguish so-called simple layouts, i.e. relatively small towns with an uncomplicated functional-spatial structure, and so-called complex layouts that were larger urban centres whose structures will not be analysed here.

In the subgroup of simple layouts one can distinguish four types of layouts which could be encountered in the towns of medieval Lesser Poland. The most frequent layout in this area was the so-called 9-square layout and its variations. According to this model, a town is enclosed within 9 squares (most often square shaped). The central square was occupied by the main market, while the parish church usually stood on the diagonal block. In this model the main market square might have had the following proportions: 1:1, 1:1.5, 1:2, or similar. The second type in the subgroup of simple layouts is the so-called turbine layout, also known as the windmill layout. This is based on a diagram in which streets run in different directions, usually towards town gates, from each of the four corners of the main square. The market square in a layout of this type is a square or rectangle, and buildings surrounding the market square continue along the main streets leading out of the market square. The third type encountered in the subgroup of simple layouts is the pseudo-oval model, also known as the Silesian model. In this model, two parallel streets run across the market square along opposite frontages, only to converge into one route in front of the town gate. Such a solution was dictated by economic and practical reasons as it minimised the number of town gates within the defensive perimeter of the town. The town gate constituted the most expensive element of such a perimeter and was at the same time its weakest link. The fourth type is defined as an orthogonal model enclosed within an oval (or circle). This oval is outlined by defensive fortifications, the shape of which is adjusted to the lie of the land [7, 9, p. 26–28].

3. Spatial development of Mielec in the medieval period

The origins of Mielec go back to the medieval settlement campaign, which resulted in serious deforestation in the western part of the Sandomierz Forest, the consequence of which was a significant widening of the settlement strip along both banks of the Wisłoka River [9]. The first settled areas were those that were considered the easiest to explore because they had favourable soil conditions. They were mainly the valleys of the Wisłoka and the Vistula rivers and their immediate surroundings [10].

It is suspected that the origins of Mielec date back to the 13th century. It is worth noting that the name Mielec appeared for the first time in the records concerning the process of demarcating the village of Pełczyska near Wiślica in the year 1224 [11]. In turn, the privilege granting permission to found the town comes from March 17, 1457, and was issued by the Royal Office of King Kazimierz Jagiellończyk at the request of Jan Mielecki, a royal courtier. It contains a mention of a right to a royal market which, when granted, would allow the town to host weekly markets on Saturdays and two fairs a year. Such privileges were intended to accelerate the development of newly established towns. The privilege indicates the village of Mielec as the site where the new town would be laid out. The village was located in the Sandomierz region, in the then Pilzno district. However, the privilege does not contain detailed information about the location of the site selected for measuring out the town, or the size of the area [2, p. 11]. Because the privilege was rather general in its character, it was necessary to have a foundation charter urgently drawn up by the founder. Such a document was issued 13 years later, and it stated that the town would be founded on freshly cleared fields.

Traffic routes running through the town determined the shape of the urban layout of Mielec. Market squares, church yards, and the main streets of the described town were directly related to these routes. Such considerable dependence of the urban layout on these routes was related to the hope of the town becoming a middle-man in trade along the north-south route to Hungary, and between Krakow and Sandomierz.

As in other towns, in the case of Mielec ownership relations were probably taken into account when the town was founded. The town was encircled by villages belonging to one owner, which made it possible for locals to visit the town and return home within a day.

We are guessing that in the case of the town of Mielec, it was assumed from the very beginning that its agricultural function would be just as important as its trade and manufacturing functions. When locating the town, more attention was paid to economic than defensive factors. In Mielec we cannot see any relics of defensive fortifications, nor can we find any information on this subject in historical sources. It is most likely that only a policing-defensive perimeter existed there.

The documents concerning the foundation of the town of Mielec, which have been preserved until the present time, contain no information about the size of plots and other elements of the urban layout. The research confirming that medieval towns were laid out on a module that was usually a large cable whose length depended on the size of the foot serving as its basic unit – together with analyses of research by other authors and spatial analyses

of town plans [12] – allowed us to determine the set of units of measure that were applied when the town was laid out. These units were as follows: 1 large cable = 10 rods = 150 feet, or 1 small cable = 10 rods = 125 feet. Mielec was laid out using a foot that was 0.3 m long, which resulted in a cable being 45 m long [13].

The market square in Mielec was initially laid out on the plan of a regular rectangle; however, as has been mentioned, as a consequence of fires in the 16th and 17th century this plan was slightly disrupted. The market square in Mielec was originally located to the east of the village of the same name. Two main traffic routes crossed at the market square: to Sandomierz from Dębica, and the road from Hungary, Krakow and Pilzno. When it was first laid out, the market square in Mielec measured 2.2 x 2 cables, therefore the proportions of the building blocks must have been 5:6. As a result of later transformations, the original shape was obliterated, yet the eight streets running out of the corners of the market square remain clearly visible.

The buildings encircling the market square were grouped into four blocks: those to the north and south are shorter, while those to the west and east are longer. These blocks constitute market frontages, and the plots in them were measured out at right angles to their fronts.

In Mielec, whose urban layout resembled the pseudo-oval one, initially all the streets ran out from all the corners of the market square and were parallel to one another. The street network in the town formed (or most probably had been laid out as such during town planning) a rectangle and an oval. The oval was made by the junction of streets at the entrance to and exit from the town, running behind the market building blocks within the policing-defensive perimeter and the service lanes.

The road that led from the south-east to Mielec split in front of the church at the town border into two branching roads that enclosed the church yard and the building blocks behind the church yard (the market block and the block measured out between the market block and the church). This lens comprised the church yard and the church within it.

The highway, which was also a trade route, led across the market square and joined all the exit routes into one after it left the town behind the building blocks. The perimeter streets were created after the town had been measured out and laid out, and after the policing-defensive perimeter had been built. They are most clearly visible on 18th- and 19th-century military maps and cadastral plans from the mid-19th century. The main function of these streets was to allow access to defensive devices on the embankments as quickly as possible.

The network of main streets that served as thoroughfares and allowed transit traffic was complemented by a network of access roads; these serviced the backyards of the market blocks where utility machinery and workshops were situated, as well as the previously mentioned perimeter streets.

Until the mid-17th century, Mielec had a relatively modest street network, primarily because of the little-developed functions of the town. The town featured streets of various types. Settlement plots occupied by the most impressive residential buildings were oriented to the main streets, which were usually wider, and the buildings along them were more compact. Less important streets were perpendicular to the main ones, and adjoining buildings were on

a smaller scale and less significant; in general, they were utility buildings with gardens. Streets that evolved from former baulks also served a vital utility function. The type of a given street was determined by changes in street functions, replacing timber buildings with masonry ones, divisions or mergers of plots, or altered functions of buildings, e.g. from housing to production [14]. Main streets were usually 2 or 3 rods wide (8.6–13 m). Second category streets were more diverse as their width was closely related to that of the main streets: they measured 1–2 rods. Streets in the lowest category were 0.5–0.75 rods wide (2–3 m).

The plan of a chartered town that was laid out at the initial stage of its founding was very important and had a huge though not decisive impact on its shape. Both the shape and the programme of these towns were defined over time, often at the first stage of their creation. The main factors that considerably influenced these features were fires, floods, and invasions by enemy armies. Undoubtedly, economic prosperity in the initial stage of a town's existence also had a significant impact on its shape as it could lead to modifications in the town plan if the implemented economic features did not fulfil their role satisfactorily and had to be modernised or expanded. The period when Mielec was established was a time of peace on the eastern border: the port in Gdańsk had opened to trade in Polish agricultural produce with Europe (after the 13-year war), and the military danger from the south of the kingdom was relatively insignificant.

It is worth noting that the traffic routes running through the town determined the shape of the town plan because the market square, church yard and main streets had been planned in such a way that they were directly linked to these trade routes. This considerable dependence of the urban layout on the trade route was related to the hope of developing its basic function, i.e. participating in and becoming a go-between in the trade along the north-south route to Hungary, and between Krakow and Sandomierz.

From the very beginning, the plan of Mielec was realised in a very simple way, yet for residents it was very clear as far as their existential needs were concerned because components such as the market square, market building blocks, and streets had been laid out first. In Mielec the church–graveyard infrastructure had already existed in the previously functioning church yard, long before the town was founded,. At the stage of measuring out the chartered plan, the church yard was adopted to the newly created urban layout.

The town of Mielec is an example not only of a defined orthogonal layout, but also of a mutation of the pseudo-oval model with single building blocks surrounding the market square which facilitated control of trade since commercial structures such as abattoirs, stalls, or houses adapted to commercial purposes were located on the side of the market square. The majority of plots had the shape of extremely elongated rectangles with buildings situated at the front. The town plots were relatively poorly developed and in most of them three basic functional zones can be distinguished: residential, garden and utility. This arrangement was typical of the majority of small towns where the role of farming was essential [6, 15].

4. Conclusion

In conclusion, it should be stated that the conducted research of the urban development of Mielec during the medieval period – in correlation with studies on the urban models applied then for founding towns – yielded concrete findings concerning both the history of the urban design of the discussed centre, and the process of protecting and popularising the cultural landscape.

It should also be emphasised that the history of the town – as far as its original urban structure is concerned – is not yet fully known and could be the subject of further urban research.

The importance of similar research is confirmed by the relatively poor condition of medieval towns, especially small ones, the predominant reason for which is insufficient knowledge about their past. Thus, it is necessary to conduct further research in this respect, the results of which should support the activities of conservation services and raise social awareness concerning the history of such towns as well as their architectural and urban design monuments.

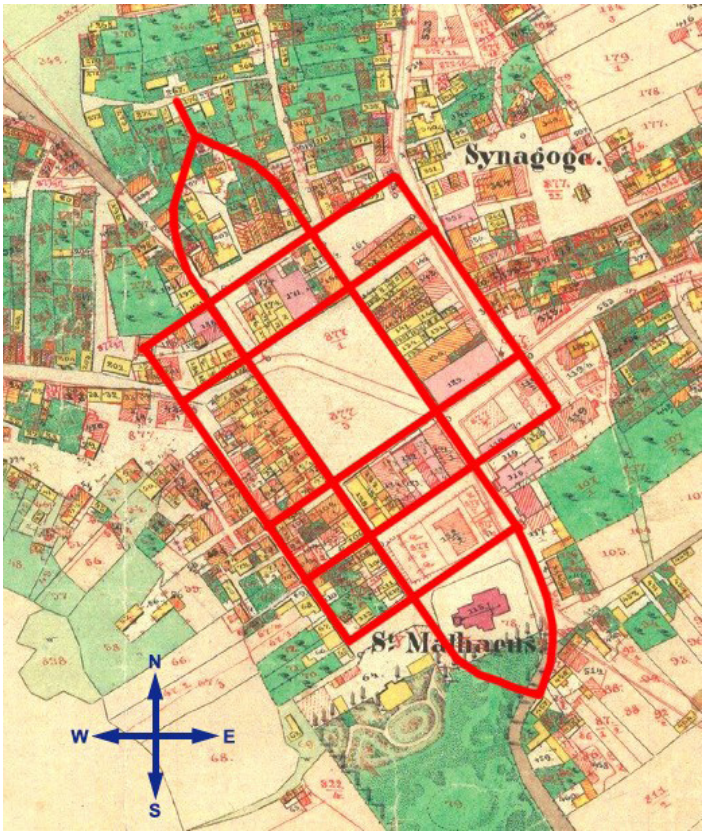

Fig. 1. Urban model of Mielec imposed on the cadastral plan from 1850 (AP in Przemyśl, Geodetic Archive, sygn. 1054M); prep. by Author

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Selected city gates in Silesia – research issues[1]

Wybrane zespoły bramne na Śląsku – problematyka badawcza

Abstract[1]

The conservation work performed on the city gates of some Silesian cities in recent years has offered the opportunity to undertake architectural research. The researchers' interest was particularly aroused by towers which form the framing of entrances to old-town areas and which are also a reflection of the ambitious aspirations and changing tastes of townspeople and a result of the evolution of architectural forms. Some of the gate buildings were demolished in the 19th century as a result of city development. This article presents the results of research into selected city gates: Grobnicka Gate in Głubczyce, Górna Gate in Głuchołazy, Lewińska Gate in Grodków, Krakowska and Wrocławska Gates in Namysłów, and Dolna Gate in Prudnik. The obtained research material supported an attempt to verify the propositions published in literature concerning the evolution of military buildings in Silesia between the 14th century and the beginning of the 17th century. Relicts of objects that have not survived were identified in two cases.

Keywords: Silesia, architecture, city walls, Gothic, the Renaissance

Streszczenie

Prace konserwatorskie prowadzone na bramach w niektórych miastach Śląska w ostatnich latach były okazją do przeprowadzenia badań architektonicznych. Zainteresowanie badaczy budziły zwłaszcza wieże, które tworzyły wejścia na obszary staromiejskie, a także były obrazem ambitnych aspiracji i zmieniających się gustów mieszczan oraz rezultatem ewolucji form architektonicznych. Niektóre budynki bramne zostały rozebrane w XIX wieku. W artykule przedstawiono wyniki badań wybranych bram miejskich: Brama Grobnicka, Głubczyce, Brama Górna, Głuchołazy, Brama Lewińska, Grodków, Brama Krakowska i Wrocławska, Namysłów i Brama Dolna, Prudnik. Uzyskane materiały naukowe stanowiły materiał wyjściowy dla próby zweryfikowania propozycji opublikowanych w literaturze, o ewolucji architektury militarnej na Śląsku między XIV a początkiem XVII wieku. Ponadto przebadano relikty dotychczas nieznanych dwóch bram miejskich.

Słowa kluczowe: Śląsk, architektura, mury miejskie, gotyk, renesans

[1] The article presents the results of research into Grobnicka (Monastic) Gate in Głubczyce, Górna Gate in Głuchołazy, Lewińska Gate in Grodków, Krośnieńska and Głogowska Gates in Kożuchów, Krakowska and Wrocławska Gates in Namysłów and Dolna (Karniowska) Gate in Prudnik.

1. Introduction

The foundation of cities in Silesia started in the first half of the 13th century with the effort undertaken by Duke Henry the Bearded and the many continuators who followed after his death in 1238. The process was supported by Czech kings, local Silesian princes, and also bishops and other powerful individuals. City charters and the foundation of cities put the issues of local administration and judiciary in order, and also created a settlement network with commercial, economic as well as military importance.

Therefore, it is not surprising that this process was especially intensive in the insecure borderland between Silesia and Czechia, where probably before 1249 a city charter was granted to Głuchołazy [63, No. 380], and before 1253 also to Głubczyce [53, pp. 32–3]. A similar situation occurred on Silesia's western frontiers, where Kożuchów was founded before 1253 [29, pp. 18–21]. Mroczko of Pogorzele probably accounted for the foundation of Grodków before 1250 [20, pp. 89–93], whereas Henry of Rozmberk accounted for the foundation of Prudnik in about 1279 [64, pp. 73]. Before 1278, a city charter was granted by Duke Henry IV Probus (the Righteous) to Namysłów [35, p. 23].

The establishing of a city center was marked by the erection of buildings that were necessary for a city's operation: a town hall (the seat of municipal authorities), a parish church, and a circuit of walls with gates. These structures, together with houses and bourgeois buildings, created the characteristic panoramas of Silesia's cities. This landscape remained mostly unchanged almost until the end of the 18th century, after which the military function of city walls was gradually reduced due to the evolution of military engineering initiated by the introduction of firearms. With the rapid economic and urban development of these cities in the 1st half of the 19th century came the gradual removal of elements that conflicted with and restricted transport – *inter alia* city gates and certain stretches of walls.

The value of Silesia's medieval military architecture was noticed at the end of the 19th century, when the towers of Grodków [22, pp. 21–22], Głuchołazy [24, pp. 21–22] and Prudnik [25, p. 58] were subjected to repair works for the first time. Unfortunately, the works not only caused the original forms and details to be covered up, but they also distorted historic shapes with the introduction of new elements. Observations made while the works were being carried out served German researchers as the basis for initial propositions about the construction and evolution of gate objects in Silesia[2]. However, these theses could not be confirmed and therefore the towers and walls have since been presented in the literature as they were perceived at the end of the 19th century or at the beginning of the 20th century. Also, restoration works were based on the results of the same research [34, 36, 37, 39, 42, 43, 44]. The scope of the works included not only analysis of the gates themselves or retained relicts thereof, but also preliminary iconographic and source research. The results of the research constituted the initial material for conservator's conclusions that formed the basis for restoration designs or for the exposure of these objects.

[2] See: the state of research presented in the description of each of the gates.

In spite of their common origin, the gates presented herein differ in time of construction, phases of transformations, present condition and historic sources. This article presents gate objects situated in several of Silesia's cities. It seems advisable to discuss each of the objects in detail, together with studies and the results of architectural research and reconstruction studies, if any.

2. Głubczyce – Grobnicka (Monastic) Gate

The circuit of medieval city walls in Głubczyce, first mentioned in 1282, consisted of a stone curtain with nineteen towers and three gates [6, p. 34, 110; 5, p. 128; 55, pp. 36–37; 67, pp. 10–11]: Górna (Nyska) Gate from the north, Dolna (Opawska) Gate from the south and Grobnicka (Monastic) Gate from the east. Probably in the 14th and 15th centuries, the three gateways were strengthened with foregates and Górna and Grobnicka Gates were made higher and covered with high tent roofs, as can be seen in a city panorama by Fryderyk B. Werner that dates back to about 1738. The development of siege techniques which used firearms involved the modernization of the towers at the beginning of the 17th century. Probably at this time the octagonal part was built on top of Opawska Gate and crowned with an attic comb, whereas a storey with pilasters was added on top of the semi-circular towers in the southern segment and covered with masonry cupolas. The demolition of the walls started with a royal order dated 1764 [54, p. 240]. The levelling of the curtain started at the end of the

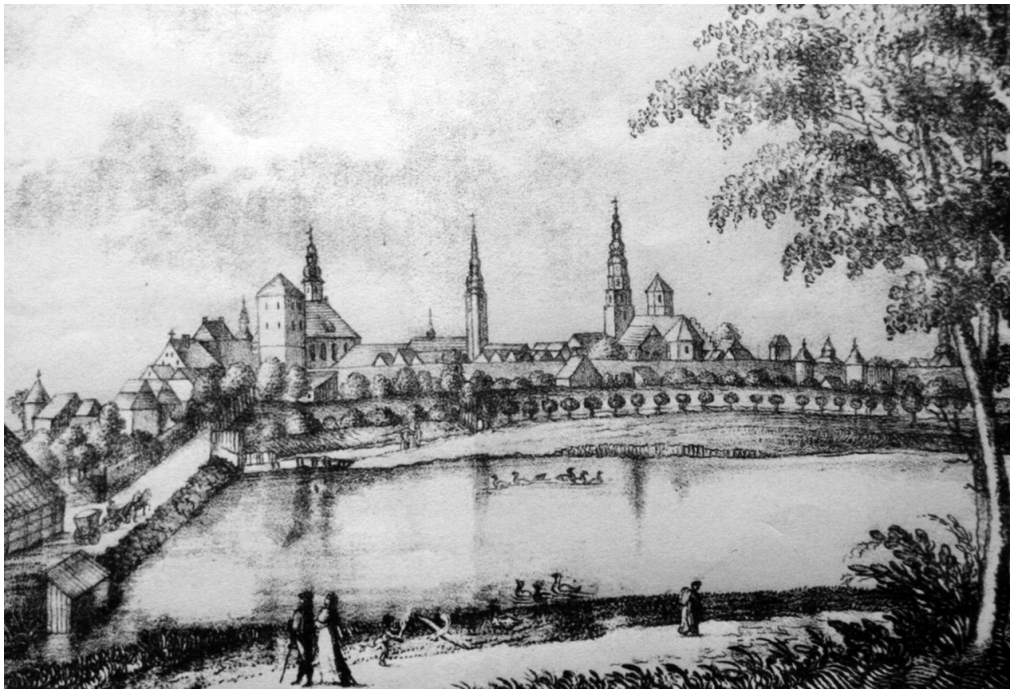

Fig. 1. Głubczyce, panorama of the city from the east from the beginning of the 19th century – Grobnicka Gate, first on the left (a drawing from the collection of the Poviat Museum in Głubczyce)

18th century, whereas Górna (Nyska) Gate was demolished in 1830 [18, p. 77; 52, p. 240]; six years later Dolna (Opawska) Gate was demolished [18, p. 77; 54, p. 241], as was Grobnicka Gate in 1853 [18, p. 77; 54, p. 241].

The oldest source entries that mention the city walls date back to 1282 [6, p. 34, 110; 5, p. 128; 55, pp. 36–37; 67, pp. 10–11;] and 15 April 1298 [67, p. 12; 59, pp. 193–203; 55, pp. 124–5]. The city gates were mentioned several times as reference points in the deeds of sale of nearby properties. Dolna (Opawska) Gate was mentioned in 1383 in a sale of land deed by Duke Mikołaj [55, p. 235] and in 1388 in the deed of sale of the city mill [67, p. 24]. The deed of purchase of a castle situated near Górna Gate [55, p. 175] is dated 10 January 1565.

The subject of the Głubczyce fortifications has been raised in the literature a number of times: German and Polish authors did not describe the walls with enough precision; they cited the oldest source documents, and according to them the wall's construction dated back to the 13th century, while the extension dated back to the turn of the 14th and 15th centuries [55, pp. 124–125; 6, p. 132; 67, p. 24; 50, pp. 173–174; 5, pp. 128; 31, p. 60; 12, p. 1–9; 21, p. 28–29; 14; 58, p. 24; 61, p. 178; 59, pp. 193–203; 52, pp. 159–167; 53; 58, p. 61]. A city gate review quoting the gate names was first published by Robert Hofrichter, who superficially described

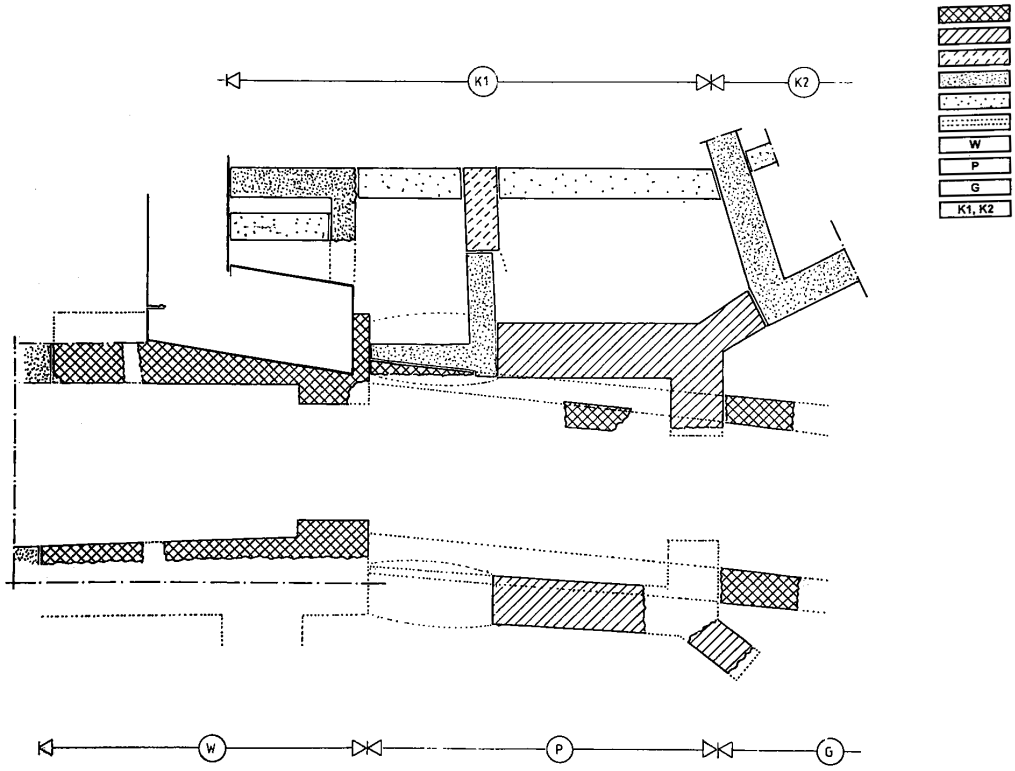

Fig. 2. Głubczyce, Grobnicka (Monastic) Gate, projection of fundaments with chronological wall stratification. A – 1st half of the 14th century; B – 2nd half of the 14th/1st half of the 15th century; C – Renaissance; D – Baroque; E – 19th and 20th century; W – tower; P– foregate, G – dam; K1, K2 – tenement houses (drawn by A. Legendziewicz)

the gate architecture and furnishings [18, p. 72]. An analysis of the architectural form of the city walls was presented by Barbara Piechaczek [56, p. 19] based on the street map produced by A. Plasqude in 1770 and on a panorama produced by F.B. Werner in the middle of the 18th century. Propositions about the formation of all the gats and walls were included by the same author in her doctoral thesis [57, pp. 33–65]. These propositions about the development of Grobnicka Gate could be reviewed based on research undertaken in 2012 [43].

The original gate tower was probably erected at the turn of the 13th and 14th centuries on almost 2-metre-wide foundations laid on an 8.5/8.9-metre rectangle-like plan. The continuous footing was laid in layers in narrow-spaced trenches with the application of dark slate stone, in shades ranging from graphite to grey. To the east, the approx. 3.2-metre-wide gateway clearance along the east–west axis was narrowed with gate frames that were probably semi-circular in shape. However, from the city side, the tower interior was open without any narrowing. The archive gate view produced by F.B. Endler in about 1800 showed that the tower had an offset at a height of about 10 meters above ground level, which may indicate the hoarding level. The eastern façade surface was broken by a high lancet recess filled with a portcullis. Unfortunately, no relicts of runners were found within the uncovered foundation walls.

To the east, the gate tower was preceded by a probable masonry causeway that was about 5.7 meters in width and tilted slightly to the south from the gateway axis. The wall segments, which were built with a technique similar to that in the tower, formed the grounds for the restoration of the causeway length, which seems to be over 12 meters.

The entrance to the city was strengthened – probably at the turn of the 14th and 15th century – by the construction of a foregate that was built on an 8/10-metre rectangle-like plan. The walls were built on foundations that were made of slate sandstone, irregularly laid on a rather hard, cream-colored lime and sand mortar. The continuous foundations of both the approx. 1.5-meter-wide side walls were laid in a narrow-spaced trench and were shifted away from the tower by about 3.5 meters. Over that space there were probably arch stretches resting on the tower and foregate foundations. The neck corners were strengthened in the east with obliquely positioned buttresses. The relicts that survived have confirmed that the width of the gateway clearance could have been about 3 meters. It should be noted that the gateway was situated along the causeway axis, and that the causeway walls were precisely cut to construct the east walls of the foregate.

3. Głuchołazy – Górna Gate

The ellipse-like circuit of walls in Głuchołaz included two gates: Górna Gate and a tower in the south, and Dolna (Nyska) Gate in the north. Due to the evolution of military techniques, the walls were modernized at the beginning of the 17th century and kept ready for use almost until the end of the following century [24, pp. 21–22]. The wall levelling started in 1834 after a city fire, and four years later Dolna Gate and the tower were demolished [31, p. 86]. In 1860, the gateway body of Górna Gate was demolished and only the tower remained [31, p. 86]. Except for the tower, only two small segments of the medieval fortification walls survived:

one in the north-western corner of the chartered city (located under a foundation charter), and the other on the east side, near the building of the former office of governor.

Due to the very few remnants that survived and the very modest source material, the earlier researchers' interest in Głuchołazy fortifications was low. Hans Lutsch was the first to describe the tower; he stated that it was erected during the Renaissance in about 1600 under the influence of Italian architecture, as was the case with the church towers in Boguchwałów and Witoszów, the parapets in the castle of Bolków, the church in Paczków, the tower of Wrocławska Gate in Nysa and Ziębicka Gate in Grodków [51, p. 187, table 188/6; 50, p. 145]. On the basis of this information, Paul Kutzer indicated governor Adelsbach as the founder of the building in his monograph on Głuchołazy [31, p. 86]. The description of the stone tower crowned with an attic comb, with palmettes and blind windows beneath, was supplemented with a print made by Arthur Blaschnik in about 1860 [31, p. 87]. Polish researchers unanimously commented on the development of the tower's architecture. T. Chrzanowski and M. Koniecki indicated the second half of the 14th century as the time when the tower was built [24, pp. 21–22]. Based on the dates shown on the former town hall's spire element on the cupola, they stated that in 1631 the tower was converted to the Renaissance style and in 1795 it was repaired in the Baroque style [24, pp. 21–22][3]. This concept was uncritically repeated by Józef Pilch [58, p. 63]. The conservation works performed in 2008 enabled the researchers to carry out architectural research on the tower and make an attempt to verify the propositions about the tower's transformations that had been published in the literature [39; 40, pp. 11–113; 41, pp. 84–89].

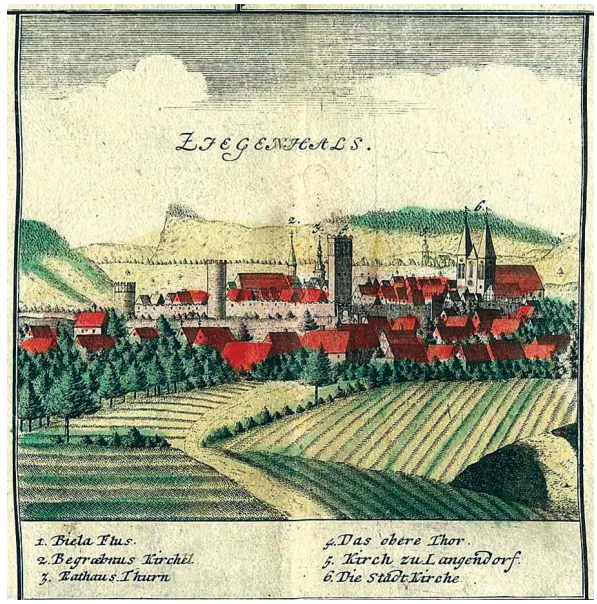

Fig. 3. Głuchołazy, panorama of the town from the south, around 1738 by F.B. Werner – Górna Gate's tower No. 4 (drawing from the collections of the University Library in Wrocław)

[3] The tower finial ensign shows the years 1631 and 1795; it comes from the tower of the Głuchołazy town hall and was put onto the tower in question during the 1899–1902 repair works [31, p. 97].

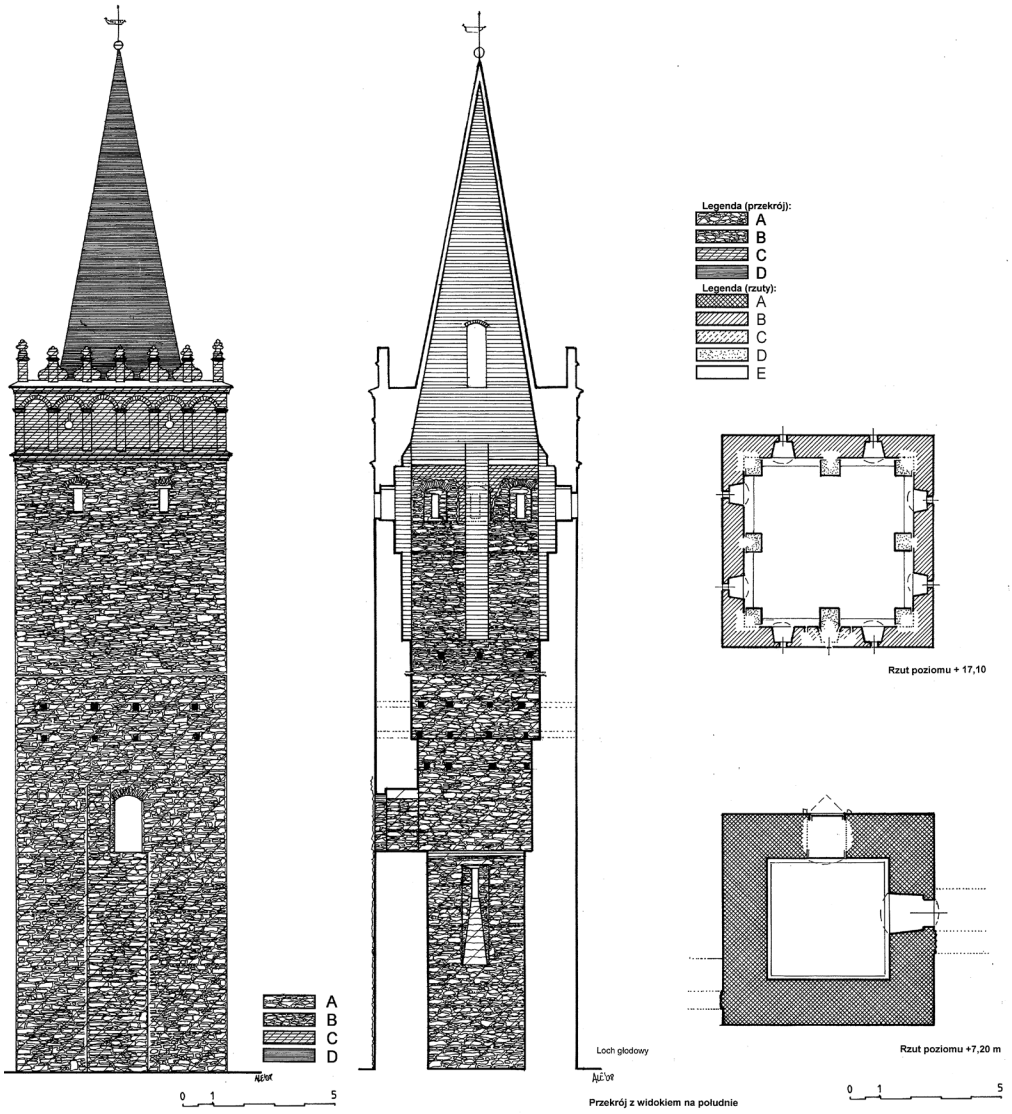

Fig. 4. Głuchołazy, Górna Gate's tower, east elevation, cross-section with a view to the south and projections with chronological wall stratification. Elevation and section. A – 1st half of the 14th century, B – 2nd half of the 15th century; C – around 1600; D – between 1898–1902; projections Signs: A – 1st half of the 14th century; B – 2nd half of the 15th century 'C – around 1600; D – between 1898–1902, E – unrecognized walls (drawn by A. Legendziewicz)

The tower at the outlet of Basztowy square was built on a 7.4/7.2-meter square-like plan. Its approx. 23-metre-high facades are made in stone without plaster, crowned with a two-storey parapet which consists of six semi-circular alcoves separated with pilasters in its lower part. The pilasters are the resting points for a protruding cornice, which forms the base of an attic consisting of seven pillars with palmettes, of which the five middle ones

encompass five pairs of volutes. A brick pyramid cupola, almost 11 meters in height, rises from behind them.

The lower sections of the tower base – up to 13 meters in height and constructed from slate stone – date back probably to the first half of the 14th century. They include another tower, almost the entire height of which survives, with relicts of a wooden finial structure inside, two entrances and a narrow window. The tower was built together with a gateway on its east side. The part made of crushed stone laid in layers on a 7.4/7.2 meter square-like plan was about 13 meters high – probably one storey higher than the curtain. The tower façade was plastered – probably due to the material that had been used for construction and the building technique applied. The finial was probably formed as a hoarding running around the wall crown on the east, south, and west. It was installed on wooden brackets mounted in the wall at a height of about 12 meters above the present ground level. The whole structure was probably covered with a short-ridged tent or hip roof. A rectangular entrance opening with a triangular head led to the inside from the city side. It was located in the northern façade at a height of about 7.2 meters above ground. A wooden platform supported by stone brackets near the opening probably linked that opening to a fortified porch on the curtain near the south-western corner of the tower. The other opening was located on the eastern façade and led to the top of the wall above the gateway.

Fig. 5. Głuchołazy, Górna Gate's Tower – view from the south (photo by A. Legendziewicz)

The interior was divided into three storeys, probably with beamed ceilings on wall offsets and pockets. On the lowest floor there was a dungeon, which was accessible through a ceiling hole and lit in the south via a narrow window with a step-like downstream apron and an overlapping stone-tile window head. The storey above the dungeon was accessible through the entrances mentioned above. The two storeys above this were accessible by ladder.

The city of Głuchołazy was captured by the Hussites on 20 March 1428 [32, pp. 45–46]. It is likely that the church, buildings and also Górna Gate tower were damaged during the siege. The slow process of the reconstruction of the city and the walls led Wrocław Bishop Jodok to exempt the inhabitants from paying rent in 1463 [1, Deeds of the city of Głuchołazy, File No. 112]. Therefore it is probable that the reconstruction of the tower was completed in the second half of the 15th century. The walls from that period were built in the upper part of the tower body to a height of about 20 meters above the present ground, or even higher due to later conversions. Narrow firing ports were located at a height of 18.3 m – three in the south, and two in each of the other facades. The division of the interior into storeys is marked by offsets at heights of about 14.20 m and 17.00 m.

The conversion of the tower involved a change in the shape of the tower. It is likely that the damaged copula and hoarding were demolished and the tower itself was made higher. The shape of the new finial remains unknown. The plastered facades were made aesthetically pleasing and were interrupted only by narrow rectangular firing ports. Relief arches made of arch stones were installed over each of the ports and the façade was plastered. The two entrance openings that had led to the tower survived and the internal layout was not subjected to significant modifications. The dungeon remained on the lowest floor. At least two new ceilings were built that rested on offsets and were accessible by ladder.

The Gothic tower was subjected to conversion in the Renaissance style probably at the end of the 16th century and the beginning of the 17th century. An attic and a new architectural décor were introduced on the façades; the color scheme consisted of grey and black on details with red palmettes and Roman white plastering. The works in Głuchołazy could have been funded by governor Henrich Adelsbach, who also introduced a new style to his office building at the beginning of the 17th century [41, pp. 76–96].

4. Grodków – Lewińska Gate

The Gothic circuit of walls in Grodków was marked out on a very regular, almost circular plan and included four gates: Wrocławska (Brzeska) Gate in the north, Nyska Gate in the south, Ziębicka (Strzelińska) Gate in the west and Lewińska Gate in the east. The walls and towers erected in the second half of the 14th century were probably damaged by the Hussites in 1428 [1, Deeds of the city of Grodków, File No. 1273]. The circuit was subjected to modernization probably in the 15th century, and the two towers of Lewińska and Ziębicka Gates were modernized before the end of the 16th century [22, pp. 21, 22]. In 1825 in Grodków, as in other cities, the circuit was partly levelled, the moat was backfilled, and

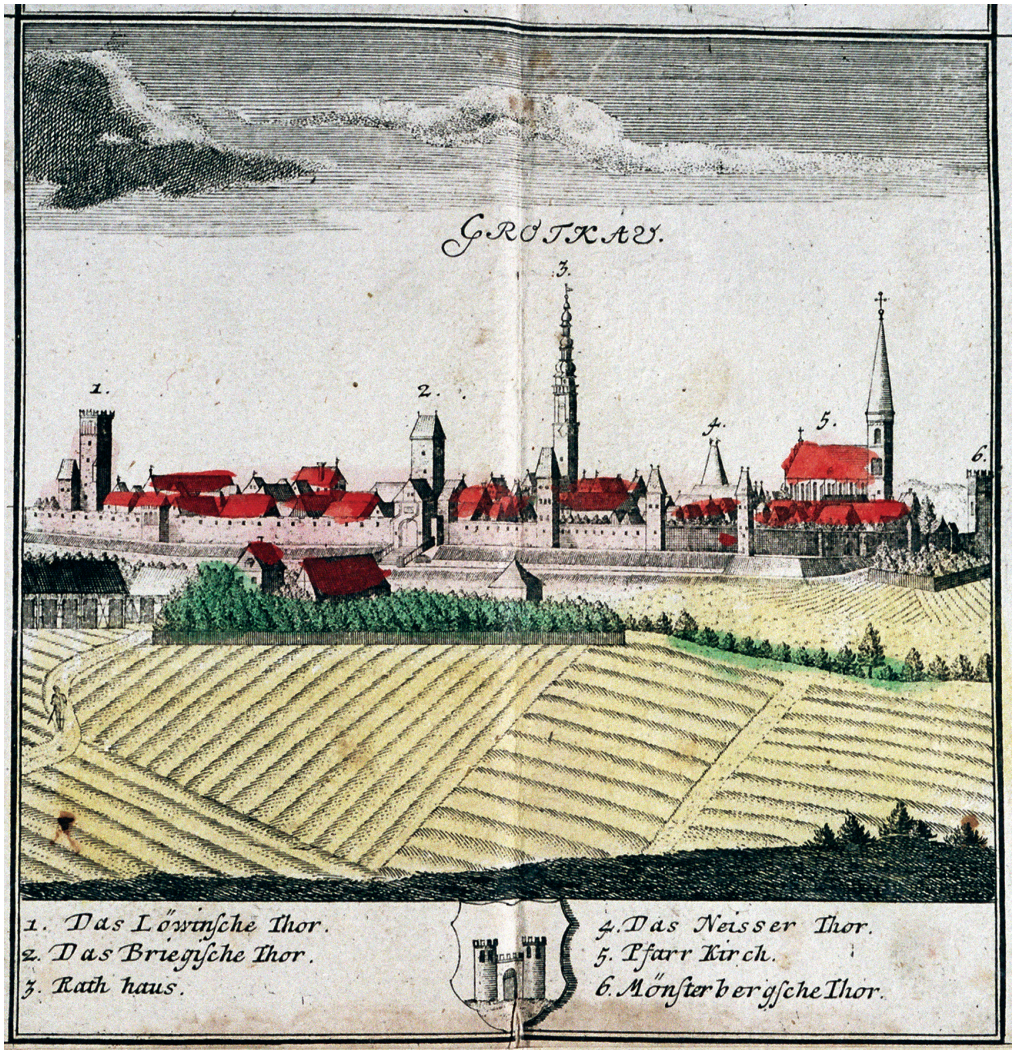

Fig. 6. Grodków, panorama of the town from the north around 1738 by F.B. Werner – Lewińska Gate No. 1 (drawing from the collections of the University Library in Wrocław)

Wrocławska and Nyska gates and stretches of the walls in the north-west and south-east were demolished [33, 22, p. 21].

The oldest mention of the walls of Grodków concerns Wrocławska (Brzeska) Gates and dates back to 1282 [8, File No. 1578]. The walls are also mentioned in a document from 1411 in which Wrocław Bishop Wacław expressed his consent to the construction of a mill within the walls [1, Deeds of the city of Grodków, File No. 1255]. The other city gate, Ziębicka, is mentioned in the deed from 1463 in which a garden in front of the gate is mentioned [1, Deeds of the city of Grodków, File No. 1280]. The City Chronicles of 1867, in which historic notes on the construction of walls around the city by the Duke of Jawor, Bolko I the Strict

[10, p. 21] are mentioned, should be given consideration. A description of the walls and information on the porch traces were published by H. Lutsch [50, pp. 50, 51]. On the basis of the City Chronicles entries, Marian Kutzner [33], T. Chrzanowski and M. Koniecki [22, pp. 21, 22] stated that Duke Bolko I the Strict funded the medieval walls in the years 1296–1301. The modernization of the city fortifications in about 1350 consisted of making the curtains higher and the erection of the towers and Wrocławska (Brzeska), Nyska, Ziębicka and Lewińska gates, presumably by the Przecław of Pogorzele, the Bishop of Wroclaw. These researchers dated the conversion of the tower finials for Ziębicka and Lewińska Gates and the construction of the parapet to about 1600. In their opinion, the medieval fortifications were probably repaired after the Thirty Years' War in the years 1664–71 on the initiative of Bishop Sebastian von Rostock, whereas the backfilling of the moats and the demolition of the walls and two city gates started in about 1825 [33, pp. 8, 15. 26–27; 22, pp. 21, 22]. Coincident opinions on the construction of the Renaissance finials were published by Mieczysław Zlat

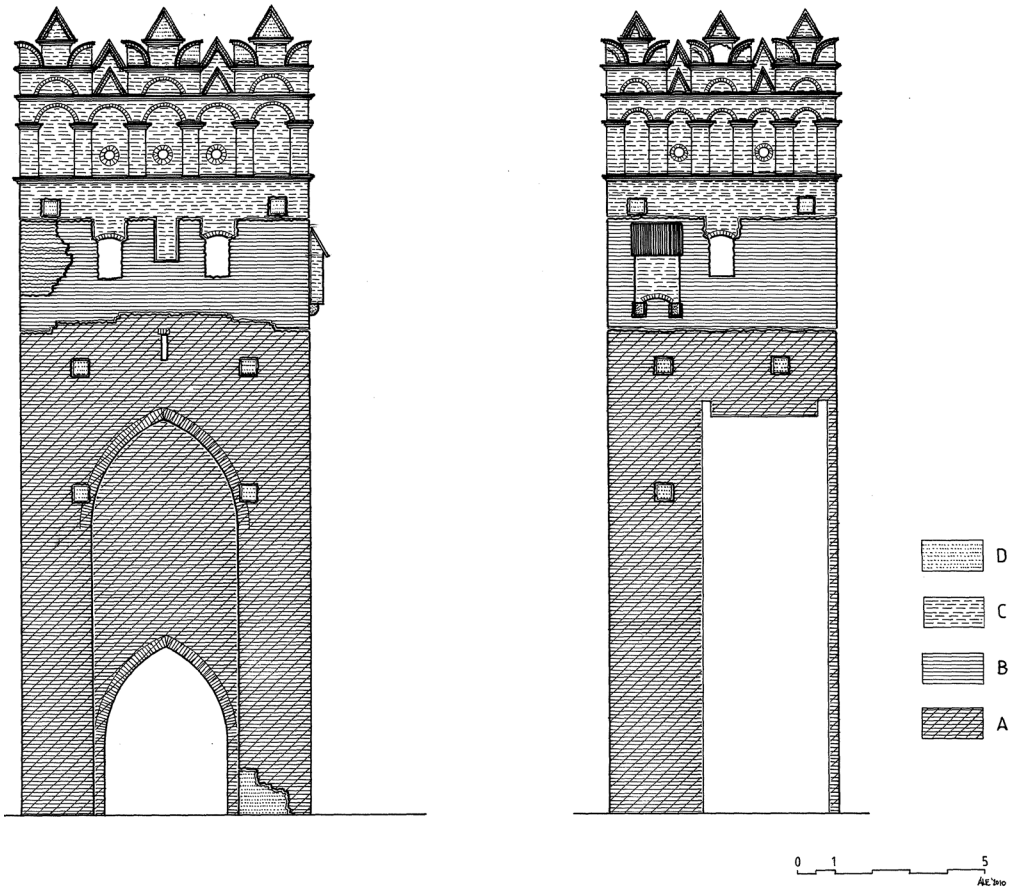

Fig. 7. Grodków, Lewińska Gate, eastern and northern elevations with chronological wall stratification.
A – 2nd half of the 14th century; B – 1st half of the 15th century; C – around 1600; D – 19th and 20th centuries
(drawn by A. Legendziewicz)

Fig. 8. Grodków, Lewińska Gate – view from the east (photo by A.Legendziewicz)

[69, p. 59], B. Piechaczek [57, pp. 66–81] and J. Pilch [58, p. 70]. The process of erecting the medieval walls in Grodków is viewed slightly differently by Czesław Lasota and Andrzej Legendziewicz – the authors of research carried out in 2005 [34, pp.4–8]. They stated that the note about the construction of the circuit in the years 1296–1301 probably concerned the wooden and earthen walls, whereas the present walls were constructed in stages in the second half of the 14th century. As far as the modern conversions of the gate towers are concerned, their view is consistent with the current one. These propositions were confirmed by the research carried out when Lewińska Gate was being repaired [40, pp. 108–109].

The Lewińska Gate tower is located in the east part of the circuit, at the end of Józef Elsner street. It was erected on a rectangle-like plan, with an outer outline of about 6.1/7.8 meters. In the basement, there is a 3.5-metre-wide gateway with lancet arch openings. On the eastern façade, there is a high lancet arch recess for a stylized portcullis, and on the northern façade there is a latrine bay. The tower, which is about 22 meters in height, is crowned with a parapet consisting of a strip of five arcades with three plinths on them, each with two quarter circles and a pillar with a triangular cap. Behind the comb, there is a V-roof from which the rainwater is drained via two gargoyles.

The original gate tower was built in the second half of the 14th century and has survived up to a height of about 13 meters. It was erected on a roughly 6.1/7.8-metre quadrilateral-like plan. In the basement there is gateway along the east–west axis, with lancet arch openings and a 1.5-brick-thick arch on the longer side. Above the entrance from the moat side, there is a lancet-arch recess with a portcullis and the gateway opening was closed with double gates. The inner storeys are marked out by offsets which support wooden floor beams. The first floor was accessible in the south via the entrance directly from the curtain footway. The other two floors were accessible by ladder, whereas the highest of the preserved floors was lit through two slot windows in the longer walls over the gateway openings. The finial form is unknown. The brick façade decors consisted of a two-color single-stretcher bond, with regularly arranged overburnt bricks and carefully made horizontal flat joints that are undercut at the bottom, and vertical flat joints with a groove [9, pp. 5, 6]. The brick base consisted of an 80–100 cm plinth made of erratic boulders. The façade was painted as soon as the walls were erected – numerous traces of red and white paint were found on the brick face and the joints, respectively.

The tower was probably repaired in about 1414, as was confirmed by a plate (known in the 19th century) with a date and the name *Johannes* on it [22, p. 22]. This was probably the time when the damaged upper part was demolished to a height of 13 meters above the present ground and the circuit walls were made higher by the addition of at least one storey. The interior was lit through two windows of an unknown shape which were situated along the longer walls' axes. The form of the new finial also remains unknown. The facades were most likely plastered, as is confirmed by the flat joint of the single-stretcher bonding.

Transformations in the gate tower's architecture came with the Renaissance; the tower and Ziębicka Gate tower were probably modernized at the turn of the 16th and 17th centuries. The Late Gothic finial of Lewińska Gate was demolished to the level of the upper window arches. The circuit of walls was made higher to over 22 meters and crowned with a two-storey attic. The façade was covered with smoothed plaster with a slightly uneven texture and a detail was introduced: bossage in the corners, around the portcullis recess, and on the window trims. A latrine bay supported by stone brackets was added in the north. The architectural décor was in two colors: the detail was grey and black, and the smoothed plaster was the color of natural lime.

5. Kożuchów – Krośnieńska and Głogowska Gates

The medieval fortifications of Kożuchów consisted of an almost complete double ring which encircled the chartered city. The inner ring was about 1300 meters in length, had ten towers, and was probably built in the first half of the 14th century; the outer ring was about 1000 meters in length, had at least eight fortified towers, and was probably built in the third quarter of the 15th century [45, pp. 63–73]. The northern fragment of the fortifications was strengthened by the inclusion of a castle [47, pp. 23–37]. The entrances to the city were secured with three gates: Żagańska in the west, Krośnieńska in the north-west and Głogowska

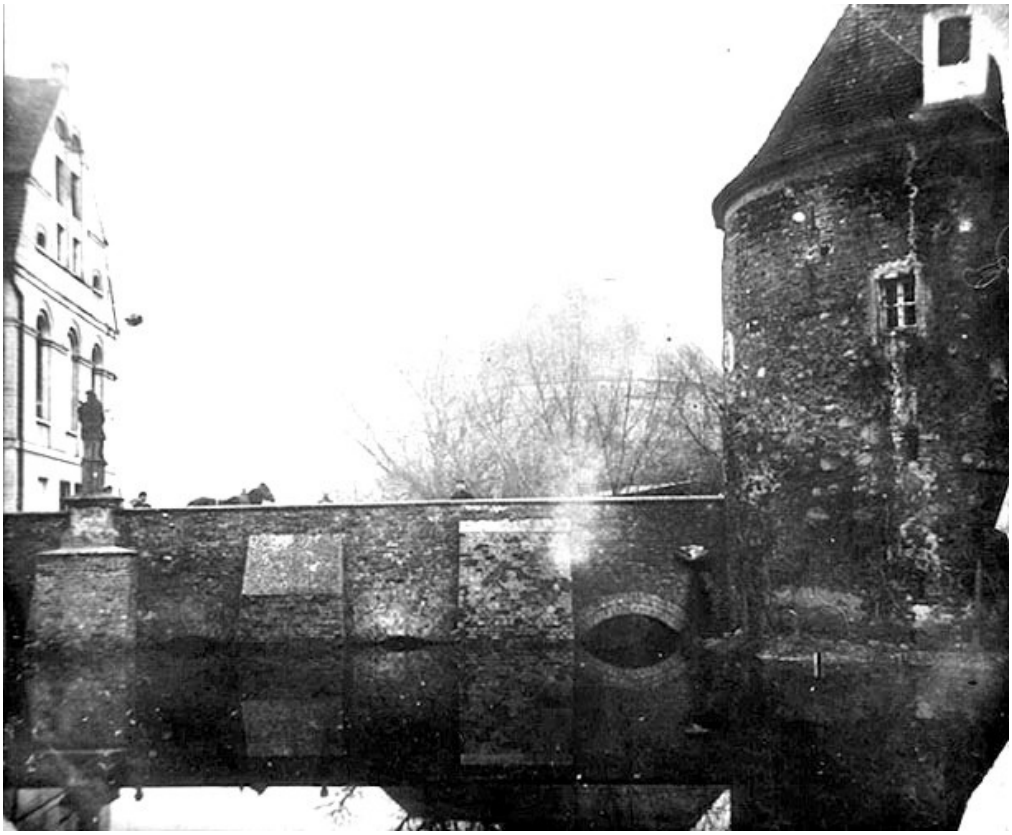

Fig. 9. Kożuchów, Krośnieńska Gate, the view of the bridge from the south, a postcard from the end of the 19th century (from the collection of Z. Szukiełowicz)

in the east. In 1418 Duchess Katharina of Opole consented to the cutting of a wicket gate (*Pestpforte*) near the parish church [15, p. 43; 4, p. 51], and at the end of the 15th century or at the beginning of the following century the Szprotawska wicket was built in the southern part [4, pp. 51–53]. At the close of the Middle Ages, each of the entrances was probably protected with a tower, a gateway in the basement and a foregate – as is confirmed by the oldest street map drawn up by Christian von Wrede in 1750 and by an 18th-century view[4] of Głogowska Gate. In Żagańska and Głogowska Gates the foregates had rectangle shapes, while in Krośnieńska Gate the foregate was elongated and resembled a horseshoe. The demolition of the fortifications probably started in 1764 after a city fire, and the gates were probably levelled at the beginning of the 19th century [4; 45, pp. 63–73]. The remnants of two of them, Krośnieńska and Głogowska, are partly presented or exposed above ground level. The remnants of the former, which consisted of the southern part of a semi-circular foregate, were subjected to conversion in the 16th and 17th centuries; the remnants of the second gate consist

[4] I thank Zdzisław Szukiełowicz for making the print available.

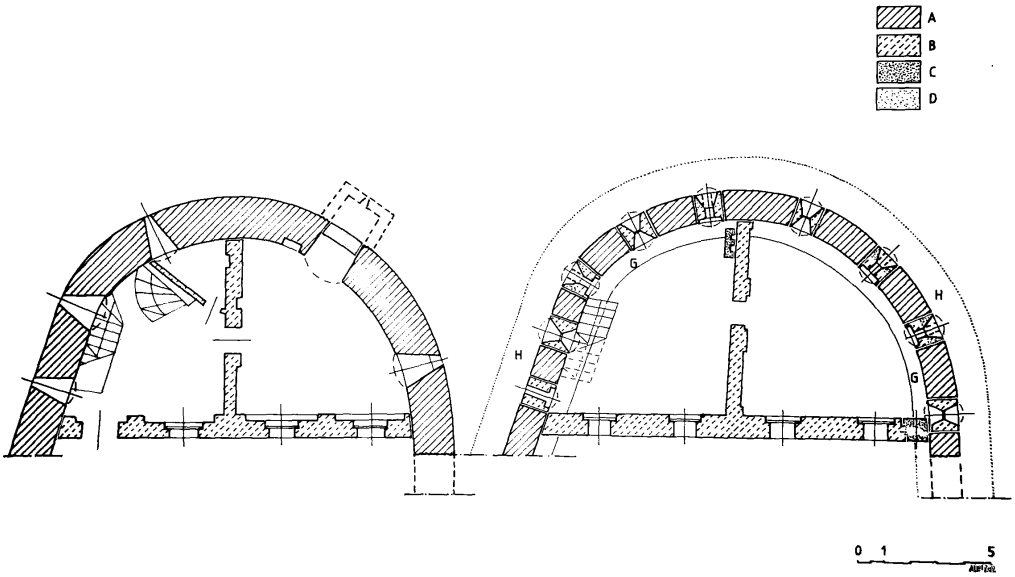

Fig. 10. Kożuchów, Krośnieńska Gate, foregate, projections of the ground level and parapet walk with chronological wall stratification. A – 2nd half 14th/1st half 15th century; B – Renaissance; C – Baroque; D – 19th and 20th century; H – hoard; G – parapet walk, W – latrine bay (drawn by A. Legendziewicz)

of the south neck wall and the outline of a tower, which is exposed as a low wall and a drawing in the roadway flooring [45, pp. 63–73][5].

The oldest source information on the city gates and walls of Kożuchów comes from a document issued in 1311 [19, p. 161 No. 3]. Two deeds (dated 1321 and 1412) contain information about a moat and walls [19, p. 162 No. 4, p. 170 No. 44]. Głogowska Gate was mentioned in 1433 [19, p. 132 No. 6a] and also in 1474, with the latter being a note about works on the gate and the building material used to strengthen the castle fortifications and the moat [15, p.133].

The current literature on the construction and development of medieval fortifications is based on the aforementioned source documents [26; 48; 27, pp. 235–248; 28; 66, pp. 9–13; 2; 3, pp. 66–77; 29; 13, pp. 109–118]. A summary of the state of research has been published by Tomasz Andrzejewski and Zdzisław Szukiełowicz [4, pp. 5, 6]. Based on the archival source material, the authors suggested that the first circuit was built at the turn of the 13th and 14th centuries, and the construction of the outer ring took place in the period preceding the 1476–82 war of the Glogów succession [4, pp. 7–12]. Detailed architectural research into the two circuits of the medieval fortifications and the relicts of the Głogowska and Krośnieńska gates was conducted by the author of this article [42]. The research was summed up and a proposition about the construction of the inner circuit in the first half of the 15th century and of the outer circuit in the third quarter of the 15th century was set out in an article published in 2012 [45, pp. 63–73].

[5] While carrying out the research I was assisted by Messrs M. Listwan and M. Lesiuk, whom I thank cordially.

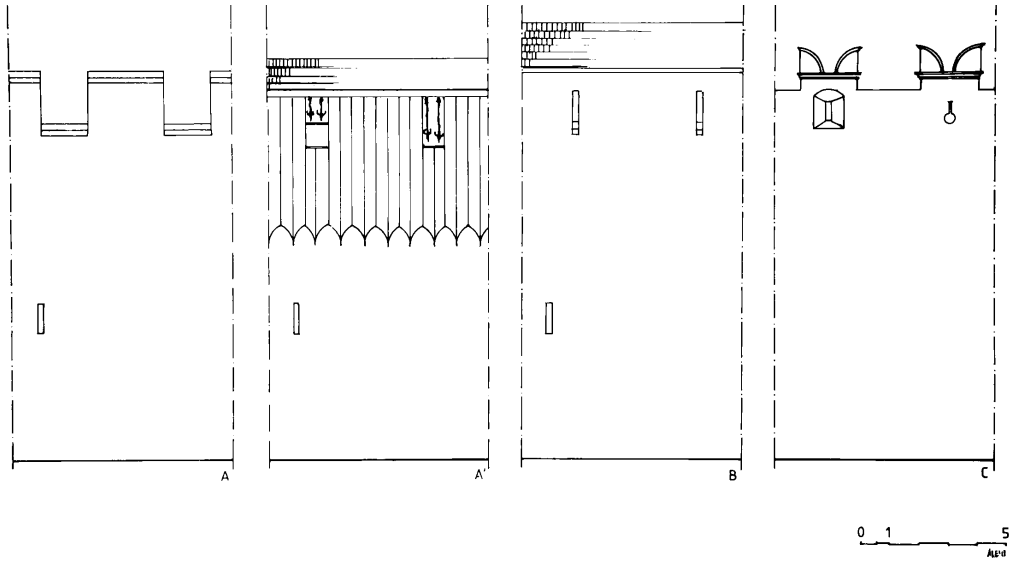

Fig. 11. Kożuchów, Krośnieńska Gate, foregate, reconstruction of the solutions of the upper part of the façade (parapet walk). A, A " – 2nd half of 14th/1st half of 15th century (crenellate and hoard); B – 2nd half of 15th century (gunports), C – Renaissance (attic and gunports (keyhole) (drawn by A. Legendziewicz)

The construction of the wall took place in stages in the first half of the 14th century. The gates were probably built first; Krośnieńska gate was rectangular and was within the tower plan but projected out beyond the curtain face. The gateway in the basement was preceded by a bridge, whose span when lifted was about 3.2 meters long. The tower's architecture remains unknown, although one can suppose that it was crowned with crenellation, which might have been strengthened with a wooden hoarding. The gate was probably modernized over a period from the mid-14th to mid-15th century. A horseshoe-shaped foregate was built to the west of the tower at that time. A foregate wall constructed with erratic boulders was added to the circuit curtain in the south and probably to the north-western corner of the tower in the north. The entrance axis tilted in a north-westerly direction and ran along the northern wall of the foregate. The gate opening located in the north edge of the western façade was preceded by a draw-span bridge. Slot openings were situated on one level on the archwise façade in the west and south, and the wall was crowned with crenellation. The hole edges and the parapet walk breastwork, with crenellations spaced at 150–160 cm intervals, were built in brick. From the moat side, the foregate was strengthened with a wooden hoarding whose brackets were fastened in wall pockets spaced at about 110–120 centimeters. Moreover, there was a bay latrine in the west, as is documented by gate views dating back to the beginning of the 20th century.

The foregate walls were built in cobblestone interleaved with pieces of bricks, laid in layers up to a height of about 80–90 centimeters. The breastwork was built in brick, 7.5–8.5 cm/12–14 cm/26.5–27.5 cm in size, ranging in color from orange to black due to baking, with a local effusion of glaze. A similar material was applied to slot-opening reveals and embrasures.

Fig. 12. Kożuchów, Krośnieńska Gate, general view from the west (photo by A.Legendziewicz)

The breastwork was laid to a regular single-stretcher bond pattern, with carefully made, horizontal, flat joints that were undercut at the bottom, and vertical flat joints with a groove.

The foregate was modernized simultaneously with the construction of the outer circuit in the third quarter of the 15th century. Slot openings were arranged in the crenellation gaps within the breastwork. Their inner reveals were shaped as splay embrasures and topped with half-brick-thick staple arches. The foregate was built in ceramic blocks, 7–8 cm/11–12.5 cm/26–27 cm in size, arranged in a regular single-stretcher bond pattern with a flatly smoothed joint.

Foregate conversions in the Renaissance style probably took place in the thirties or forties of the 16th century[6]. A four-storey building with an entrance in the north was separated with a wall parallel to the gateway within a semi-circular section. It was covered with a V roof, which was limited along the curtain line with an attic consisting of repeated, dovetail (two-quadrant) segments on 40/160-centimetre plinths. The parapet segments were arranged on the top floor along the axes of the mostly rectangular and keyhole gunports, of which one survived.

The entrance to Kożuchów from the east was protected by Głogowska Gate, whose framing consists of a tower erected on a rectangle-like plan with outer dimensions of about 9.5/9.75 meters. Probably due to boggy ground, its outline was located within the circuit. The

[6] The first parapet with a similar comb layout was completed in 1529 during the encastellation of Saint John's Parish Church in Paczków [65, pp. 171–174].

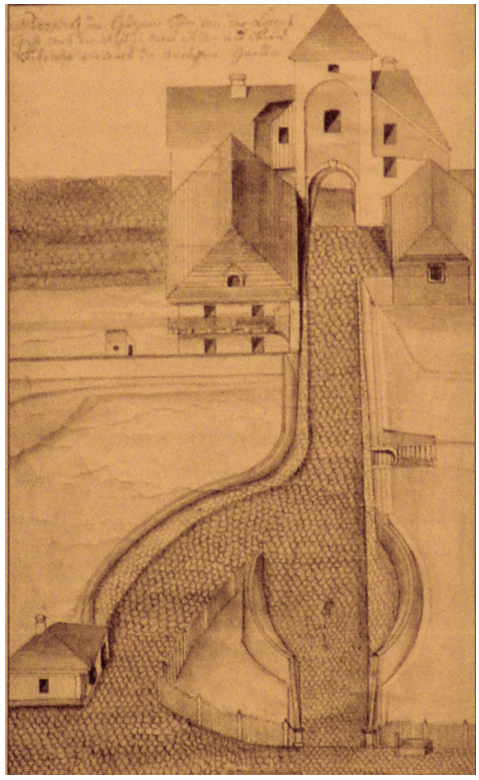

Fig. 13. Kożuchów, Głogowska Gate from the 2nd half of the 18th-century view from the moat (illustration from the collection of the Regional Chamber in Kożuchów)

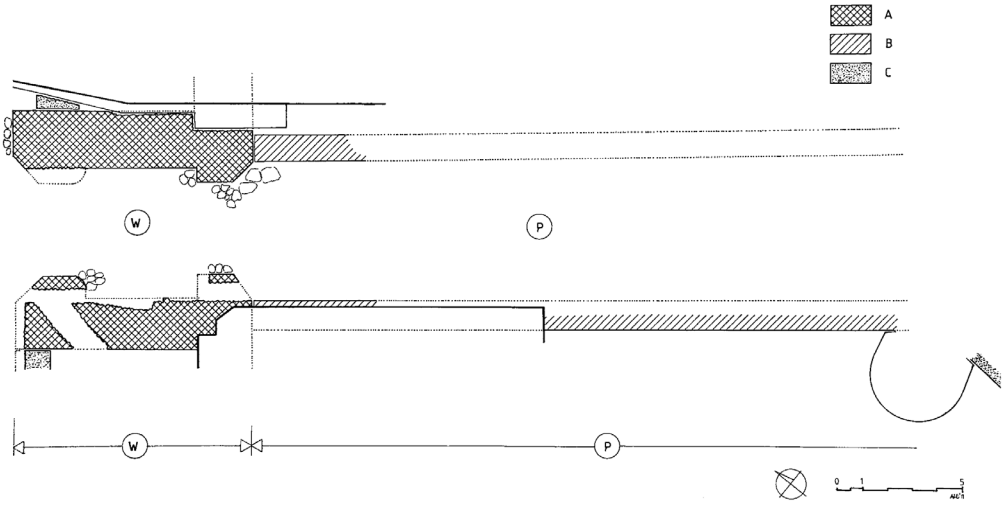

Fig. 14. Kożuchów, Głogowska Gate, projection of fundaments with chronological wall stratification. A – 1st half of 14th century; B – 2nd half of 14th/1st half of 15th century; C – 18th century; W – tower, P – foregate; reconstruction lines – dotted (drawn by A. Legendziewicz)

gateway was located in the basement, as was the case with Krośnieńska Gate. The edges of its openings with chamfered corners were framed with carefully pressed blocks of bog iron ore. Analysis of archival iconography indicates that on the eastern façade there was a lancet recess for a portcullis whose runners had probably been at a distance not greater than 1 meter from the gateway edge. The city was probably also secured with a drawbridge and a double gate. The opening from the side of the city was also framed with chamfered edges. Bog iron ore blocks were also used to build the chamfered base and the facade, which was probably plastered. Analysis of a Kożuchów panorama dated 1537 indicated that the tower finial consisted of crenellation and was covered with a short-ridged hip roof [62].

The tower's foundation walls were built in boarded trenches, in erratic boulder filled with smaller stones. The basement walls are preserved to a height of about 20–30 centimeters above the historic cobblestone level. The wall face was made of precisely pressed blocks of bog iron ore, with the wall having been filled with cobblestones and lime mortar.

Głogowska Gate was probably extended at the same time as Krośnieńska Gate. Its rectangular foregate, about 8.4 meters in width and about 25 meters in length, was erected along the axis of the gateway opening from the moat side. It was abutted onto the frontal façade of the tower. The eastern neck closure probably consisted of a drawbridge. The gateway was about 6 meters wide and the walls were almost 1.2 meters thick. The side walls were built in erratic boulder, which was laid in layers interleaved with smaller stones and pieces of bricks.

Analysis of the existing Głogowska Gate iconography showed that the gate architecture was probably converted in the 18th century and given Baroque forms. The tower was surrounded by two single-storey, four-axis tenement buildings. The gate consisted of two storeys and the gateway opening was trimmed with keyed framing. The façade was framed and crowned with protruding molding. The building was covered with a tent roof, a spire with a gold-plated knob, a spire element and a seven-point star. The gate object was probably demolished in the first half of the 19th century, before 1819 [4, p. 49; 45, p. 71].

6. Namysłów – Krakowska and Wrocławska Gates

The chartered city of Namysłów was on a plateau headland restricted by the Widawa river, on an elongated quadrilateral plan whose longer sides converge in a westerly direction. The medieval fortifications were strengthened with three gates: Krakowska (Kluczborska) in the east, Wrocławska (Brzeska) in the south-west and Wodna in the north, all of which were built in the 14th century. They consisted of two (circles) circuits: an inner one, *i.e.* curtains and 37 towers built between 1348 and at least 1418; and an outer one, which was intended for the usage of firearms and was built from 1462 up to the beginning of the 16th century [36]. The fortifications were modernized in the 17th century, while the erection of a fortified tower jacket started in 1653 [17, pp. 164–165]. The levelling of the jacket started in 1764; the medieval walls, certain fortified towers and Wrocławska and Wodna gates were demolished in the 19th century [17, p. 174, 204; 23, pp. 44–46].

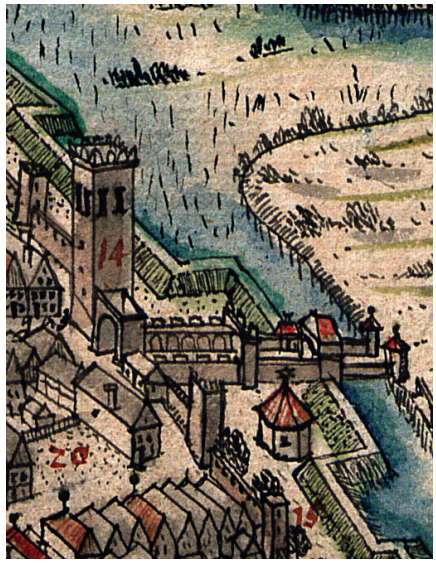

Fig. 15. Namysłów, Krakowska Gate complex from the middle of 18th century – a fragment of the F.B. Werner (drawing from the collections of the University Library in Wrocław)

An older city chronicle written by Jan Froben between 1495 and 1503 contains notes on the construction of the wall [16][7]. The entries contained therein lead to the proposition that the inner circle was built in stages, starting from the east stretch, which was completed before 1348 [16, line 1], then the south stretch that ended in Wrocławska Gate was rebuilt in 1396, and finally the north stretch and Wodna Gate were completed after 1415 [16, line 14]. The modernization of the east stretch was completed at the end of the 14th century, when Piekarska tower was built in 1394; two years later, in 1398, the tower, Krakowska Gate, and the Kaczmarska tower were also built [16, line 10].

The subject of medieval fortifications was first raised by H. Lutsch, who mentioned wall relicts and the year 1350 as the time when the construction of the wall started [49, p. 499]. This topic has been presented more extensively by Kurt Degen [11, pp. 123–126]. Based on the Froben chronicle, he came to the conclusion that the city was secured with walls in 1350 and that the two gates, Krakowska (Kluczborska) and Wrocławska (Brzeska), existed in 1371. More features were added later: Wodna Gate with a tower in 1388, watchtowers along the walls and near certain gate towers in 1390, Piekarska tower behind the parish church in 1394, Wrocławska Gate with a tower in 1396, and Karczmarska tower by Krakowska Gate and Oborowa tower in front of the castle in 1398. The construction of the inner circuit was finished in 1415 when a stretch west of the Wodna Gate was completed. The topic of the construction of the city fortifications was more thoroughly examined by Kurt Bimler [7, pp. 78–90]. Based on the Froben chronicle and street maps, he found that the construction of the walls in the

[7] The Koschny chronicle is considered missing, and that by reverend W. Libich duplicates Froben chronicle entries.

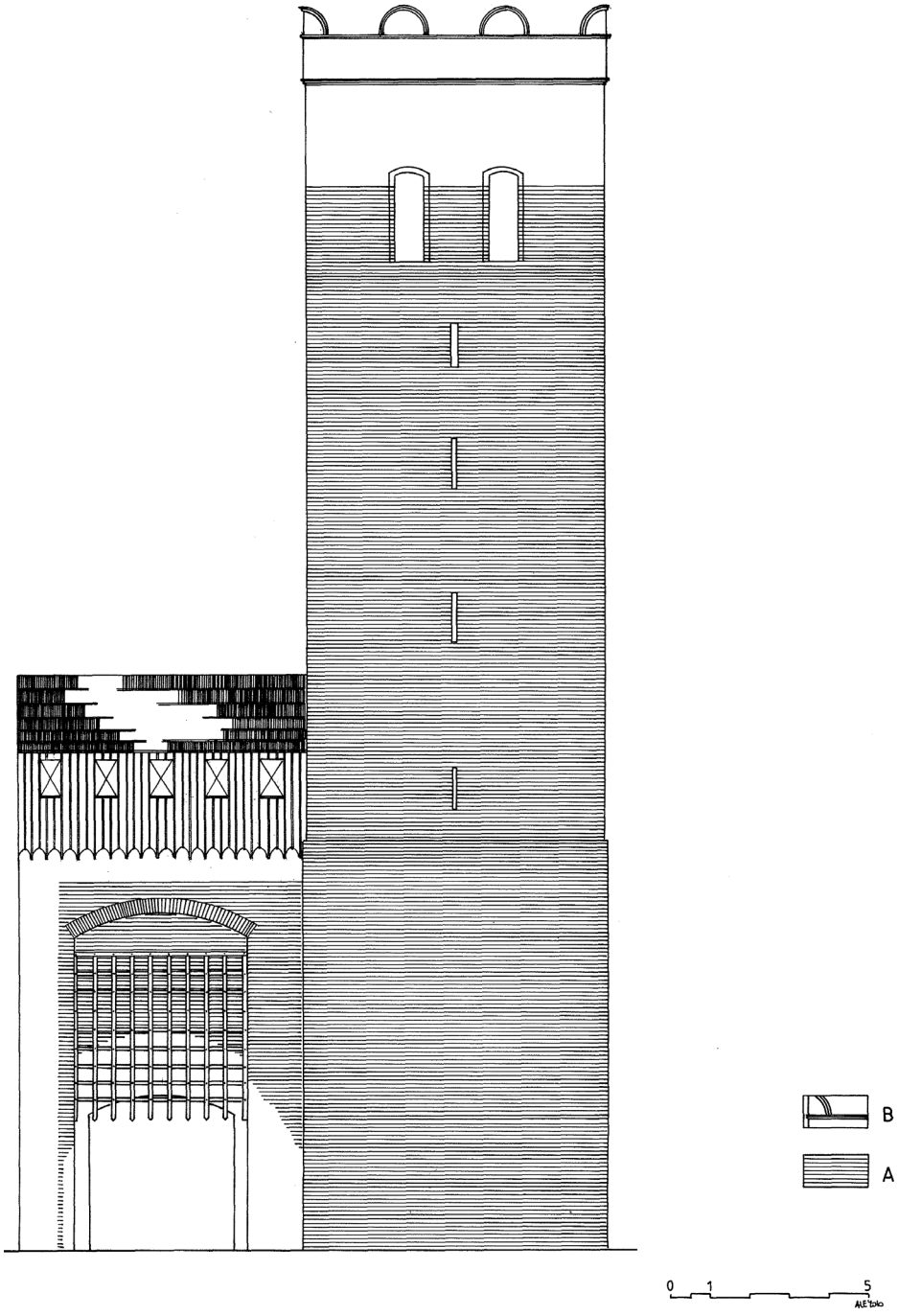

Fig. 16. Namysłów, Krakowska Gate complex, eastern elevation with chronological wall stratification and reconstruction of the attic from around the middle of the 16th century.
A – from around 1396, B – reconstruction lines (drawn by A. Legendziewicz)

Fig. 17. Namysłów, Krakowska Gate complex – view from the west (photo by A. Legendziewicz)

Fig. 18. Namysłów, the Wrocławska Gate complex from the middle of 18th century – a fragment of F.B. Werner (drawing from the collections of the University Library in Wrocław)

east and of Krakowska Gate started in 1350, and then the work continued in the north and south towards the west. Wodna Gate with a tower was erected in 1388, and Piekarska tower was erected in the north-eastern corner of the circuit in 1394. Karczmarska tower, also called Wysoka, was built in the south-eastern corner in 1398. A new Wrocławska Gate was built in 1390. The opinions of K. Degen and K. Bimler were compiled by T. Chrzanowski and M. Koniecki [23, pp. 44–46]. A concise description of the construction and the indication that the circuit was built between 1350 and 1359 was published by J. Pilch [58, pp. 118–119].

The latest research into medieval walls carried out by Cz. Lasota and A. Legendziewicz shows a slightly different view [36]. By referring to the Froben chronicle note dated 1348, the authors confirmed that Namysłów was protected with masonry fortifications and Krakowska Gate in the east; however, there were no walls in the north, south and by certain fortified towers [36, pp. 6–9]. The analysis of further city chronicle entries and the notes on the wall subsidies given by Charles IV, the Holy Roman Emperor, prove that priority was given to the fortified circuit of this strategically located city [36, p. 6]. After the curtain had been built west of Wodna Gate, its east stretch was modernized: certain fortified towers were made higher in 1390, and two high towers, Piekarską in the north-eastern corner and Kaczmarska in the south-eastern corner, were erected in 1394 and 1398 [36, pp. 7, 8]. These works were accompanied by the construction of a new Krakowska Gate and a tower in around 1396 [36, pp. 7, 8]. Research on architectural and restoration issues relating to this gate was published by the author of this article [40, pp.106–108]. Architectural research on the preserved relicts of the Wrocławska Gate was carried out in 2012 [44].

Krakowska Gate tower was built on a 7.6/7.8-meter, square-like plan and it was as high as 26 meters above the present ground level. Its interior was divided with beamed ceilings into at least seven storeys. The lowest floor was designed as a dungeon. It had a staple vault and a circular hole to throw prisoners in. Higher floors marked out by offsets were accessible by ladder. The entrance to the inside was situated on the western façade at a height of about 9.8 meters above the present ground level and topped with a semi-circular arch. Each of the storeys was lit through slot openings in embrasures which were capped with half-brick-thick staple arches. At level +9.85, there is one opening in the east wall, at level +13.80 there are three of them in the north, east and south, whereas at higher levels there are four of them. Engraved inscriptions and drawings were found on the side walls of embrasures, with the oldest one dating back to 1418. Two holes of uneven heights of up to 1.80 meters and a width of about 1 meter survived in each of the walls on the top preserved storey (at +24.80 m). Their outer edges were formed to create deep, half-brick-wide jambs – relicts of wooden flap closures. Smooth façades were erected to a regular, single-stretcher bond pattern in two colors, with randomly arranged, glazed heads with a blueish tone. Remnants of red paint were found on clean joints on the wall face, which may prove that the façade was painted soon after erection.

A curtain with a gateway was added to the south-western corner at the same time as the tower was built. The rectangular opening was topped with a staple arch and closed with a double gate and a portcullis installed in a recess. A wooden porch with a hoarding was probably built over the gateway.

Wrocławska Gate, whose relicts are under the roadway in B. Chrobrego street, was built as one of the first elements of the city fortifications. The Froben chronicle confirms that it was probably erected after 1350 [16, line 1; 36] and subjected to conversion in 1396 [16, line 10]. The first gate consisted of a tower and an about 7-metre-long stretch of curtain, which adhered to the tower in the west. The tower, whose height is now unknown and whose outer outline sides were about 7.5 meters long, was built on a continuous foundation ranging from 1.5 to 1.7 meters in width. It was built in erratic boulder and interleaved with fragments of bricks. The curtain foundation running in a westerly direction and ranging between about 2 and 2.5 meters in width was built with the adoption of a similar technology. A gate opening of unknown shape was at a distance of about 2.5 meters from the tower façade. Based on the relicts recorded, its width can be estimated at about 2.5 meters.

In the light of the Froben chronicle, the object was rebuilt by master *Eintz* in 1396 [16, line 10]. The excavations confirmed that the relicts of the gate neck that adhere to the south-western corner of the tower might be part of this rebuilt gate. The findings consisted of two

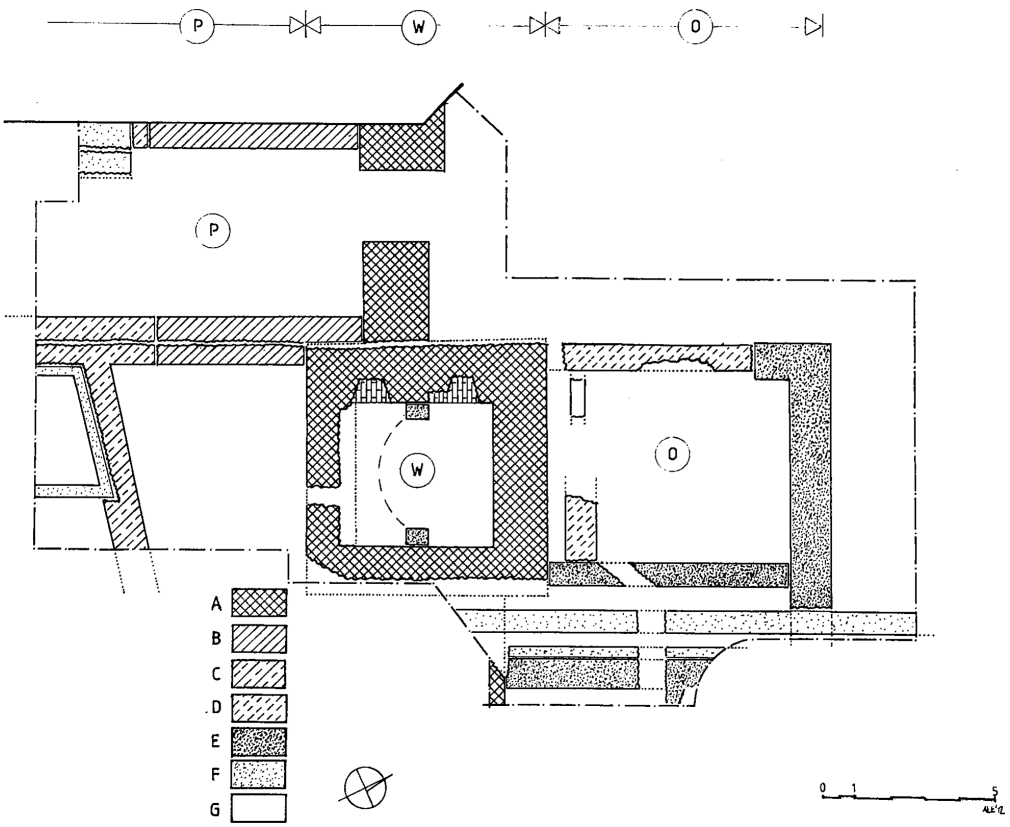

Fig. 19. Namysłów, the Wrocławska Gate Complex, projection of fundaments with chronological wall stratification. A – 2nd half of the 14th century; B – around 1396; C – end of the 15th century; D – 16th century; E – 18 century; F – 19th century; G-unrecognized walls; W – tower, P – foregate; O – guardhouse (Renaissance); reconstruction lines – dotted (drawn by A. Legendziewicz)

parallel continuous foundations that were over 8 meters in length and about 6 meters apart. The south closure of the gateway remains unknown; it was rebuilt in the second half of the 15th century, together with the construction of an outer circuit. The approx. 1.50-meter-wide foundations were built in erratic boulder and interleaved with pieces of bricks.

It is likely that a print by F. B. Werner that dates back to the middle of the 18th century shows the architecture of the gate after these conversions. The tower was probably made higher to the level of two storeys above the curtain crown and the foregate. In the upper part there was a rectangular firing port in each of the south, north and west walls, and two such ports in the east wall. The form of a tower finial remains unknown as it was replaced with an attic in the Renaissance.

The construction of an outer fortification belt intended for use with firearms near Wrocławska Gate was mentioned in a note from 1499 that concerned a fortified tower at the rear of nearby Saint George's Church and the Church of the Holy Spirit [16, line 139]. It can be assumed that the modernization of the circuit in that part of the city was complete at the turn of the 15th and 16th centuries. An outer wall was erected obliquely to the south wall of the gate tower at a distance of about 5 to 6 meters from the tower. The south closure of the gate neck was converted while the outer wall was being built. The walls were partly demolished, and only about 6.2–6.5-metre-long stretches remained. The approx. 1-metre-wide continuous footings were built of 7.5–9cm/12–13cm/25–26cm bricks of different colors ranging from orange to black due to baking.

Changes in the architecture of the object came with the Renaissance. A guard building was built near the north wall of the tower on a rectangular plan, of which the remains of the footings of two walls survived. A south wall foundation of about 1.5 meters in length was found at a distance of about 50cm from the north façade of the tower, whereas the west wall foundation, which is about 4.8 meters in length, was built in parallel to the gateway axis. The tower and foregate finials were also rebuilt at that time. They received an attic consisting of semi-circular elements, and of quadrant elements in the corners.

7. Prudnik – Dolna (Karniowska) Gate

There were three gates in the medieval circuit of the city walls in Prudnik: Górna (Nyska) Gate pointing at Nysa and Głuchołazy, Dolna (Karniowska) Gate pointing at Biała, Głogówek and Krnov and Nowa (Kapucyńska) Gate, which was built in 1556 [68, p. 200]. Analysis of archival iconography indicates that the transformations in the architecture of the towers that secured entrances to the towns took place in the second half of the 16th century. The process of demolition of the circuit started in the first half of the 19th century – Górna Gate was demolished in 1843 and Nowa Gate was demolished four years later [68, p. 200]. The following elements of the first circuit survived: Baszta Więzienna [the prison tower] and a stretch of the curtain, both of which are now parts of Museum Ziemi Prudnickiej, and Dolna Gate tower, which is partly blended in with the tenement buildings on the south frontage of S. Batory street.

The two lowest storeys of the gate tower were built on a 7.8/8.1-metre square-like plan. From a height of 15 meters above ground level the tower is octagonal in view. It is topped with a masonry pyramid cupola surrounded by a low crenellation-type attic.

The first note on the fortified circuit dates back to 1327 and comes from the mention of a journey by Duke Bolesław III the Wasteful via Prudnik and Głubczyce to Racibórz [68, p. 27]. Dolna Gate is mentioned in a deed dated 31 July 1481 as the boundary of the municipal properties governed by Governor George of Wrbno [68, s. 49]. A document dated 1 July 1556 contains a note on the assignment of a square in the suburb, in front of the Dolna Gate, to the city by Isabella Jagiellon, Queen consort of Hungary on behalf of her son, John Sigismund, for the construction of an inn for travelers [68, pp. 63–64].

The aforementioned notes formed the grounds for the consistent image of the transformations in the tower's architecture in the current literature. H. Lutsch supported the opinion on the medieval origin of the tower and linked its Renaissance form to the 1580 conversions that are proved by an element on the spire [51, p. 11, table 186/5]. A similar view of the development of the tower architecture was presented by Ernst Königer [30, p. 59, il.12]. The findings were confirmed by T. Chrzanowski and M. Koniecki, who supported the view that the Gothic tower was built in the 15th century and transformed at the end of the 16th century [25, p. 58, il.63]. The above findings were also quoted by J. Pilch [58, p. 168]. The relevant architectural research was carried out while preservation work was undertaken in 2006 [37]. The results were used to verify the propositions published so far and to discuss the façade restoration issues [40, pp. 105–117].

The oldest parts of Dolna Gate were probably built in the second half of the 14th century, as is proved by the construction material applied – crushed stone laid in layers – and the building

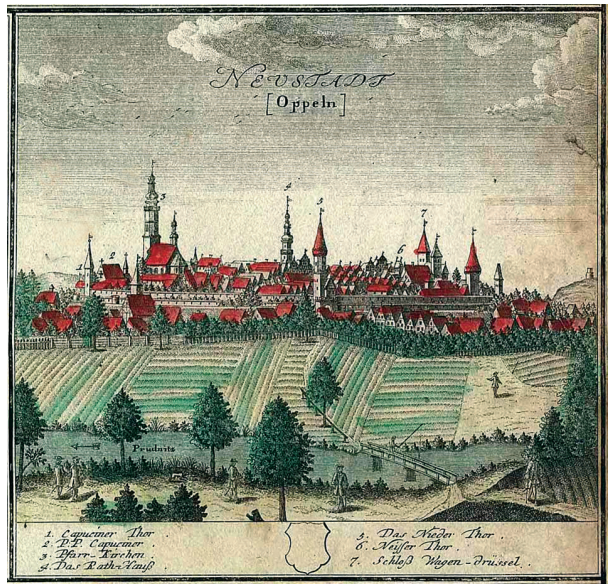

Fig. 20. Prudnik, panorama of the city from the east from around 1738 by F.B. Werner – Dolna Gate – No. 5 (drawing from the collections of the University Library in Wrocław)

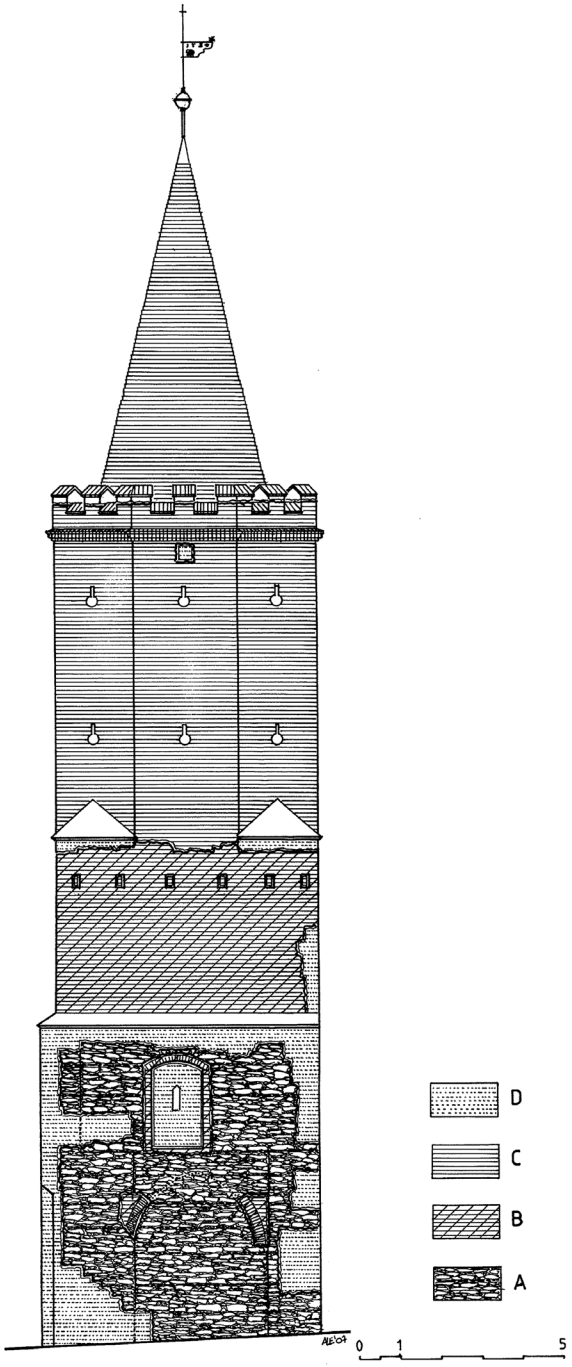

Fig. 21. Prudnik, Dolna Gate's tower, north elevation with chronological wall stratification.
A – 1st half of 14th century; B – 2nd half of 15th century; C – around 1580; D – 19th and 20th centuries
(drawn by A. Legendziewicz)

Fig. 22. Prudnik, Dolna Gate's tower – view from the east (photo by A. Legendziewicz)

method. The architectural layout of the gate object consisted of a square, a plastered tower, and a gateway adjoining the tower on the north side. Its height could have been about 10 meters and it was higher than the adjoining gateway. The original finial remains unknown, but it was probably crenellation. The tower was accessible through an entrance in the north at the first-floor level. In the basement, where the walls were up to two meters thick, there was a prison dungeon that was originally covered with a ceiling. The gateway ran into the north of the tower. Its outer wall was up to two meters thick and the inner walls were a little over one meter thick. A parapet walk was situated at a level of about 6 meters above the present ground, with an almost 2-metre-high breastwork with probably crenellation merlons of unknown spacing.

The tower and the gateway were rebuilt probably in the second half of the 15th century; the gates might have been preceded by a foregate in a rectangle shape, as was seen in a street map from 1750. The stone finial of the tower was demolished and a brick structure that was about 5 meters high was built on top to a single-stretcher bond pattern. A hoarding was built around the tower wall crown in the east, north and probably south, at a height of over 11 meters above the present cobblestone level. Its construction was based on wooden brackets fixed in the wall at 80–110 cm intervals; a row of wall pockets just beneath the octagonal part survived to the present times. A new finial was probably shaped in the form of a hip roof. The stone and brick parts of the façade were probably integrated by the application of thin mortar,

which is evident in how the brick wall joint was formed. The entrance framing in the north was also transformed, as the entrance opening was enlarged and enclosed with brick jambs and topped with a staple arch. Inside the tower, above the dungeon, there was a brick barrel vault with a hole to throw prisoners in.

The gateway was rebuilt and took the form of a gatehouse with a roof whose ridge ran in parallel to the curtain line. A cross vault, with retainers carved in the stone wall of the tower in the south, was built in the basement above the gateway. Above, there was a fortified storey accessible through a door opening in the tower.

The renaissance transformations that took place probably in 1580 involved the demolition a Gothic finial and the construction of a two-storey, about 7-metre-high octagonal structure on top of the tower. The walls were crowned with a low crenellation-type attic, with a high pyramid copula and a sandstone spire with a mast and a knob and a decorative spire element showing the date of the rebuild.

8. Summary

The conservation projects implemented over recent years made it possible to undertake research into medieval gates in several of Silesia's cities. The results formed the grounds for the verification of the propositions published to date in literature and at the same time they revealed the complexity of the construction and evolution of the city gate objects. The examples presented above indicate that decisions on the construction of fortified walls were taken by municipal authorities relatively quickly after city charters had been granted and these cities had become established. Originally, the cities were presumably surrounded with wooden and earthen embankments, which from the end of the 13th century were replaced with masonry circuits. When they were erected, particular emphasis was placed on the form and military functions of the city entrances. The gate openings were strengthened by being located in the tower's basements (*e.g.* Głogowska Gate in Kożuchów) or close to the towers (*e.g.* Dolna Gate in Prudnik). The gateways were secured with doors and portcullises, with the latter being installed in specifically shaped recesses and equipped with runners (*e.g.* Lewińska Gate in Grodków). The towers were higher than the adhering curtains and probably crowned with crenellation and wooden hoardings (*e.g.* the Górna Gate tower in Głuchołazy).

The first stage of modernization in the second half of the 14th century and at the beginning of the following century probably consisted in the introduction of foregates. These foregates were usually built on a rectangle plan (*e.g.* Grobnicka Gate in Głubczyce), whose length was as much as 25 meters (*e.g.* Głogowska Gate in Kożuchów). Krośnieńska Gate in Kożuchów was an exception as its foregate was built on an elongated horseshoe plan. It cannot be confirmed unambiguously whether or not the tower was made higher and crowned with hoardings while the neck was being constructed (as was the case with Dolna Gate in Prudnik). The recognized transformations could have been related to the reconstruction after the Hussite wars. The modernization of the gate objects could have involved the erection of new objects, as was the case with Krakowska Gate in Namysłów

Modern transformations to city gate architecture mostly consisted in giving cities a Renaissance look, *inter alia* by the addition of finials in the form of ornamental parapets in the place of a military hoardings. This is one indication that the military significance of the medieval circuits of city walls was slowly disappearing. However, it was also a symbol of the inhabitants' wealth and emphasized a representative form of city entrance.

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Abandoned heritage – the first European airports

Opuszczone dziedzictwo – pierwsze europejskie porty lotnicze

Due to the development of air transport and urban expansion, the locations of pre-war airports were often changed. The question of the fate of the abandoned airports and their entire infrastructure arose. This article looks at the issue of derelict, pre-war airfields. Examples of airports which were successfully adapted as well as the ones which were abandoned and closed yet but equally important in historical context are shown. In this paper, alternative possibilities for using the former civil airports which allowed memory of important, historical events to be honoured are shown as well as benefits of their preservation are presented.

Keywords: airports, architecture, urban planning, historic landscape, heritage of technology, Johannisthal Air Filed, Paris Le Bourget, Tempelhof, Gdańsk – Wrzeszcz, Kraków Rakowice – Czyżyny, abandoned airports

Abstract

W związku z rozwojem transportu lotniczego oraz ekspansji urbanistycznej lokalizacja przedwojennych portów lotniczych często ulegała zmianie. Rodzi się pytanie: jaki los spotkał opuszczone lotniska i ich całą infrastrukturę? Niniejszy artykuł porusza kwestię opuszczonych przedwojennych lotnisk. Przedstawione zostają przykłady udanych adaptacji ww. portów lotniczych, jak również tych niszczejących, ale niemniej istotnych w kontekście historycznym. W artykule zostają ukazane alternatywne możliwości wykorzystania dawnych cywilnych lotnisk, dzięki którym stało się możliwe uhonorowanie pamięci po ważnych wydarzeniach historycznych. Przedstawione także zostały korzyści płynące z działań mających na celu zachowanie tych miejsc.

Słowa kluczowe: porty lotnicze, architektura, urbanistyka, dziedzictwo techniki, Johannisthal Air Filed, Paris Le Bourget, Tempelhof, Gdańsk – Wrzeszcz, Kraków Rakowice – Czyżyny, opuszczone lotniska

1. Introduction

Historical objects associated with industry and transport are the subject of wide interest with many of them being protected. Numerous conferences concerning the heritage of technology have been held, it is also possible to find a very great number of publications related to the subject of the protection and reuse of such places. However, there are few publications related to air transport, although it deserves the same attention as rail or water transport which are often discussed in connection with heritage protection. Aviation is the youngest branch of transport, which has dynamically developed. Within a few years air communication has became widely available and has been steadily gaining in popularity. The growing number of new, larger aircraft which were capable of flying more passengers flights and the development of the technical infrastructure have forced airports to grow in size. The development of urban infrastructure in the vicinity was another reason for relocating airports. Therefore, air traffic has been moved to new locations [21, 10]. The question was being posed: what happened to the areas formerly occupied by the airports and their infrastructure? In the literature, we can find only basic information about the remains of abandoned airports. The purpose of this article is to identify the value of the remnants of the former airports in the context of the heritage of aviation technology as well as presenting possible ways to reuse abandoned airport areas and the benefits that could come from it.

The first stage of the study was to become familiar with airport classification according to their functions (airfield, military airport, sport airports, civil airports). The preparation of the article covered a wide range of literature [21, 13, 6, 7, 14, 10]. The next step consists of collection, verification and organizing material. The subject of this article is a collection of airports which were opened before World War II and stopped fulfilling their function as civil airports. From this group, only those airports which played a significant role in history were selected. Some of them could be used as examples of the effective use of the heritage of technology as well as examples of successful adaptation and reuse. Understanding the way old airports in other European countries are being preserved is the background for the study. The development of aviation and transforming its infrastructure is presented based on source materials. The study used the comparative method and logical reasoning. The value of the abandoned airports as well as the presentation of the possible reuse of the rest of their infrastructure and benefits which may come from that can be presented thanks to the steps shown above.

2. Former civil airports

The first airports appeared at the beginning of the 20th century. Initially they were used for sport and recreation activities and by military units. The heyday of aviation was during wartime. Planes were becoming more and more agile, which was their main advantage for instance during reconnaissance activities during the war. Therefore their production increased and this led to growth in the number of airports. When the political situation became more

stable, planes started being used for passenger flights. Due to the technical development of the aircraft, their constant improvement as well as the development of airport infrastructure and the growing availability of civil flights, the lack of space in existing airports areas became obvious. On the other hand, new buildings and urban sprawl began to move closer to the airports. The development of aviation, the urban expansion as well as political and economic changes led to the closure of many airports and moving them to new locations. Former civil airports met different fates: some of them are being used by aviation clubs and for sporting purposes, others were destroyed and new buildings built or they are simply left as derelict buildings. Nevertheless, some of them were adapted to new functions. That last group may become a model of the protection and honouring the old airports and their infrastructure which are often associated with important historical events [6, 10, 13, 21].

2.1. Johannisthal Air Field

Although as "the mother of all airports" the airport Berlin-Tempelhof is commonly called [5], it was not the first German airport. The first commercial airfield in Germany and one of the first airports in Europe was the airport located in Johannisthal, near Berlin. The airfield was opened in 1909 and initially used for air-shows. It was located in an open, grassy area. On its outskirts were spread hangars and stands. Soon the Johannisthal Air Field became a meeting place for European pilots and events organized there became international. Although the first objects were only temporary it did not take much time until the lack of infrastructure was filled and soon administrative buildings, halls, as well as technical equipment (among others lighting and an anemometer) appeared at the Johannisthal Air Field. In Johannisthal, the most important manufacturers and designers of the aircrafts soon settled [25].

During the First World War the airport in Johannisthal was used by military and for aircraft production. In 1912 the German Experimental Institute (DVL-Deutsche Versuchsanstalt für Luftfahrt) was established and the airport became an important place where research was conducted. 1919 was very significant for the airport history too, because then the Deutsche Luft-Reederei (German airline, Lufthansa's predecessor) began its first post and passenger flights there. Passenger traffic was moved from Johannisthal to Berlin when the new airport

Fig. 1. Former airfield in Johannisthal. The place is a subject of interest of photographers and graffiti artists (source: Abandoned Berlin [29] accessed: 12.12.2018)

Berlin-Tempelhof was built (1923). The army returned to Johannisthal and up to the 80s it was used for military purposes. In 1995 the airport was officially closed.

The runway was converted into a park, part of the former airport was rebuilt for the Aerodynamic Park University of Humboldt. Other buildings (in original equipment could be found) are still decaying. These objects have aroused interest among lovers of abandoned buildings, as well as being an attractive place for graffiti artists [8, 25, 29, 30, 31, 33, 36].

2.2. Gdańsk-Wrzeszcz Airport

Gdansk-Wrzeszcz Airport was founded in 1910 in Gdansk by the Prussian military authorities. At the beginning it was used for military purposes. In 1917 a school for pilots was established and that time the second hangar was also built. After the First World War, the airport was used for civil aviation purposes and in 1920 international flights began. The airport's buildings consisted of: a couple of hangars, station, workshops, fuel warehouse and houses for the airport staff. This place was of great importance to European air transport and it was one of the first which supported civil flights. In the 1930s. the airport in Gdańsk-Wrzeszcz was used for night flights and was also used during difficult weather conditions, which set it apart from other airports. An additional distinction for the airport was the participation in the international air contest Europe-Rundflug.

During the World War II, the airport was used for military exercises. In 1945 during the Soviet offensive the airport infrastructure was seriously damaged by Allied air raids and later by the Red Army. After the war, the airport was rebuilt and extended. It was used by military and civil aviation, and carried flights between Berlin, Copenhagen and Stockholm. In the 70s, there was a big economic revolution and it was decided to move the airport. It required expansion; however, it was impossible to extend the airport area in its current location. The official closure of the airport in Wrzeszcz was in 1974. The same year air traffic was moved to the newly built airport located in nearby Rębiechowo (opened 1974) [6, 7, 13, 21, 34].

The area of the former Gdańsk-Wrzeszcz Airport was absorbed by a new housing estate, and that district was named "Zaspa", which is still in use. Of the former infrastructure, the remnants of the runway and one of the hangars could be seen. The hangar was adapted into a shopping centre, the other two hangars were demolished, and the area has been allocated

Fig. 2. An old hangar in Gdańsk-Zaspa, 2019 (photo by A. Szuta)

for housing. Only street names, the remaining airstrip, and adapted hangar recall the history of this place [7, 21].

2.3. Berlin-Tempelhof Airport

The airport was located in the centre of Berlin and had good communications with the rest of the city. The first flights took place in 1903 on a grassy airstrip. In 1909 a demonstration flight was given by Oliver Wright, and this event brought gather a large number of viewers. In 1919, the first passenger flight took place. In the 1920s. Tempelhof was used by the German airline DHL (Deutsche Luft Hansa) [5]. During the interwar period, Tempelhof was a major hub in Europe. Soon a decision to build a building which would reflect the power of Germany was made. The terminal project was innovative – it envisaged separate levels for people and luggage as well as a wide underground level. Construction of the Tempelhof terminal was completed in 1937 while finishing works were stopped because of the outbreak of World War II.

During the war, Tempelhof was mainly used for the production of aircraft. Although Soviet troops devastated many of the premises, the Americans, who received the airport in 1945, made all necessary repairs. In the following year the first international flight was held. During the blockade of Berlin (1948–1949) all supplies for the city could be transferred only by air transport. Due to this, airplanes landed at Tempelhof almost constantly. After the end of the blockade, Tempelhof was partly controlled by military forces and also served civil transport. Tempelhof was again one of the most widely used airports in Europe. The times of its grandeur lasted until the opening of the Berlin-Tegiel Airport in 1975 to which many airlines moved. Tempelhof was closed for the first time and used only for special occasions [22]. The Fall of the Berlin Wall and the economic boom led to the reopening of Tempelhof airport in 1989. In 1994 American forces were deactivated; nevertheless, within a few years the transfer of air traffic from Berlin-Tempelhof and Berlin-Tegel airports to Berlin-Schönefeld was discussed. In 2008 Tempelhof was closed for the second time. The question arose: what to do with the Tempelhof airfield?

In 2009 a competition for the adaptation of Berlin-Tempelhof airport, whose terminal building has been protected from 1995, was announced. The former airport became the subject of many works. Although the projects differ a lot, a linking element in these conceptions could

Fig. 3. Berlin-Tempelhof Airport a bird's-eye view and facade of the terminal
(source: [37, 38] accessed: 26.02.2019)

be found. Every project introduced new functions to the terminal (for instance a video label or an office) and none of them changed anything in the structure of the building or its facade in order to preserve its nature. The winning project was created by GROSS Studio. However, about 4 years after that investors cooperating with Berlin saw the potential of the place and wanted to establish some new buildings there. It was decided to vote in response. Berliners voted that the Park should remain green space. The largest park in Berlin, the "Tempelhofer Park" was founded in May 2010. In the former Tempelhof airport various cultural events, fashion shows, etc. were held. It has been also used by skaters and for other sport activities. In 2015 year, Tempelhof became the largest shelter in Germany for refugees [5, 9, 19, 22].

2.4. Paris-Le Bourget Airport

The Le-Bourget Airport was located near Paris in the village of Le Bourget. In 1914 the army established an Air Reserve there, and few a months later the place became a respectable, military airport. Wooden hangars, workshops, and administrative offices were built there. The area of the airport was continuously enlarged. In addition it was not only a good place for the military but it also created ideal conditions for aerospace experiments as well. After World War I, the potential of the aviation industry and its development also for civil purposes was noticed. The first airport in France which held civil flights was Le Bourget. From 1919, it was also used for civil aviation. Although military and civil industry lived in a symbiotic relationship, the aviation development required an increase in the airport's area. In the 1930s, in the background to other European airports, the Le Bourget airport became obsolete due to its project and small area. For this reason, a new terminal based on the European model was designed. It was officially opened in 1937. By the end of the 1930s. Le Bourget became the most beleaguered airport right after Berlin-Tempelhof.

In 1940 German bombardment damaged the airport's military and civil infrastructure and during the war the airport was occupied by the Luftwaffe. Then American and British bombing seriously damaged the terminal. After the liberation of Paris the airport was used by the British and American armies, who quickly repaired it and soon civil flights were held there again. In 1951 Le Bourget played the host in a very prestigious meeting at which the most recent creations of the aviation industry were displayed. In 1974, the Charles de Gaulle Airport was opened and the air traffic was transferred there from Le Bourget. As a result of releasing the space at Le Bourget, the oldest museum of aviation in the world "Museum of Air and Space" (Musee de l'Air et de l'Espace) was moved there. The museum suffered from lack of space for a long time and, due to that, using the inactive part of the airport was seen as a good solution [17, 18, 23].

Till 1977, Paris-Le Bourget functioned as one of the capital's airports. The last commercial flight took place in 1982. The Air and Space Museum, which already took part of the airport, expanded its exhibition space into the terminal building, which has been protected since 1994. Every year (since the '50s) it has held the international air and space show "Paris Air Show". Currently part of Paris-Le Bourget Airport is a museum and the other part is used for business aviation – Paris-Le Bourget Airport is one of the most used airports for business flights in Europe [20, 23].

Fig. 4. Air and Space Museum in Paris (source: [39, 40] accessed: 26.02.2019)

2.5. Kraków-Rakowice Airport

Rakowice-Czyżyny Airport was established between two villages Czyżyny and Rakowice, both of them located near Kraków. It is one of the oldest airports in Europe. In 1912, the Austro-Hungarian army bought an area covered by orchards and vegetable gardens from the Cistercians. The area served as a landing area, and the first attempts at flights were held there too. Already in autumn of that year the construction of the first buildings and technical facilities was carried out [13, 35]. The airport developed quickly and a few years later it became an important hub. The airport was continually developed, new structures were built, and it also gained in importance for the military [34]. In 1917 the airport was named "Kraków-Rakowice Airport" and was added to the postal line Vienna – Kraków – Lviv – Ploskirow – Kiev – Odessa, which was the first regular post airline in Europe. In the 20s, the Civil Air Station Cracow was opened at the airport, one of the first civil air stations in Poland was also established there. Simultaneously as the rank of the airport increased, so increased its area. Regular transport activities started in 1923. By the end of the 20s. Kraków-Rakowice was a major hub connecting foreign flights to Brno, Vienna and Budapest. In 1924, the airport infrastructure was still being developed (one of the hangars which was built then today belongs to the Polish Aviation Museum) [13].

In 1939 the airport was bombed by the Germans and during the war it was used by the Luftwaffe. In 1945 it was again bombed and occupied by the Russians. While leaving, the Germans destroyed much of the airport. In December 1945 the control of the airport was transferred from Russian to Polish authorities. The damaged facilities were rebuilt and only a year later the first passenger flight was held there. At the beginning of 60s, the decision to liquidate the airport was made. This was due to the development of the metallurgical combine steelworks which was associated with the building of some new residential areas. In 1963, civil transport was moved to Kraków-Balice Airport. An army base was stationed at Kraków-Rakowice Airport till 1966, and till 1969 it served as an alternate airport [13, 21, 34, 35].

The origins of the museum on the site of the former airport Rakowice-Czyżyny started in the 60s when the unused equipment began to be stored there. Because of an aviation exhibition, other aviation exhibits were soon moved to Cracow. The landing area of the

Fig. 5. Polish Aviation Museum in Cracow (source: [32, 35] accessed: 12.12.2018)

former airport was gradually built up, and new residential and service buildings were built there. A landing strip on the side of the airport which hadn't been built up was created, and then, in 2010, a new, main building of the museum was opened. In this modern object a rich display of aircraft is presented. This place held both museum and educational functions. In December 2018, the Polish Aviation Museum in Cracow was highlighted as one of the 20 best museums of aviation in the world [21, 32, 35].

3. Advantages of using heritage of technology in various fields

According to the definition of the Hague convention, cultural goods are "movable or immovable property of great importance to the cultural heritage of every people, such as monuments of architecture, art or history, whether religious or secular; archaeological sites; groups of buildings which, as a whole, are of historical or artistic interest; works of art; manuscripts, books and other objects of artistic, historical or archaeological interest; as well as scientific collections and important collections of books or archives or of reproductions of the property defined above" [27]. In the rudiments of the knowledge of monuments and conservation is valorisation of the cultural goods. On its basis, legal-administrative and/or political and economic decisions are taken. One of the criteria for the application to be included on the World Heritage List says that goods should: "be an outstanding example of a type of building, architectural or technological ensemble or landscape which illustrates (a) significant stage(s) in human history" [26]. UNESCO's documents deal with the usage of the heritage in sustainable development. Another document concerning heritage conservation can also be found at the level of the voivodeships's development strategy. Among others.

it aims to: "develop and form the national consciousness, nurturing and developing local identity; stimulating economic activity, preservation of the cultural and natural environment values considering needs of the future generations and keeping spatial governance" (author's translation) [28]. B. Szmygin in his work shows that monuments are an important factor in the development, as well as tourism largely based on heritage, which is taking on increasing importance in the modern economy [1, 24].

On the heritage of technology and what are the effects of its use it is possible to find much in a wide range of literature. Technological heritage is a part of the cultural heritage as well as being a trace of the former events especially connected with technical and technological processes. In the method of valorisation heritage of technology TECHNITAS developed by J. Affelt certain words are defined, it is worth quoting two of them here "*Heritage of technology* includes all good that man created in order to survive and to improve the conditions of his existence, which are an essential component of the civilization and culture; those are movable or immovable material objects as well as linked with those incorporeal objects of heritage with its surrounding and landscape which is characterized by them" (author's translation) *Technology heritage resource* is "a group of objects which are components of a resource; it is identified by a proper name, location, ownership, legal status, the technical or functional cohesion, etc." (author's translation) [4] .

Heritage can help in the creation of social identity, and former industrial buildings allow the original cultural landscape and cityscape as well to be preserved. This could be possible if the objects are reminders of important historical events as well as they might transmit symbolic political, patriotic, and multicultural content. [2, 3] The subject of the post-industrial heritage was raised among others at the conference "Post-industrial heritage and its culture-forming role" (Dziedzictwo Postindustrialne i jego kulturotwórcza rola) (The first edition was held in 2009 [11] and the second in 2010 [12]). An attempt to highlight and spread in a wider scale subjects related to the heritage of technology was made then. At this time a number of the important articles were also published which concerned the heritage of technology, and the main suncategories of the technological heritage were presented too. Three categories could be found there, one of them is industrial heritage which includes transport and its infrastructure. About the opportunities in using monuments of communications technology as a tourist attraction for cities and regions writes among others T. Turner. Referring to monuments of public transport, he observed many possibilities for their use due to the fact that it becomes possible to strengthen recognition of the former transport infrastructure as a tourist attraction of the cities and regions [36].

Subjects related to the aviation infrastructure are sparsely raised in the field of the architecture and urban planning or work connected with the conservation and reuse of technology heritage resources. However, mentions which concerned using former airport areas could be found in the work of the Institute of Tourism. The issue of the social and economic benefits which are the result of the people's interest in aviation is being raised there. Research shows that not only new airports (such as Kansai International Airport) could be the subject of tourist interest but also old buildings, such as the Museum of Air and Space which was created in the former airport of Paris Le Bourget [17]. This last example shows that

strengthening the cognitive and educational values of historically important places is possible via the thoughtful choice of new functional programs and keeping clear what the old function of the place was. Such places could also contribute to the shaping of local identity and cause an increase in interest in the heritage of air transport [11].

4. Applications and summary

Aviation has aroused emotions since the beginning of its existence with air shows attracting huge crowds. The keen interest of constructors and engineers resulted in the constant modernization of flying machines, thus the popularization of air transport increased. Aviation is the youngest branch of the transport industry, but one of the fastest developing. All of the airports discussed in this article are the first such places in their countries. Firstly they were used as sports or military airfields and later began to be used for civilian traffic as well. Often soon after delineating areas intended for aviation purposes it turned out that these areas were too small and did not provide opportunities for the development of the airport infrastructure. The decisions to change the current location of the airports were made then. Some of the abandoned airports were reused for new functions and others were left alone.

All of the airports which have been discussed in this article have characteristics that affect the creation of social identity – these objects are reminders left after important historical events, and as well they transfer symbolic political and patriotic content. Every one of them is an important element in the history of aviation not only in the scale of their country but also in the European context. Although they could be regarded as symbols of the development of aviation, only a few have been honored by proper respect. Paris Le Bourget airport was partly adapted into a museum and the other part supports business flights. Similarly to this, the former Kraków-Czyżyny Airport fulfills museum and educational functions. Equally important in the historical context: Gdańsk-Wrzeszcz Airport, Johannisthal Airfield, and Berlin-Tempelhof Airport which are, like the two abovementioned airports, witnesses to important historical events in a more than regional range, are being treated marginally. The abandoned infrastructure of the Johannisthal airport could be probably used for cultural and social activities, although it is possible that soon this airport's area will be absorbed by new buildings as occurred in the case of Gdańsk-Wrzeszcz Airport. The only souvenirs left after the former events in Gdansk are a hangar converted into a shopping center and the remains of the concrete airstrip. It is difficult to identify the former use of the area and respect for the historical context is also difficult to find there. It couldn't be said that preserving the historical values for subsequent generations has been undertaken. It looks otherwise with the situation of the former airport Berlin-Tempelhof – an attempt to revitalize the airport was made. The area was dedicated to establishing a new park. However, in a part like in the case of Johannisthal it became a place for entertainment of the graffiti artists, the old terminal became a shelter for refugees also.

This article shows that the heritage of technology is an integral part of the cultural heritage. Therefore, industrial heritage, including buildings related to transport and its infrastructure

may become one of the means to achieve the aims which are formulated (among others) in the voivodeships's development strategy. Although it is possible to find a wide range of literature related to the heritage of technology, air transport is overlooked there. The research areas usually focus on land and marine transport infrastructure, however, it is possible to draw from the experience of these forms of transport for studies. Disciplines which are related to tourism raise the subject of the economic benefits of the use of airports for museum and educational purposes. Regrettably, the use of former airports for these purposes is small and in Poland, hardly ever. Though there are many abandoned airports, only a few stand out as significant participation in the building of European history, as those which were presented in the article. The examples of the Museum in Le Bourget and the Polish Aviation Museum in Kraków prove that it is possible to attractively reuse the remains of the former airports. Both airports were treated with proper reverence and respect the solemnity of the space. These examples show advantages that come from using former aviation areas: they might contribute to shaping public awareness of the history of the site, inform future generations about the essence of the place where they are as well as being used for the purposes of historical education and popularization of aviation heritage.

Former airports – regardless of the amount of the retained material – whether it is only a hangar or whole areas along with most of the airport infrastructure, might contribute to stimulating interest in the heritage of technology. The airports discussed in the article are symbols of past events and are also related to historical characters. They are important elements of the cultural heritage in the context of cities, countries and even Europe. Their remains may be a valuable element in shaping local identity and could result in increasing interest in the heritage of air transport as well as contributing to the preservation and transmission of important cultural values for future generations.

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The dumping of oscillatory phenomena in the process of bioethanol production by continuous fermentation

Tłumienie zjawisk oscylacyjnych w procesie produkcji bioetanolu metodą fermentacji ciągłej

Abstract

This article presents the results of numerical research on the dumping of oscillatory phenomena occurring in the continuous bioethanol production process. Proportional and proportional-integral types of controllers were tested for this purpose. Numerical analysis showed that the appropriate selection of the K_c value makes it possible to suppress the oscillations in the system. The introduction of the integral term improves the performance of control system. Using numerical calculations, it was shown that the PI controller is effective at dumping the occurring oscillations. The presence of the integral term allows the reduction of the gain coefficient value. After the proper selection of parameters, the PI controller effectively supresses the oscillations present in the system.

Keywords: bioethanol production, *Saccharomyces cerevisiae*, oscillatory behaviour, process control, PI controller

Streszczenie

W niniejszym artykule zaprezentowano wyniki badań numerycznych, dotyczących tłumienia zjawisk oscylacyjnych występujących w procesie produkcji bioetanolu metodą ciągłą. Przebadano w tym celu regulator typu proporcjonalnego oraz proporcjonalno-całkującego. Analiza numeryczna wykazała, iż odpowiedni dobór wartości współczynnika wzmocnienia K_c umożliwia tłumienie zjawisk oscylacyjnych w układzie. Wykazano także, iż wprowadzenie członu całkującego poprawia jego działanie. Za pomocą obliczeń symulacyjnych wykazano, że regulator proporcjonalno-całkujący dobrze radzi sobie z tłumieniem występujących oscylacji. Obecność członu całkującego pozwala na zredukowanie wartości współczynnika wzmocnienia. Po odpowiednim doborze parametrów, regulator PI skutecznie tłumi obecne w układzie oscylacje.

Słowa kluczowe: produkcja bioetanolu, *Saccharomyces cerevisiae*, zachowania oscylacyjne, sterowanie procesem, regulator PI

Nomenclature

C – intracellular storage carbohydrate concentration (g/g biomass)
D – dilution rate (h^{-1})
E – ethanol concentration ($g \cdot l^{-1}$)
G – glucose concentration ($g \cdot l^{-1}$)
G_0 – feed glucose concentration ($g \cdot l^{-1}$)
O – dissolved oxygen concentration ($mg \cdot l^{-1}$)
O^* – dissolved oxygen solubility limit ($mg \cdot l^{-1}$)
K_i – i-th pathway Michealis constant ($g \cdot l^{-1}$)
K_o – oxidative pathway oxygen saturation constant ($mg \cdot l^{-1}$)
X – biomass concentration ($g \cdot l^{-1}$)
Y_i – i-th pathway yield coefficient (g biomass $\cdot g^{-1}$ substrate)
e_i – i-th pathway intracellular enzyme concentration ($g \cdot g^{-1}$ biomass)
$k_L a$ – oxygen mass transfer coefficient (h^{-1})
r_i – i-th pathway growth rate (h^{-1})
$r_{i,\max}$ – maximum growth rate of all pathways at any instant (h^{-1})
u_i – i-th pathway cybernetic variable controlling enzyme synthesis
v_i – i-th pathway cybernetic variable controlling enzyme activity
α – specific enzymatic synthesis rate ($g \cdot g^{-1} \cdot h^{-1}$)
α^* – parameter for constitutive enzyme synthesis ($g \cdot g^{-1} \cdot h^{-1}$)
β – specific enzymatic degradation rate of intracellular enzymes ($g \cdot g^{-1} \cdot h^{-1}$)
γ_i – stoichiometric parameters ($g \cdot g^{-1}$)
φ_i – stoichiometric parameters ($g \cdot g^{-1}$)
μ_i – i-th pathway modified specific growth rate constant (h^{-1})
$\mu_{i\max}$ – i-th pathway maximum specific growth rate constant (h^{-1})
S – controller output signal
V – volume of bioreactor (m^3)
F_{vf} – volumetric flow rate of feed stream ($m^3 \cdot h^{-1}$)
K_p – gain coefficient of controller
T_i – time of integration
$e(t)$ – control error

On diagrams

LP – limit point
HB – Hopf bifurcation point

1. Introduction

Saccharomyces cerevisiae is a very important microorganism in many branches of industry and science [1]. One of its uses is in the production of bioethanol. Bioethanol is currently the most widely used biofuel in the world [2]. As a result, the improvement of its production process remains a very important challenge. A characteristic feature of continuous baker's yeast cultures is the occurrence of extracellular and intracellular parameter oscillations [3-9]. These parameters include among others the concentration of glucose, the concentration of ethanol, the pH value of the process environment, the concentration of biomass and the concentration of stored intracellular carbohydrates. In practice, the dumping of these oscillations is still a challenge which industrial companies do not always deal with [10]. For this reason, the possibility to suppress occurring oscillations is considered in this publication.

2. Mathematical model

The analysis involved the production of bioethanol under aerobic conditions, carried out in a continuous stirred tank bioreactor. The bioreactor is equipped with an automatic control system coupled with a valve regulating the volumetric flow rate of the feed stream. The process system is shown in Fig. 1.

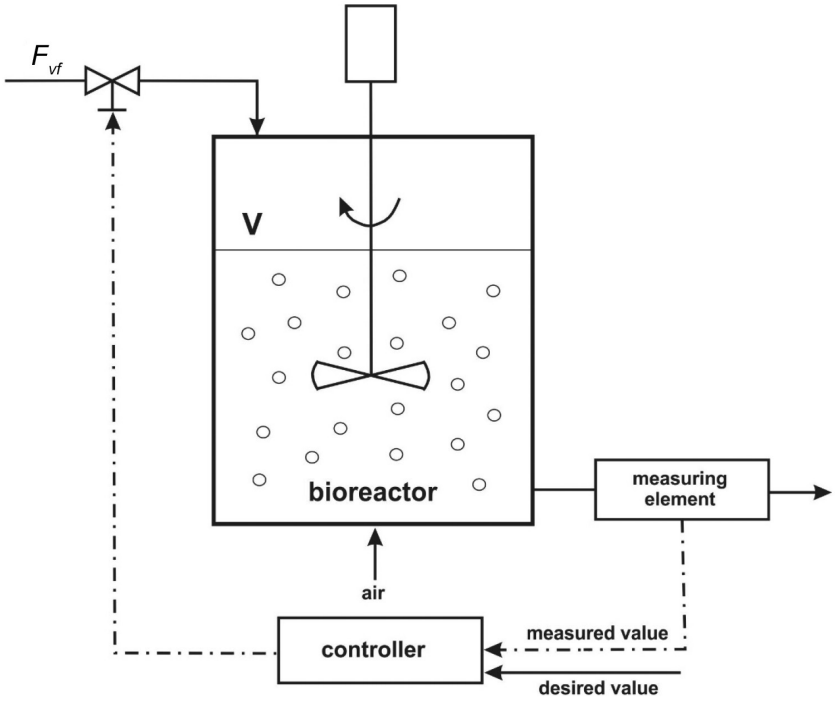

Fig. 1. Scheme of the process system with automatic bioreactor controller

2.1. Model of continuous stirred tank bioreactor

This biochemical process has been described by a structured and nonsegregated model of yeast growth dynamics [11]. The proposed model considers the occurrence of three biochemical reactions which are enzymatically controlled. These include the reaction of glucose fermentation (R_1), the reaction of ethanol oxidation (R_2) and the reaction of glucose oxidation (R_3). Biomass growth rates according to a given biochemical reaction are modelled by equations (1-3).

$$r_1 = \mu_1 e_1 \frac{G}{K_1 + G} \tag{1}$$

$$r_2 = \mu_2 e_2 \frac{E}{K_2 + E} \cdot \frac{O}{K_{O2} + O} \tag{2}$$

$$r_3 = \mu_3 e_3 \frac{G}{K_3 + G} \cdot \frac{O}{K_{O3} + O} \tag{3}$$

The specific growth rate in equations (1-3) is expressed by relationship (4).

$$\mu_i = \mu_{i\max} \frac{\mu_{i\max} + \beta}{\alpha + \alpha^*} \tag{4}$$

Metabolic pathways are regulated by cybernetic variables u_i and v_i (equations 5 and 6), which control the synthesis and activity of key enzymes. They are responsible for the dynamic competition between the three metabolic pathways, which is the characteristic feature of this model and it is confirmed by experimental research [11].

$$u_i = \frac{r_i}{\sum_j r_j} \tag{5}$$

$$v_i = \frac{r_i}{\max_j r_j} \tag{6}$$

The mathematical model of the process system includes eight state variables which can be classified into two different groups. The first group is comprised of extracellular process variables, such as glucose concentration (G), ethanol concentration (E), biomass concentration (X) and oxygen concentration in the liquid phase (O). The second group is formed of intracellular variables in the form of the concentration of stored carbohydrates (C), the concentration of enzymes catalysing the glucose fermentation reaction (e_1), the concentration of enzymes catalysing the ethanol oxidation reaction (e_2) and the concentration of enzymes catalysing the glucose oxidation reaction (e_3). Therefore, the aerobic continuous culture of microorganisms in a continuous tank bioreactor with perfect mixing (Fig. 1) can be described by the system of eight ordinary differential equations (7-14). Table 1 presents parameter values for the above-described model.

$$\frac{dG}{dt} = D \cdot (G_o - G) - \left(\frac{r_1 v_1}{Y_1} + \frac{r_3 v_3}{Y_3} \right) \cdot X - \varphi_4 \left(C \frac{dX}{dt} + \frac{dC}{dt} \right) \tag{7}$$

$$\frac{dX}{dt} = -D \cdot X + X \cdot \sum_i (r_i v_i) \tag{8}$$

$$\frac{dE}{dt} = -D \cdot E + \left(\varphi_1 \frac{r_1 v_1}{Y_1} - \frac{r_2 v_2}{Y_2} \right) \cdot X \tag{9}$$

$$\frac{dO}{dt} = -D \cdot O + k_L a \cdot (O^* - O) - \left(\varphi_2 \frac{r_2 v_2}{Y_2} + \varphi_3 \frac{r_3 v_3}{Y_3} \right) \cdot X \tag{10}$$

$$\frac{dC}{dt} = \gamma_3 r_3 v_3 - (\gamma_1 r_1 v_1 + \gamma_2 r_2 v_2) C - \sum_i (r_1 v_i) C \tag{11}$$

$$\frac{de_1}{dt} = \alpha u_1 \frac{G}{K_1 + G} - \left(\sum_i (r_i v_i) + \beta \right) e_1 + \alpha^* \tag{12}$$

$$\frac{de_2}{dt} = \alpha u_2 \frac{G}{K_2 + E} - \left(\sum_i (r_i v_i) + \beta \right) e_2 + \alpha^* \tag{13}$$

$$\frac{de_3}{dt} = \alpha u_3 \frac{G}{K_3 + G} - \left(\sum_i (r_i v_i) + \beta \right) e_3 + \alpha^* \tag{14}$$

Table 1. Values of kinetic parameters of the cybernetic model [12]

Parameter	Unit	Value	Parameter	Unit	Value
μ_{1max}	h^{-1}	0.44	K_1	$g \cdot l^{-1}$	0.05
μ_{2max}	h^{-1}	0.19	K_2	$g \cdot l^{-1}$	0.01
μ_{3max}	h^{-1}	0.36	K_3	$g \cdot l^{-1}$	0.001
Y_1	$g \cdot g^{-1}$	0.16	φ_1	$g \cdot g^{-1}$	0.403
Y_2	$g \cdot g^{-1}$	0.75	φ_2	$g \cdot g^{-1}$	2.087
Y_3	$g \cdot g^{-1}$	0.60	φ_3	$g \cdot g^{-1}$	1.067
$k_L a$	h^{-1}	225	φ_4	$g \cdot g^{-1}$	0.95
K_{O2}	$mg \cdot l^{-1}$	0.01	α	$g \cdot g^{-1} \cdot h^{-1}$	0.3
K_{O3}	$mg \cdot l^{-1}$	2.2	β	$g \cdot g^{-1} \cdot h^{-1}$	0.7
γ_1	$g \cdot g^{-1}$	10.0	α^*	$g \cdot g^{-1} \cdot h^{-1}$	0.03
γ_2	$g \cdot g^{-1}$	10.0	O^*	$mg \cdot l^{-1}$	7.5
γ_3	$g \cdot g^{-1}$	0.8			

2.2. Process Control

Biochemical processes are characterised by high response time delays of steady state disturbance. This is caused by running cell processes which are enzymatically catalysed [1]. When a disturbance occurs in the system, the reaction of the biomass cells must precede the intracellular synthesis of the relevant enzymes. Thus, the responses appearing in biological systems are slow. Therefore, controlling such a process requires the selection of the appropriate controller.

The basic automatic controller used in industry is a proportional controller (P). The dependence of the output signal on the control error is described by equation (15).

$$S(t) = \mathrm{S}(0) + K_p e(t) \tag{15}$$

This type of controller is used to control objects with small time constants and small delay times. In addition, the object should exhibit slow dynamics of occurring disturbances. A characteristic feature of this controller is the presence of a static error. This means that it is not possible to adjust the object to set the value with the P controller.

In the analysed case, the volumetric flow rate F_{vf} of the bioreactor feed stream was taken as the control variable. The dependence of the flow rate on time being the output signal of the controller is given by expression (16).

$$F_{vf}(t) = F_{vf}(0) + \mathrm{K}_p\, e(t) \tag{16}$$

After taking into account equation (16), the expression for the dilution rate, present in the balance equations of the bioreactor (7-14), takes the form of equation (17).

$$D = \frac{F_{vf}(0) + K_p e(t)}{V} \tag{17}$$

The proportional-integral controller (PI) is another commonly used controller in industry. The output signal is proportional to both the control error and the integral of the control error, as shown in equation (18).

$$S(t) = S(0) + K_p \left(e(t) + \frac{1}{T_i} \int_0^t e(t)dt \right) \tag{18}$$

PI controllers are used to control objects of any time constants and high time delays. It is possible to control an object in which there are significant but slowly changing disturbances. It is worth noting that its use allows complete removal of the static regulation error [13].

In the analysed case, the dependence of the volumetric flow rate F_{vf} from time, which is the output signal of the regulator, is shown in equation (19).

$$F_{vf}(t) = F_{vf}(0) + K_p\left(e(t) + \frac{1}{T_i}\int_0^t e(t)dt\right) \tag{19}$$

After considering equation (19), the expression for the dilution rate, present in the balance equations of the bioreactor (7-14), takes the form of equation (20).

$$D = \frac{F_{vf}(0) + K_p\left(e(t) + \frac{1}{T_i}\int_0^t e(t)dt\right)}{V} \tag{20}$$

The glucose concentration was taken as the control variable (G). Therefore, appearing in the above presented equations control error was defined by relationship (21).

$$e(t) = G_{SET} - G(t) \tag{21}$$

where:

G_{SET} – the set value of glucose concentration in system,
$G(t)$ – the current value.

3. Numerical techniques and calculations

The analysed system of ordinary differential equations (equations 7-14) does not have an analytical solution. In order to obtain a solution, it is necessary to perform numerical calculations. The first part of the calculations aimed at steady state analysis and the identification of the areas of oscillatory solutions was performed in the XPPAUT 8 program [14]. This program is integrated with the commonly used AUTO package for bifurcation analysis [15]. Based on the results of the bifurcation analysis, three sets of process parameters were selected; these are characterised by a different oscillation amplitudes. The second part of the calculations was performed using the Gear's method. This method is recommended for the numerical integration of stiff systems of ordinary differential equations [16]. Numerical studies included the determination of time trajectories and the simulation of proportional and proportional-integral controller operations on the process system in which oscillations occur.

4. Results and discussion

Section 4.1 presents example results of the bifurcation analysis and the process parameters for three selected limit cycles. In point 4.2, the process control area with a description of the automatic controller influence on the position of the control valve is defined. In sections 4.3 and 4.4, the results of numerical simulations showing the workings of the P and PI controllers and their influence on the stabilisation of the process system are presented.

4.1. Bifurcation analysis of steady states

An example of a bifurcation diagram obtained for the value of dilution rate $D = 0.1000\ [h^{-1}]$, is shown in Figure 2. The continuous line signified stable steady states and the unstable steady states are marked with a dashed line. As the bifurcation parameter, the concentration of glucose in the feed stream G_0 was used. The area of oscillatory solutions is determined by the Hopf bifurcation points HB_1 and HB_2. Both points are subcritical; this means that the limit cycles generated in their environment are unstable. Between points HB_1 and LP_1, unstable cycles are generated. In point LP_1, the nature of the oscillatory solutions changes and between the LP_1 and LP_2, stable cycles are generated. In LP_2, the system loses its stability again, which recovers at LP_3. Then, between the points LP_3 and LP_4, stable limit cycles are again generated. However, in point LP_4, the system loses stability once more.

In Fig. 2, three selected values of process parameters have been marked with a vertical dashed line. These are analysed in the following sections. The generated oscillatory time series for selected values of process parameters are shown in Figure 3. Their course indicates the high dynamics of the analysed process.

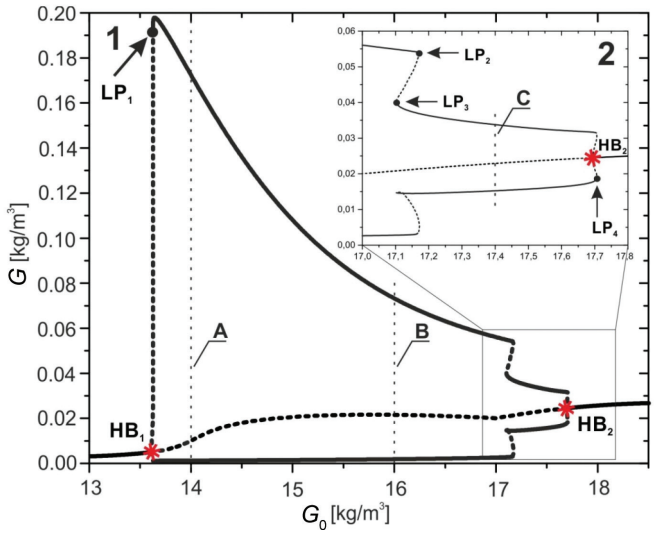

Fig. 2. Bifurcation diagram for value of dilution rate $D = 0.1000\ [h^{-1}]$ relative to feed stream glucose concentration G_0; A – $G_0 = 14.0\ [kg/m^3]$, B – $G_0 = 16.0\ [kg/m^3]$, C – $G_0 = 17.4\ [kg/m^3]$

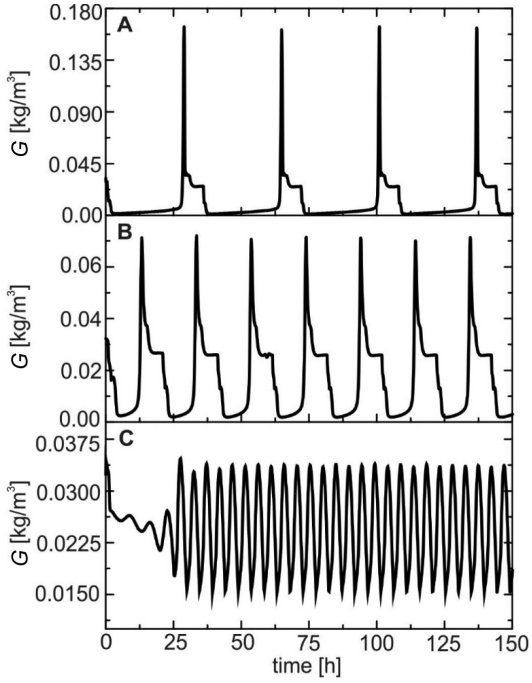

Fig. 3. Time trajectories of glucose concentrations (G); A – $G_0 = 14.0$ [kg/m³], $D = 0.1000$ [h⁻¹]; B – $G_0 = 16.0$ [kg/m³], $D = 0.1000$ [h⁻¹]; C – $G_0 = 17.4$ [kg/m³], $D = 0.1000$ [h⁻¹]

4.2. Definition of process control area

The control of the process system is accomplished via a valve, which regulates the value of feed stream flow. It is therefore necessary to define the area of flow rates that it can regulate. For this purpose, the value of the critical dilution rate D_{kr} was determined. This value is the process limit, beyond which the biomass cells are washed out from the system. This situation is illustrated by the bifurcation diagram shown in Fig. 4. The diagram was made for three predefined sets of process parameter values. On the basis of this, the approximate value of $D_{kr} = 0.4$ [h⁻¹] was determined.

Having the D_{kr} value and the assumed volume of the bioreactor $V = 10$ [m³], it is possible to estimate the maximum stream feed flow through the bioreactor below which the process may run. In the analysed case, it is $F_{vf\max} = 4.0$ [m³/h]. This means that the control valve must regulate the flow rate in the range from 0 (in the closed position) to $F_{vf\max}$ (in the fully open position). Next, using this value and the assumed diameter of the bioreactor feeding pipe $d = 0.1$ [m], the maximum flow rate of the stream feed through this pipe was estimated to be $U_{\max} = \frac{4F_{vf\max}}{3600\pi d^2} = 0{,}142$ [m/s]. This is a rational value that can occur in a real industrial process.

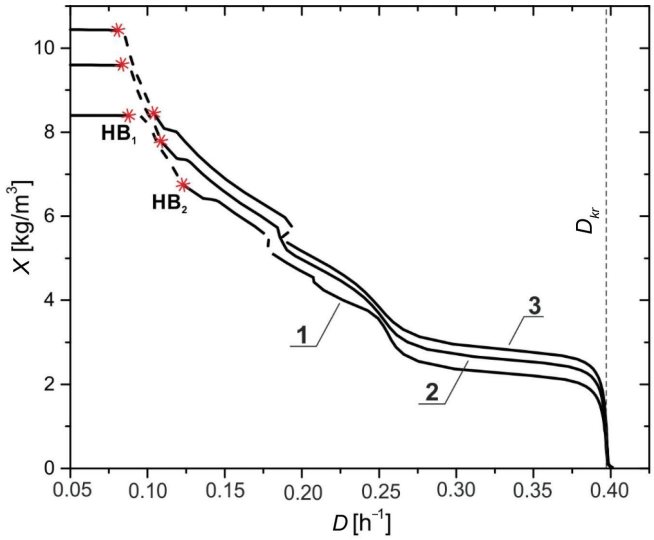

Fig. 4. Bifurcation diagram for G_0 = 14.0 [kg/m³] (1), G_0 = 16.0 [kg/m³] (2), G_0 = 17.4 [kg/m³] (3), relative to dilution rate D, made to determine the value of critical dilution rate D_{kr}

4.3. Evaluation of the possibility of controlling the process system using the P controller

The possibility of controlling the oscillatory behaviours using a proportional controller was investigated. For this purpose, numerical simulations were performed for all three oscillatory trajectories, assuming three different values of the gain coefficient K_{c1} = 25.0, K_{c2} = 34.0 and K_{c3} = 45.0. In the simulations, the glucose concentration in the system was set at G_{SET} = 0.03 [kg/m³]; this is marked in Fig. 5 with horizontal dashed blue lines.

The conducted research has shown that for the assumed value K_{c1} = 25.0, the controller is able to suppress oscillations for stationary states B and C, as shown in Fig. 5.A2 and 5.A3. It is not able to control the steady state A, which is shown in Fig. 5.A1. In this case, the controller suppresses the occurring oscillations, the amplitude of which decreases but does not disappear. In the case of the other two values of the gain factor K_{c2} = 34.0 and K_{c3} = 45.0, the controller suppresses the occurring oscillations for all three stationary states (diagrams 5.B1-3 and 5.C1-3). Furthermore, the numerical investigations showed that the setting K_{c2} = 34.0 is the lowest value of the controller gain coefficient, for which the controller suppresses oscillations occurring in the system with different amplitudes for steady states A, B and C. Unfortunately, as mentioned before, this type of controller is not able to compensate the regulation error completely. As a consequence, its value stabilises at a certain level, so that the system does not reach the set point G_{set}.

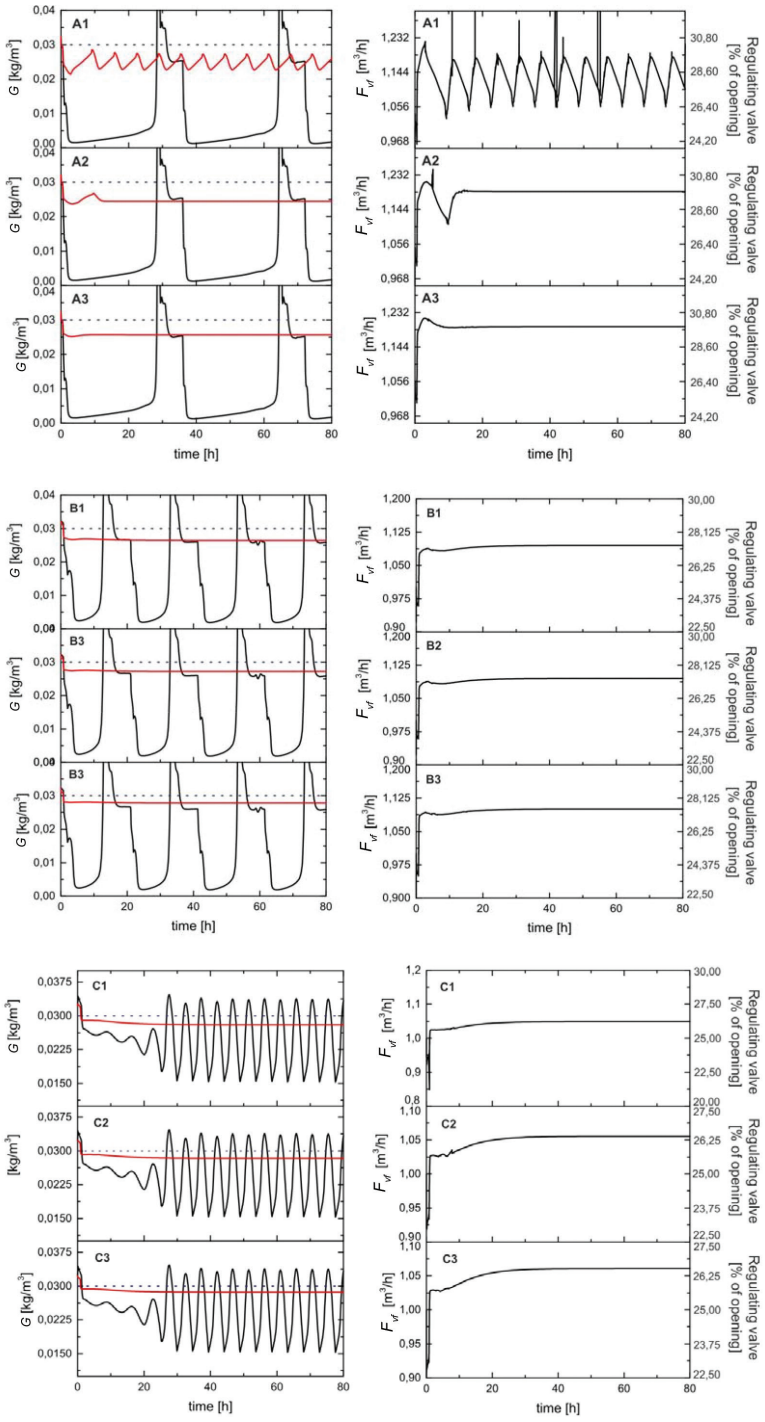

Fig. 5. Dumping of oscillations for the value of gain factor $K_{c1} = 25.0$, and $K_{c2} = 45.0$; A – $G_0 = 14.0$ [kg/m^3], $D = 0.1000$ [h^{-1}]; B – $G_0 = 16.0$ [kg/m^3], $D = 0.1000$ [h^{-1}]; C – $G_0 = 17.4$ [kg/m^3], $D = 0.1000$ [h^{-1}]

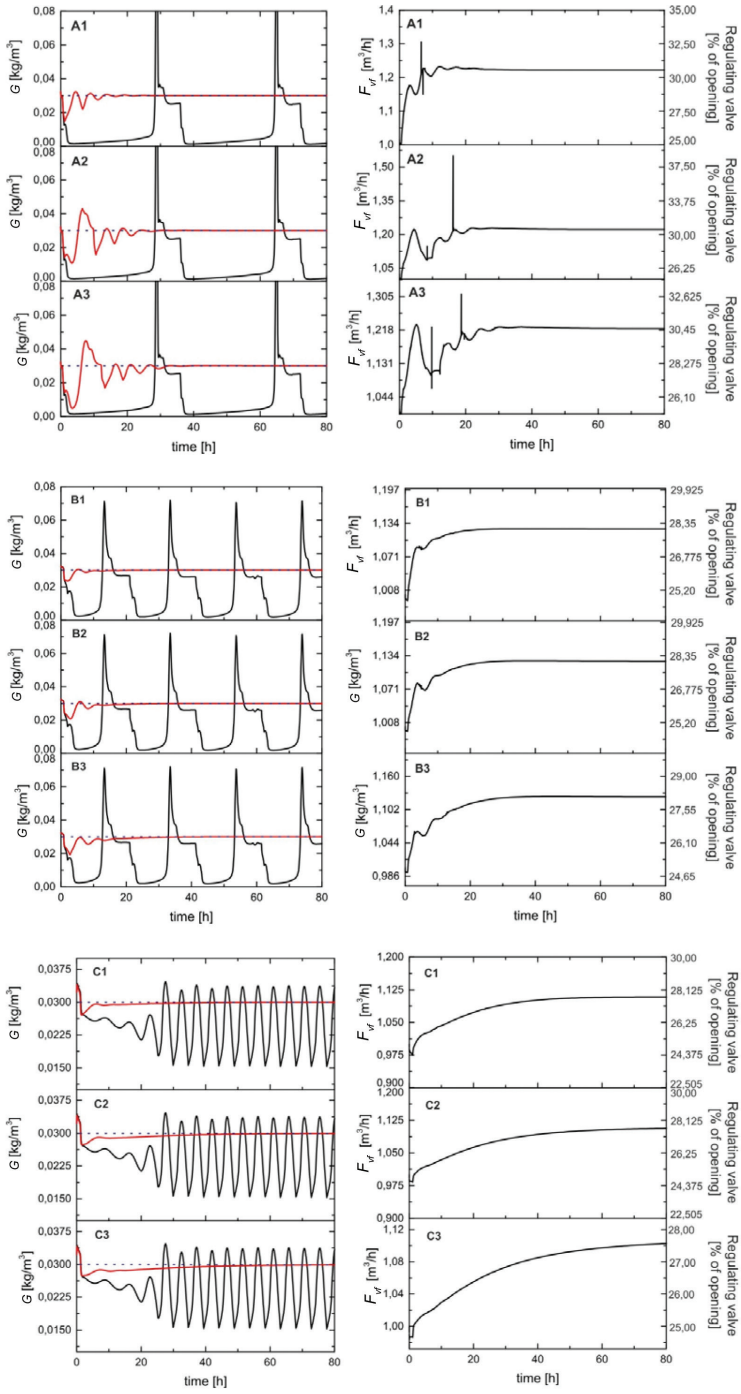

Fig. 6. Dumping of oscillations for the value of gain factor $K_c = 3.0$ and time of integration $T_{i1} = 0.5$, $T_{i2} = 1.0$, $T_{i3} = 1.5$ A – $G_0 = 14.0$ [kg/m³], $D = 0.1000$ [h⁻¹]; B – $G_0 = 16.0$ [kg/m³], $D = 0.1000$ [h⁻¹]; C – $G_0 = 17.4$ [kg/m³], $D = 0.1000$ [h⁻¹]

4.4. Evaluation of the possibility of controlling the process system using the PI controller

Due to the occurrence of a static error in the case of the P controller, as a result of which the system was not able to reach the settled value of G_{SET}, it was decided to investigate the proportional-integral controller (PI). Similarly to the previous case, a series of PI controller simulations were performed for all three selected oscillatory steady states. On the basis of these, the values of the gain coefficient $K_c = 3.0$ and time of integration $T_{i1} = 0.5$, $T_{i2} = 1.0$, $T_{i3} = 1.5$ were proposed. Also in this case, a set point of glucose concentration in the system was assumed to $G_{SET} = 0.03$ [kg/m^3]; this is marked on the diagrams in Fig. 6 with horizontal dashed blue lines.

The addition of an integral term resulted in a significant reduction of the gain coefficient value K_c. For the analysed set of gain coefficients and integration times, the controller suppressed oscillations each time and reached the set point G_{SET} (Fig. 6.A1-3, 6.B1-3 and 6.C1-3). Thus, the introduction of the integral term eliminated the occurrence of a static error. The performed research also showed that increasing the value of the integration time T_i has a negative effect on the suppression of oscillations in the system. This is manifested by the extension of the time required to reach the stable steady state.

5. Conclusions

The numerical tests aimed at estimating the possibility of the suppression of oscillations occurring during the production of bioethanol using a continuous method were performed. Proportional and proportional-integral types of controller were tested for this purpose. Numerical analysis showed that by appropriate selection of gain coefficient value K_c, it is possible to regulate the oscillatory phenomena in the system. Unfortunately, this type of controller is accompanied by the occurrence of a static control error. This fact may disqualify this type of regulation for industrial use. The introduction of the integral term into the control system significantly improves its operation. As a result, the proportional-integral controller is effective at dumping the occurring oscillations. In addition, a system with this type of regulation is able to compensate the regulation error completely. The presence of the integral element results in a significant reduction of the gain coefficient value. After proper selection of settings, the PI controller is able to effectively suppress the oscillating phenomena occurring in the continuous process of bioethanol production.

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Influence of a multi-method style of narration style on stimulating learning environments in a museum

Wpływ narracji polimetodycznej na przekaz edukacyjny w muzeum

Abstract

In this paper, an analysis of the impact of interactive technologies on stimulating learning experiences in a museum is presented. For research purposes, the Family Home of John Paul II Museum in Wadowice was chosen as a case study. The exhibition of the Museum in Wadowice uses a multi-method style of narration with its visitors. The museum utilizes the traditional method of exhibiting artifacts however, due to the demands of the contemporary visitor who is accustomed to life in a world of moving images, interactivity and mobile media, the exhibit proposes an enriched form of communication.

Keywords: museum, transdisciplinary, John Paul II, communication, exibition

Streszczenie

W artykule przeanalizowano wpływ interaktywnych technologii multimedialnych na ludzkie procesy poznawcze w muzeum. Jako przykład autorzy wybrali Muzeum Dom Rodzinny Jana Pawła II w Wadowicach. Ekspozycja opisanego muzeum używa do komunikowania z odbiorcą narracji polimetodycznej. Muzeum wykorzystuje tradycyjną metodę ekspozycji pamiątek. Jednakże ze względu na zapotrzebowanie odbiorcy żyjącego w epoce ruchomych obrazów, interaktywności i mobilności mediów proponuje się w eskpozycji ubogacenie przekazu.

Słowa klucze: muzeum, transdyscyplinarność, Jan Paweł II, komunikacja, wystawa

1. Introduction

Nowadays, increasing the number of visitors is an important task for every museum operator [1]. Due to the extent to which information technology (IT) has enhanced f human learning [2], designers of museum exhibitions have many opportunities to create friendly learning environments. Consequently, it is possible to design modern museum exhibitions in a more multifaceted fashion, while combining different types of IT tools into a cohesive entity [3, 4]. This research aims at analyzing the impact of a multi-method style of narration on stimulating learning environments in a museum. For purpose of this research, the Family Home of John Paul II Museum in Wadowice was chosen as a case study [5–7].

2. Experiential design of a museum space

One of the major shifts in museum and exhibit design in the last decade has been a focus on visitor experience. Experience design is not driven by a single design discipline. Instead, it requires a transdisciplinary perspective that considers multiple aspects. For every museum, the human-exhibition interaction (HEI) is one of the most important issues to be studied during an exhibition design process[8]. In general, the HEI relates to the behavior data (BD), the interactive communication among exhibition design factors (EDFs) and audience experience factors (AEFs). In Fig. 1, the framework of human-exhibition interaction (HEI) as a communication process is presented [8].

The main factor which determines the architecture of a museum is the final location of the exhibition (cityside, park, or inside a building). This context has to be used for assembling the museum space despite the fact that it also imposes certain limitations on designers. The architecture of the museum is expressed in its various parts, i.e. the architecture also contributes to the museum as a whole. The process of museum design often mirrors the architectural process or schedule, moving from a conceptual plan, through schematic design, design development, contracting process, to fabrication and installation. The first stages establish a thematic direction and improve creative and appropriate design keys to realize the interpretive and communication goals of the exhibition. The final stages employ technical expertise in translating the visual language of the designs into detailed documents that provide all the specifications required to fabricate and install an exhibit.

Taking into consideration the structural as well as architectural points of view, there are two basic cases for this type of projects, i.e. the exhibition space which is located in a historical building, and the exhibition space which is part of a newly-created building. However, for both cases, the process of developing an exhibit (from a concept, to a physical, three dimensional exhibition) has to be solved. The main goal of this process is to assemble a communicative environment that 'tells a story' in a three dimensional architectural space.

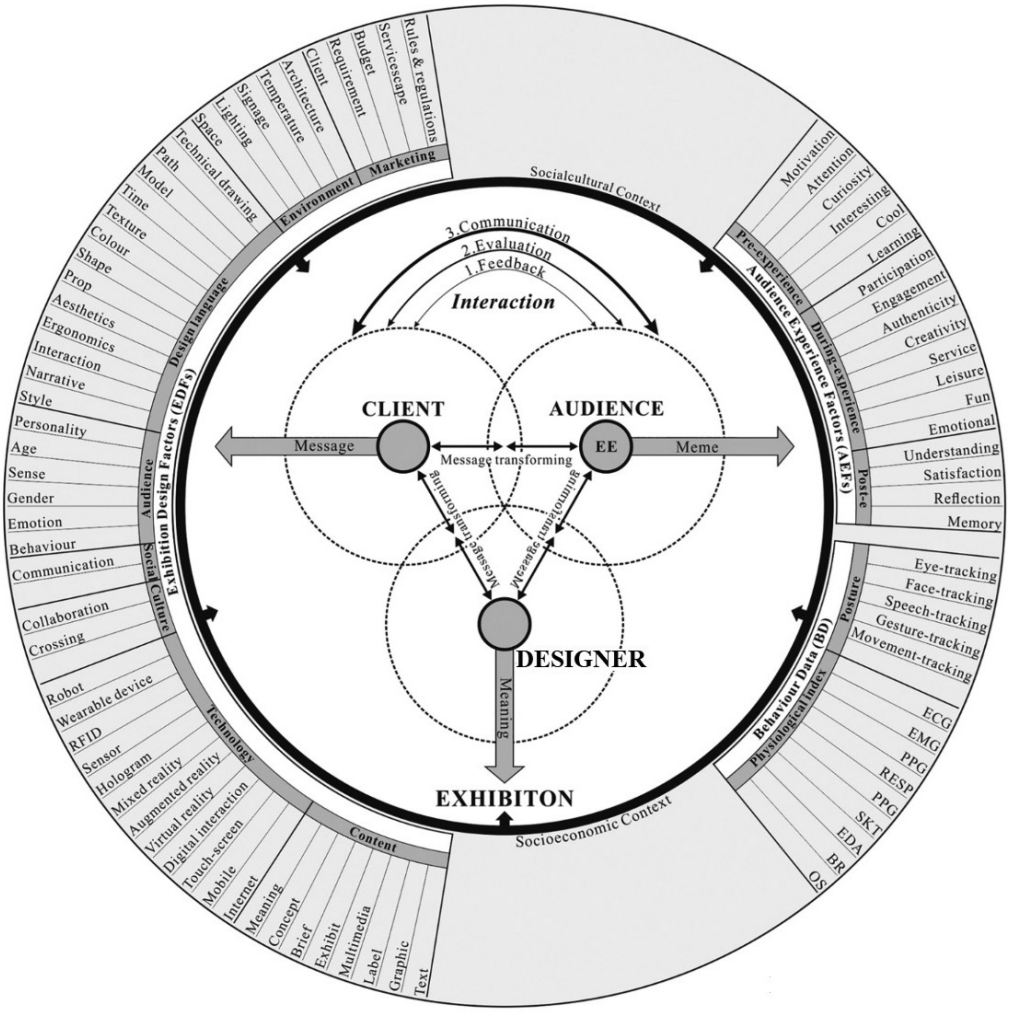

Fig. 1. Framework of HEI with EDFs, AEFs, and BD in exhibition design [8]

3. The new exhibition in the Family Home of John Paul II Museum in Wadowice

The exhibition arranged in the Family Home of John Paul II Museum in Wadowice – a facility reopened in 2014 – uses multi-method narration to communicate with the visitor. The presentation of values that guided the character therefore becomes more attractive and each recipient may find the most suitable methods of acquiring knowledge and discovering the character. Along with polymethodic narration of the exhibition, there can be observed a tendency for designing, building, and creating architectural environments that allow efficient, safe and comfortable, one-way flow of visitors through the maze of artifacts, musical experiences and visual representations. The spatial arrangement of the new museum allows

for a build-up of a dramatic tension, while representing the life of the Polish Pope. At the same time, the museum does not abandon traditional methods of exposing several hundred of collected exhibits. Resignation from traditional methods of exposing may not only seem inconsiderate and hard to understand in terms of showing a historical person to different generations of people, but can also be alien to the museum's methodology, which aims to bring the visitor closer to the original document and the heritage left by former years or centuries. However, due to the demands of society living in times of mobile images, interactivity and media mobility, the exhibition is enriched in the aforementioned way.

The exhibition leads visitors or pilgrims through an educational route presenting various facets of a person's life . Such behavioral setting of the exhibition radically influences the liveliness of the relationship between the character (John Paul II), the sender (the author of the exhibition) and the receiver (visitor). Therefore, besides exposing collected exhibits and artifacts,modern museums of today show a very efficient model of communication derived from the world of theater, cinema or educational games (mazes, for instance). This world of dynamic relationships becomes a new achievement of museum staging. Naturally, the process is supported by the use of digital media, which facilitate intuitive handling of the history, context, background, backdating and recognizing recent biographies of characters. This tendency can already be distinguished in many museums built around the globe. The main idea is to experience a specific kind of catharsis and to get to understand major moral values shared by the character. Emotions, assembly of attractions, interactivity and educational paths all are elements of various exhibitions, from which the museum in Wadowice stands out as the place.

4. The relationship between the exhibition and the architecture of the museum

The emergence of new media, new generations of visitors and a particular trend of popularizing history all have changed the concept of a museum, especially in terms of the approach to how an exhibition is organizaed. Those factors did influence the architectural design of the museum The volume of the object has been adapted to create a path of visit, so that the guests can learn about the character's life by accompanying him throughout its various moments. That allowed for the creation of a space that presents a consistent message, while simultaneously creating a frinedly, educational environment. In Wadowice, the visitor can see the entire history of John Paul II's life by visiting subsequent floors of the museum. Exhibition on each floor is divided into several thematic zones.

As a result of a cooperation between the exhibition's creator and the architect, an easy-to-follow, one-way path of visit was arranged inside the building. Operating within the existing tissue of the old tenement house, a number of different volumes and spaces were assembled to create a maze-like interior. All consequently connected, yet different spaces make it possible to arrange them in diverse styles to suit numerous functions.

The tour through the museum begins on the ground floor. Starting from the entrance door, the first section of the exhibition is placed in a corridor, chronologically showing

artifacts from the Pope's young years and later allowing guests to experience first signs of his spiritual vocation. At the end of the hallway, a staircase leads the guests to access a balcony on the second floor (Fig. 2a). The Wojtyła Family home accessed from its balcony (which for the convenience of guests is now a part of an interior, glazed-roof atrium) is a significant break between the Pope's life adventures' presentation. As opposed to the previous part that mostly influenced the cognitive activity of the visitor, this part tries to influence the viewer's perception through emotions and the space'scomplete realism. Meandering through the sequence of artifacts, visitors enter another space. A strong *genius loci* of the sloping ramp, prompts reflection among visitors (Fig. 2b). Hanging banners prepared by pilgrims for the series of the Pope's pilgrimages only strengthen the emotions during that uphill walk. The main part of the top floor's exhibition is occupied by a darkened corridor, prepared for the interactive display and sound experiences of all 104 pilgrimages undertaken by the Pope. That completely neutral architectural character of the space is only interrupted by an illuminated floor path leading to the most important artifact in the room: the revers of the original image of God's Mercy with John Paul II's handwriting, exposed at the end of the corridor (Fig. 2c). The last part of the exhibition, the basement, is filled with many small rooms, many of which tend to create the atmosphere of meditation. Most significant architectural feature is the

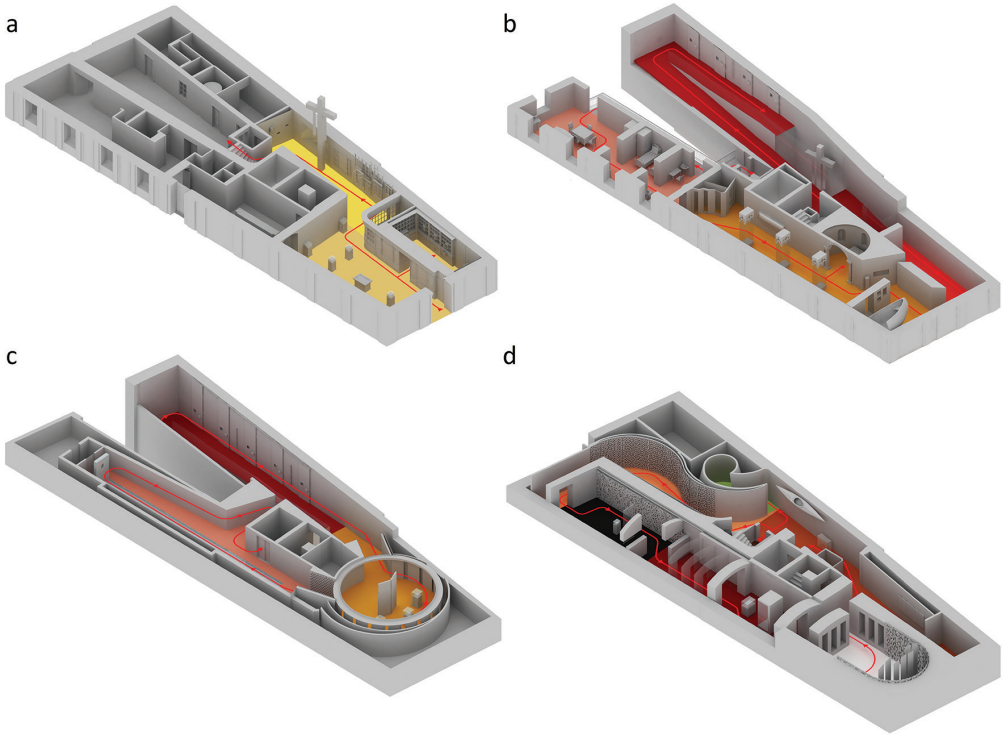

Fig. 2. Architecture of the museum: a) ground floor of the building – exhibition in the hallway (yellow) leading to the staircase; b) the flat of Wojtyła Family (pink) and the sloping ramp (red) prompt reflection among visitors; c) a long, dark room (pink) is set as a neutral background for interactive exhibition; d) curved walls (orange, green) emphasize the importance of the space

curving wall covered with a mosaic showing the Pope with young pilgrims: a very important part of John Paul II's vocation. Going further, the visitor walks into a spiral corridor, ending with a circular room: a place to fall into a deep reverie (Fig. 2d).

The technical capabilities provided by new media techniques, combined with all the artifacts gathered in the museum are presented in consciously designed spaces, which seem to play an equally important role in creating an interesting, completed exhibition.

5. Conclusion

On the basis of the analysis of how a multi-method style of narration stimulates learning environments in the Family Home of John Paul II Museum in Wadowice, the following main conclusions can be drawn from the investigation:

- A clear understanding of visitor post-purchase decision-making process can contribute to enhancing the number of visitors, which is an important task for every museum operator. Regarding this observations, good cooperation between museum operators, architects as well as communication specialists is necessary;
- The new trends in museum narration seem to be permanently embedded in the architectural space of cultural institutions. Especially modern IT tools open new possibilities to make museum exhibitions more cohesive as well as more legible. Moreover, because of modern IT tools, it is possible to share the message of the museum's exhibition to a greater number of visitors;
- Nowadays, the multi-method style of narration is necessary for creating stimulating learning environments. Considering the generational changes and their impact on communication styles as well as learning IT methods, all have great influence on museum spaces and exhibitions. It should be pointed out that IT tools and cohesive architectural space are both very important factors which influence the legibility of museum exhibition. On the other hand, it must be emphasized that artifacts are still irreplaceable when it comes to the museum exhibitions.

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Nonlinear second-order delay differential equation

Nieliniowe równanie różniczkowe rzędu drugiego z opóźnieniem

Abstract

The aim of this paper is to prove the theorem on the existence and uniqueness of the classical solution of the initial-boundary value problem for a nonlinear second-order delay differential equation. For this purpose, we apply the Banach contraction principle and the Bielecki norm. The paper is based on publications [1–7] and is a generalisation of publication [6].

Keywords: second-order delay equation, initial-boundary value problem, Banach contraction principle, Bielecki norm

Streszczenie

W artykule udowodniono twierdzenie o istnieniu i jednoznaczności klasycznego rozwiązania zagadnienia początkowo-brzegowego dla nieliniowego równania różniczkowego rzędu drugiego z opóźnieniem. W tym celu stosowane jest twierdzenie Banacha o punkcie stałym i norma Bieleckiego. Artykuł bazuje na publikacjach [1–7] i jest uogólnieniem publikacji [6].

Słowa kluczowe: równanie rzędu drugiego z opóźnieniem, zagadnienie początkowo-brzegowe, twierdzenie Banacha o punkcie stałym, norma Bieleckiego.

1. Preliminaries

Is this paper, we study the following problem

$$x''(t) = f(t, x_t, x'(t)), \quad t \in [0,T], \ T > 0, \tag{1.1}$$

$$x_0 = \phi, \quad x'(T) = \beta x'(0), \quad \beta > 1, \tag{1.2}$$

where $f : [0,T] \times C([-\tau,0],\mathbb{R}) \times \mathbb{R} \to \mathbb{R}$ and $\phi \in C([-\tau,0],\mathbb{R})$, $\tau > 0$, are given functions.

Therefore, for any function $x : [-\tau,T] \to \mathbb{R}$ and any $t \in [0,T]$, we denote by x_t the function $x_t : [-\tau,0] \to \mathbb{R}$ defined by the formula $x_t(s) = x(t+s)$, $s \in [-\tau,0]$.

It is easy to see that the condition $x_0 = \phi$ means that $x(s) = \phi(s)$, $s \in [-\tau,0]$.

Moreover, for $\phi \in C([-\tau,0],\mathbb{R})$ we use the norm

$$\|\phi\|_0 = \sup_{-\tau \le s \le 0} |\phi(s)|.$$

2. Theorem on the existence and uniqueness of the classical solution

Let $C^* := C([-\tau,T],\mathbb{R}) \cap C^2([0,T],\mathbb{R})$.

Definition 2.1. The function $x \in C^*$ is said to be a solution of problem (1.1) – (1.2) if x satisfies equation (1.1) and conditions (1.2).

Now, we will prove the following lemma:

Lemma 2.1. Function $x \in C^*$ is a solution of problem (1.1)–(1.2), where $f \in C([0,T] \times C([-\tau,0],\mathbb{R}) \times \mathbb{R}, \mathbb{R})$ if and only if x is a solution of the following integral equation:

$$x(t) = \begin{cases} \phi(t), & t \in [-\tau,0], \\ \phi(0) + \dfrac{t}{\beta - 1} \displaystyle\int_0^T f(s, x_s, x'(s))ds + \int_0^t (t-s) f(s, x_s, x'(s))ds, & t \in [0,T]. \end{cases}$$

Proof. If $x \in C^*$ is a solution of (1.1) – (1.2) then we have

$$x''(t) = f(t, x_t, x'(t)), \quad t \in [0,T]. \tag{2.1}$$

Integration by parts gives

$$x(t) = x(0) + tx'(0) + \int_0^t (t-s)x''(s)ds. \tag{2.2}$$

Differentiating (2.2), we get

$$x'(t) = x'(0) + \int_0^t x''(s)ds.$$

Thus,

$$x'(T) = x'(0) + \int_0^T x''(s)ds.$$

Applying the boundary condition we obtain

$$x'(0) + \int_0^T x''(s)ds = \beta x'(0).$$

Thus,

$$x'(0) = \frac{1}{\beta - 1}\int_0^T x''(s)ds. \tag{2.3}$$

Equation (2.2), together with (2.1) and (2.3), imply

$$x(t) = \phi(0) + \frac{t}{\beta - 1}\int_0^T f(s, x_s, x'(s))ds + \int_0^t (t-s)f(s, x_s, x'(s))ds. \tag{2.4}$$

Conversely, if x is a solution of equation (2.4) then direct differentiation of (2.4) gives

$$x'(t) = \frac{1}{\beta - 1}\int_0^T f(s, x_s, x'(s))ds + \int_0^t f(s, x_s, x'(s))ds,$$

$$x''(t) = f(t, x_t, x'(t)), \quad t \in [0, T].$$

Thus,

$$x'(0) = \frac{1}{\beta - 1}\int_0^T f(s, x_s, x'(s))ds,$$

$$x'(T)=\frac{1}{\beta-1}\int_0^T f(s,x_s,x'(s))ds+\int_0^T f(s,x_s,x'(s))ds=\frac{\beta}{\beta-1}\int_0^T f(s,x_s,x'(s))ds,$$

which gives

$$x'(T)=\beta x'(0).$$

The proof of Lemma 2.1 is complete.

Now, using Lemma 2.1 and the Banach contraction theorem, we shall prove the existence and uniqueness of the solution for problem (1.1) – (1.2).

Theorem 2.1. Assume that $f\in C([0,T]\times C([-\tau,0],\mathbb{R})\times\mathbb{R},\mathbb{R})$ and there exists $m\in L^1([0,T],\mathbb{R}_+)$ such that

$$\left|f(t,u,z)-f(t,\tilde{u},\tilde{z})\right|\le m(t)(\left\|u-\tilde{u}\right\|_0+\left|z-\tilde{z}\right|) \tag{2.5}$$

for all $t\in[0,T]$, $u,\tilde{u}\in C([-\tau,0],\mathbb{R})$, $z,\tilde{z}\in\mathbb{R}$ and

$$M(T)<\frac{\ln\beta}{T+1}, \tag{2.6}$$

where $M(t):=\int_0^t m(r)dr.$

Then problem (1.1) – (1.2) has a unique solution $x\in C^*$.

Proof: for $x\in C^1([0,T],\mathbb{R})$ let

$$\left\|x\right\|_1:=\max_{s\in[0,T]}\left\{e^{-\gamma M(s)}(\max_{r\in[0,s]}\left|x(r)\right|+\left|x'(s)\right|)\right\},$$

where

$$T+1<\gamma<\frac{\ln\beta}{M(T)}. \tag{2.7}$$

Define an operator

$$F:C^1([0,T],\mathbb{R})\to C^1([0,T],\mathbb{R})$$

by the formula

$$(Fx)(t)=\phi(0)+\frac{t}{\beta-1}\int_0^T f(s,x_s,x'(s))ds+\int_0^t (t-s)f(s,x_s,x'(s))ds,$$

where $x_s(r)=x(s+r)=\phi(s+r)$ for $s+r\le 0$.

For any $x,y\in C^1([0,T],\mathbb{R})$ and $t\in[0,T]$, by (2.5), we have

$$\left|(Fx)(t)-(Fy)(t)\right|\le\frac{t}{\beta-1}\int_0^T\left|f(s,x_s,x'(s))-f(s,y_s,y'(s))\right|ds$$

$$+\int_0^t(t-s)\left|f(s,x_s,x'(s))-f(s,y_s,y'(s))\right|ds$$

$$\le\frac{t}{\beta-1}\int_0^T m(s)\left(\left\|x_s-y_s\right\|_0+\left|x'(s)-y'(s)\right|\right)ds$$

$$+\int_0^t(t-s)m(s)\left(\left\|x_s-y_s\right\|_0+\left|x'(s)-y'(s)\right|\right)ds$$

$$\le\frac{T}{\beta-1}\int_0^T m(s)\left(\left\|x_s-y_s\right\|_0+\left|x'(s)-y'(s)\right|\right)ds$$

$$+T\int_0^t m(s)\left(\left\|x_s-y_s\right\|_0+\left|x'(s)-y'(s)\right|\right)ds.$$

Observe that (see[6])

$$\left\|x_s-y_s\right\|_0=\max\{\left|x(r)-y(r)\right|,\ r\in[0,s]\}\ \text{ if } s\in[0,\tau]$$

and

$$\left\|x_s-y_s\right\|_0\le\max\{\left|x(r)-y(r)\right|,\ r\in[0,s]\}\ \text{ if }\ s\in(\tau,T].$$

Therefore,

$$\left|(Fx)(t)-(Fy)(t)\right|$$

$$\leq \frac{T}{\beta-1}\int_0^T m(s)e^{\gamma M(s)}e^{-\gamma M(s)}\left(\max_{r\in[0,s]}\left|x(r)-y(r)\right|+\left|x'(s)-y'(s)\right|\right)ds$$

$$+T\int_0^t m(s)\ e^{\gamma M(s)}e^{-\gamma M(s)}\left(\max_{r\in[0,s]}\left|x(r)-y(r)\right|+\left|x'(s)-y'(s)\right|\right)ds$$

$$\leq \frac{T}{\beta-1}\left\|x-y\right\|_1\int_0^T m(s)e^{\gamma M(s)}ds+T\left\|x-y\right\|_1\int_0^t e^{\gamma M(s)}ds$$

$$=\frac{T}{\beta-1}\left\|x-y\right\|_1\frac{1}{\gamma}e^{\gamma M(s)}\Big|_0^T+T\left\|x-y\right\|_1\frac{1}{\gamma}e^{\gamma M(s)}\Big|_0^t$$

$$=\frac{T}{\gamma}\left\|x-y\right\|_1\left(\frac{e^{\gamma M(T)}-\beta}{\beta-1}+e^{\gamma M(t)}\right).$$

It follows from (2.7) that

$$e^{\gamma M(T)}-\beta<0.$$

Consequently,

$$\left|(Fx)(t)-(Fy)(t)\right|\leq\frac{T}{\gamma}\left\|x-y\right\|_1 e^{\gamma M(t)}. \tag{2.8}$$

Observe that

$$(Fx)'(t)=\frac{1}{\beta-1}\int_0^T f(s,x_s,x'(s))ds+\int_0^t f(s,x_s,x'(s))ds.$$

Thus,

$$\left|(Fx)'(t)-(Fy)'(t)\right|\leq\frac{1}{\gamma}\left\|x-y\right\|_1\ e^{\gamma M(t)}. \tag{2.9}$$

From (2.8), (2.9) and from the definition of the norm $\|\cdot\|_1$, we have

$$\|Fx - Fy\|_1 \leq \frac{T+1}{\gamma}\|x - y\|_1. \tag{2.10}$$

By (2.10) and (2.7), F is a contractive operator. Consequently, by the Banach fixed point theorem, the proof of Theorem 2.1 is complete.

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A THREE-WAY CATALYST SYSTEM FOR A FIVE-STROKE ENGINE

TRÓJFUNKCYJNY REAKTOR KATALITYCZNY DLA SILNIKA Z DODATKOWYM ROZPRĘŻANIEM GAZÓW WYLOTOWYCH

Abstract

This paper presents the results of research on the development of an exhaust gas aftertreatment system for a turbocharged five-stroke engine. This engine was designed and constructed at Cracow University of Technology. A characteristic feature of the five-stroke engine is the use of an additional expansion process to increase overall efficiency. A challenge for a catalytic converter is the fact that it has a low exhaust gas temperature. Two three-way catalytic converters were tested – one with a ceramic support and the second with a metal support. The results of the tests showed that the reactor with a ceramic support obtains an acceptable conversion efficiency starting with an exhaust gas temperature of 280°C. For the metal-support reactor, a few percent increase in torque and a decrease in the brake-specific fuel consumption of the engine was obtained; however, the converter itself did not show signs of operation even with an exhaust gas temperature of over 380°C. The performed analyses highlighted directions of further development works in this area.

Keywords: five-stroke engine, spark ignition, three-way catalyst, exhaust gas aftertreatment, conversion efficiency

Streszczenie

W artykule przedstawiono efekty badań nad opracowaniem układu oczyszczania spalin dla turbodoładowanego silnika pięciosuwowego, który został zaprojektowany i wykonany na Politechnice Krakowskiej. Cechą charakterystyczną silnika pięciosuwowego jest zastosowanie dodatkowego rozprężania spalin w celu zwiększenia sprawności ogólnej. Wyzwanie dla reaktora katalitycznego stanowi niska temperatura spalin. Badaniom poddano dwa reaktory trójfunkcyjne, z rdzeniem ceramicznym i z rdzeniem metalowym. Wyniki przeprowadzonych prób wskazały, że reaktor ceramiczny uzyskuje akceptowalną sprawność konwersji od temperatury spalin 280°C. Dla reaktora metalowego uzyskano kilkuprocentowy wzrost momentu obrotowego i obniżenie jednostkowego zużycia paliwa silnika, jednak sam reaktor nie wykazywał oznak działania nawet przy temperaturze spalin powyżej 380°C. Przeprowadzone analizy wskazały kierunki dalszych prac rozwojowych w przedmiotowym obszarze.

Słowa kluczowe: silnik z dodatkowym rozprężaniem gazów wylotowych, zapłon iskrowy, trójfunkcyjny reaktor katalityczny, układy oczyszczania spalin, sprawność konwersji

Symbols and abbreviations

α_{thr} – throttle opening, %
α_{ign} – ignition timing, °CA
λ – relative air-fuel ratio, –
ABDC – after bottom dead centre
add. – additional
ATDC – after top dead centre
BBDC – before bottom dead centre
BDC – bottom dead centre
BMEP – brake mean effective pressure, bar
BSFC – brake specific fuel consumption, g/kWh
BTDC – before top dead centre
CA – crank angle, °
cyl. – cylinder
downstr. – downstream
EGT – exhaust gas temperature, °C
EVC – exhaust valve closing, °CA
EVO – exhaust valve opening, °CA
exp. – expansion
FC – fuel consumption, kg/h
HP – high pressure cylinder
IVC – intake valve closing, °CA
IVO – intake valve opening, °CA
LP – low pressure cylinder
MBT – Maximum Brake Torque
n – rotational speed, rpm
NDIR – nondispersive infrared
rel. – relative
RON – research octane number, –
SI – spark ignition
t – time, s
T – torque, Nm
TDC – top dead centre
temp. – temperature
turb. – turbine
TWC – three way catalyst
upstr. – upstream
V_{ch} – combustion chamber volume, dm^3
V_{cyl} – cylinder swept volume, dm^3

1. Introduction

More than 130 years have passed since the construction of Karl Benz's first automotive vehicle powered by an internal combustion engine [13]. Since then, combustion engines have found a wide range of applications in road, rail, sea and air transport. The spreading of internal combustion engines and sustaining their popularity was favoured, above all, due to the development of technology producing high-energy liquid fuels in the process of refining of crude oil. It can also be expected that the engines will continue to be an important source of propulsion for motor vehicles in the upcoming decades [6]. This is despite the fact that combustion engines, including those used to drive vehicles, have a number of disadvantages. Firstly, combustion engines do not have a particularly high level of efficiency with regard to converting the energy of the burned fuel into mechanical work. The operation of internal combustion engines is also associated with the emission of significant amounts of CO_2 and the toxic components of exhaust gases, which entails the necessity of using expensive methods of limiting their emissions [14, 23]. Hydrocarbon fuels most often used to feed engines come from crude oil processing, the reserves of which are gradually depleting, and finding a substitute is not easy. Attempts to use alternative fuels, such as natural gas or the fuels, or their components obtained from the processing of plants are associated with many different problems of a logistical, operational or even social nature. The use of plants for the mass production of fuels may lead to an increase in food prices [3]. The use of alternative fuels does not eliminate CO_2 emissions and toxic exhaust components, and only limits them to a certain extent [11]. Some hopes in this regard were associated with the use of hydrogen, which is not accompanied by CO_2 emissions; however, the difficulty of storing this medium in a sufficient amount on board the vehicle and the problematic control of the combustion process makes it an unsuitable fuel for powering engines used for vehicle propulsion. With good availability in industrial conditions, hydrogen can be successfully used to feed engines that drive electricity generators [7]. In traction applications, it is definitely more efficient to use hydrogen to feed commercially available vehicles powered by electricity produced in high-efficiency, on-board fuel cells [44].

The circumstances described above mean that in the next ten to fifteen years one can expect an ongoing decline in the use of the combustion engine as the sole source of vehicle drive which, according to the contemporary global automotive development concept, is to be eventually replaced by electric motors. However, the rapid and widespread deployment of pure electric vehicles faces many problems. As has been well publicised, the use of electric drive completely eliminates the emission of carbon dioxide and toxic gases in the place of use of the vehicle, which is a totally positive benefit. However, when considering the method of generating electricity in a given area, it may transpire that the equivalent emission of carbon dioxide resulting from the use of an electric vehicle may exceed the emission generated by a modern car powered by an internal combustion engine [38]. Another key issue that is yet to be resolved is the highly limited capacity of energy storage in batteries that are currently available, which in addition, remain both expensive and heavy. Other problems with regard to extending the use of electric drives in the automotive industry are issues related to methods

of production and the recycling of batteries. These are energy-intensive processes which, to greater or lesser degrees, constitute environmental pollutants. In some cases, these pollutants may even be toxic [15].

For the above reasons, the promotion of development of hybrid drive systems is a favourable solution for the continuous development of the automotive sector with a simultaneous significant reduction in the consumption of hydrocarbon fuels and exhaust emissions [43]. The simultaneous use of a combustion engine and electric machine for the vehicle's drive primarily enables the recovery of braking energy; additionally, it enables the specific use of an internal combustion engine which would not be possible when the combustion engine was the only source of propulsion. This concept assumes that, firstly, the combustion engine mainly works only when it is necessary, and if it is working, the algorithm of the engine management system predicts working in situations in which it achieves the highest possible levels of efficiency. In principle, regardless of the type of hybrid drive system, this usually means the operation of the engine in the high load region, close to the maximum level. In hybrid propulsion systems, it is possible to limit the idling time and the time spent working with a low load to the minimum which is required; this is where the combustion engine achieves a very low level of efficiency. In such systems, internal combustion engines optimised for work in a specific part of their operation map are used.

After many years of continuous development, the internal combustion engine is now a device that has actually been refined to close to the limit of its technical possibilities. Designers of modern internal combustion engines are looking for solutions that improve efficiency by even a fraction of a percent. Similarly, extending the area in which the engine operates close to the minimum brake specific fuel consumption by the speed range of 100 rpm or 0.1 MPa of brake mean effective pressure is considered a great success. Many methods of improving the efficiency of the internal combustion engine are known. Some of these are focused on limiting mechanical losses [21], others on reducing thermal losses [48]. The extension of the range in which the internal combustion engine works most effectively usually consists of the introduction of variable valve timing, variable valve lift, variable intake port length, multi-stage charging, and more recently, also in the variable compression ratio of the engine [33].

2. Increased expansion ratio

The application of an expansion ratio which is significantly higher than the compression ratio is one of the methods that fits in with the development trends of internal combustion engines outlined above and currently offers some possibilities in reducing fuel consumption, i.e. in increasing the efficiency of converting the thermal energy of the burned fuel into mechanical energy [39]. The use of a high expansion ratio in order to achieve high engine efficiency was observed by the inventor of the concept of a four-stroke work cycle – French engineer Alphonse Beau de Rochas and was recorded in his 1861 patent [29]. Fig. 1 presents the theoretical 1-2-3-4-1 cycle of a spark ignition engine.

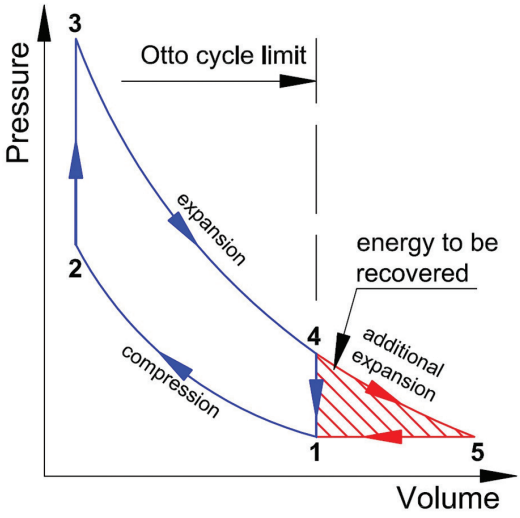

Fig. 1. Otto cycle with the marked area of work of additional expansion

In this figure, the area 4-5-1 is marked red. This refers to the heat that can be theoretically recovered in the process of the additional expansion of the exhaust gas up to the ambient pressure (pressure for points 1 and 5). In the classic Otto cycle, this heat is rejected into the environment in an isochoric process 4-1, and in the real engine, this event corresponds to the opening of the exhaust valve, while the pressure and temperature in the cylinder remain significantly higher than the ambient pressure.

As can be seen in theoretical approaches, increasing the expansion ratio of the charge over the compression ratio enables a clear reduction of engine heat losses associated with the release of hot exhaust gases into the atmosphere. In practical approaches, one should take into account many other phenomena and regularities occurring in the case of a cycle with an increased charge expansion ratio which are omitted in simple theoretical analyses. These factors have an impact on reducing the real benefits in the form of an increase in thermal efficiency. Nevertheless, the fact is that the increased expansion ratio is used in modern engines irrespective of whether they rely on spark ignition or compression ignition [30]. There are several main ways to differentiate the expansion ratio over the compression ratio. The following should be mentioned here:

1. The idea of the 19th-century English inventor and engineer James Atkinson was of a four-stroke work cycle in which the stroke length of the piston in the intake and compression strokes is clearly smaller than the stroke length in the power and exhaust strokes. Atkinson obtained such an effect in two ways. In the first engine, called "differential", the abovementioned effect was achieved by using a system of two pistons working in one cylinder and linked by a special arrangement of connecting rods. The second of Atkinson's engines, called "cycle", was more similar in its form to classic solutions. A single piston worked in the cylinder, and to achieve a differentiated stroke length in each stroke, a system of kinematic links with a split connecting rod and a pivoting connecting-rod fulcrum was used [10].

2. The concept of Ralph Miller, according to which the closing of the intake valve occurs significantly before the piston reaches the bottom dead centre (BDC). This means early intake valve closing comparing to the classic engine. Such control of the opening of the intake valve results in a decrease in the volumetric efficiency, internal cooling of the charge expanded in the cylinder after closing the valve until the piston reaches the BDC, and, above all, the effective length of the compression stroke decreases, which also reduces the effective value of the compression ratio. However, in such an engine, the charge expansion process occurs at the full length of the power stroke, which causes the expansion ratio to be higher than the effective value of the compression ratio. Typically, mechanically driven compressors or turbochargers are used to compensate for the loss of engine performance caused by the reduction of volumetric efficiency in engines with early intake valve closing [31].
3. This is the concept of the delayed closing of the intake valve, in which it closes long after the piston reaches the bottom dead centre. Part of the cylinder charge is forced back to the intake manifold, thus the effective length of the compression stroke is also shortened, which, when carrying out the expansion process (as occurs in the classical engine), gives an expansion ratio that is significantly higher than the effective compression ratio.
4. This is the division of the expansion process into two working spaces similar to steam engines with multiple-expansion. In such an engine, after carrying out the classic four-stroke process, the exhaust gases are not removed to the atmosphere but instead flow to a separate cylinder with a volume significantly higher than the working cylinder. The exhaust gases are subjected to a double expansion to pressure and temperature levels that are much closer to the ambient levels than occur in the classical engine.

Among the aforementioned methods of obtaining an increased expansion ratio in the internal combustion engine, James Atkinson's original engines (in which the complex system of kinematic links prevented the achievement of a high output shaft rotational speed) should be treated as a historical solution. Nevertheless, it is worth noting that new simulation results [16] as well as experimental research on similar types of engine [12] can be found in literature. Engines obtaining an increased expansion ratio in relation to the compression ratio by means of early or late intake valve closing are currently being designed, mass produced and used not only in many automotive vehicles, but also in railway, industrial and marine applications. Typically, such engines are called Miller engines or Atkinson engines, but unfortunately, there are no strict rules for distinguishing between each of these engine types [22]. Miller's name appears rather more often. For example, engines that use early intake valve closing, usually with a charging system, are more often called Miller engines. In these engines, the charging system is used to compensate for a significant loss in volumetric efficiency. The reduction of the cylinder filling results from the earlier closing of the intake valve and also from the significantly lower cam lift that controls the intake valve. With a short valve opening period, the lift limit is the result of the allowable valve acceleration that occurs during the rise and fall phases [46]. The term "Miller engine" also refers to machines obtaining an increased expansion ratio by retarding the closure of the intake valve. This applies to both the supercharged and

the naturally-aspirated version [17, 18]. However, retarded intake valve closure is also applied in other scenarios, such as within a wide range of naturally-aspirated spark ignition engines used in vehicles with Toyota hybrid propulsion systems, and more recently also Hyundai-Kia. The abovementioned engines are referred to by their producers as Atkinson-cycle engines [1, 20]. Due to the described inconsistency in the nomenclature, the term "Atkinson-Miller cycle" can also be found in the literature. This term is mainly used in theoretical works [49]. It should be mentioned here that while both Atkinson and Miller aimed to realise an increased expansion ratio of the charge, Atkinson's original idea did not adopt the use of a non-standard opening of the intake valve, which was a fundamental assumption of Ralph Miller [32]. In the light of this fact, it can be argued that engines that are currently produced which perform a cycle with an increased expansion ratio should be named after Ralph Miller rather than James Atkinson.

A different way of increasing the expansion ratio is realised in engines with an additional expansion of the load in a separate cylinder. Such engines were already being constructed by the end of the 19th century, and they were modelled on steam machines with a multiple-expansion process. At the time, such engines were called "compound engines" in English, "moteur compound" in French and "Verbundmotor" in German [35]. Nowadays, the term "five-stroke engine" is most commonly used to describe this type of engine; the term comes from the fifth stroke of additional charge expansion preceded by a classic four-stroke cycle. At the end of the 19th and the beginning of the 20th century, two-stage expansion engines were developed by several inventors, including Rudolf Diesel [45], but they did not gain much popularity due to problems with the correct implementation of the additional expansion process. These difficulties were mainly material based. The exhaust gas at the inlet to the additional expansion cylinder still had a high temperature. This forced a requirement to cool the valves of the inlet channels of these cylinders and this effectively reduced energy gains from the additional expansion process. The idea of building an engine with additional expansion of the charge returned at the end of the 20th and beginning of the 21st century in the era of the dynamic development of materials, technologies and construction methods used in automotive engineering. The decisive factor here was the specific feature of the five-stroke engine in which the fired cylinder can have optimum parameters due to high specific power, while the use of an additional expansion process in a separate cylinder enables the engine to achieve a higher level of thermal efficiency. Currently, five-stroke engines are being developed in several research and development facilities [2, 28]. Due to the specific features of these engines, they are suitable for the purpose of driving an on board or a stationary electric generator. Various engine arrangements of this type are known. The most popular is the system with two fired cylinders (high-pressure) and with one additional expansion (low-pressure) cylinder located between them. The fired cylinders work in a four-stroke cycle, with the working phase shifted by 360°CA and alternately supply exhaust gases to the central low-pressure cylinder operating in a two-stroke mode. This means the full use of both fired cylinders as well as an additional expansion cylinder.

3. Brief description of the engine and the motivation for aftertreatment development

The four-cylinder in-line spark-ignition engine, in which two inner cylinders serve as a common volume of additional expansion of exhaust gases coming from the outer fired cylinders, was designed and built at Cracow University of Technology in 2011–2013 as part of the project No. N N509 559040 [41]. The engine design was based on an existing four-cylinder four-stroke engine. The change in the nature of the work from four-stroke to five-stroke was mainly based on the extensive modification of a cylinder head, camshafts, intake, exhaust systems, and charging system. The scheme of the modified cylinder head of an engine developed at Cracow University of Technology is presented in Fig. 2.

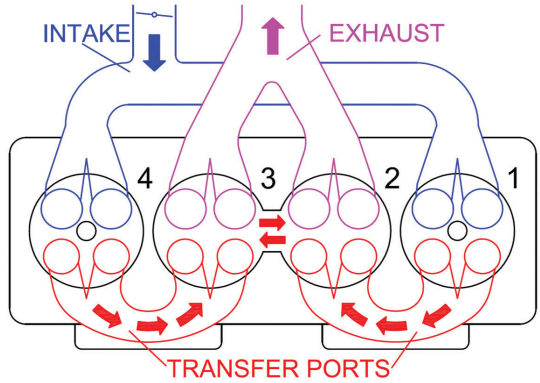

Fig. 2. Scheme of the modified cylinder head of a five-stroke engine designed at Cracow University of Technology

In the engine presented in Fig. 2, a classic four-stroke cycle is implemented in cylinders 1 and 4. The shift of the working phase between these cylinders referred to as fired or high-pressure (HP) is 360°CA. Low-pressure cylinders (LP) nos. 2 and 3 have been connected by a port made in the cylinder head and have one common volume to which the combustion gases from cylinders 1 and 4 are alternately provided for additional expansion. Only after the additional expansion to a volume twice as large as the volume of the medium at the beginning of the compression stroke in cylinder 1 and 4, does the exhaust gas leave the engine through the four exhaust valves of cylinders 2 and 3 simultaneously. In order to efficiently use the features of the engine with a two-stage expansion process, a turbocharging system was applied. In brief, the use of the process of additional expansion of exhaust gases is the more beneficial, the higher the temperature and pressure at the end of the main expansion process are. With a properly conducted combustion of the stoichiometric mixture these will depend on the amount of charge delivered to the cylinder [36, 37]. In practice, the restriction is the increase in the exhaust gas pressure upstream from the turbine resulting from the increase of the required boost pressure. The increase in exhaust backpressure leads to the limitation of the positive effects of the additional expansion process; therefore, the dependence of the thermal efficiency of the five-stroke engine on the load has

a local maximum. Depending on the rotational speed, maximum efficiency was obtained at the boost pressure within the range 0.2 to 0.65 bar [34]. In Fig. 3, the theoretical pressure courses in the fired cylinders (red) and in the internally connected additional expansion cylinders (blue) are presented. The figure shows the pressure drop between the end point of the power stroke in the fired cylinder and the beginning of the additional expansion process – the red line passing into the blue line. This results from the undesirable expansion of gases in the volume of the port connecting the cylinders and in the chambers above the pistons (previously being the combustion chambers) of the additional expansion cylinders. In the case of this engine, these volumes should be treated as undesirable (as is the case with the clearance volume in the piston compressor); however, it was not possible to minimise them in the cylinder head built on the basis of the existing structure.

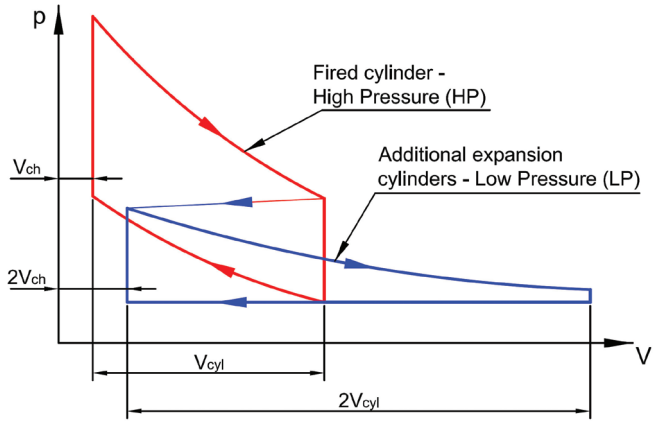

Fig. 3. The basic theoretical cycle of the fired cylinder (red line) and the cycle of additional expansion conducted in a separate cylinder (blue line)

The basic technical specifications of the engine with additional expansion of exhaust gases developed at Cracow University of Technology in its current configuration are shown in Table 1.

Table 1. Basic technical data of a five-stroke engine developed at Cracow University of Technology [34]

Parameter	Value/Description
type and manufacturer of the base engine	Volkswagen EA113, 2.0 dm^3 TFSI, 147 kW
no. of cylinders in 5-stroke arrangement	2 fired / 2 for additional expansion
displacement of fired cylinders, dm^3	0.992 (both)
displacement of add. exp. cyl., dm^3	0.992 (both)
bore, mm	82.5
stroke, mm	92.8
no. of valves	4 per cylinder

Table 1 cont.

Parameter	Value/Description
compression ratio, –	10.5
overall expansion ratio, –	21
fuel system	direct Injection
injection pressure, MPa	7
engine Management System	AEM EMS 30-1010
control of Air-Fuel Ratio	closed-loop, wideband O_2 sensor
injector driver	Denso 131000-1041
ignition system	individual coils
fuel	petrol, RON 98
IVO/IVC fired cylinders	7° ATDC / 17° ABDC
EVO/EVC fired cylinders	28° BBDC / 8° BTDC
IVO/IVC additional exp. cylinders	28° BTDC / 8° BBDC
EVO/EVC additional exp. cylinders	28° BBDC / 8° BTDC
turbocharger model	BV35-54359710015
boost pressure control method	variable geometry of turbine nozzle

The engine developed at Cracow University of Technology was the subject of several previous studies [34–37] and [39–41]. These works focused mainly on aspects related to the description of the design itself in which the engine was constructed on the basis of an existing four-stroke engine, issues of the thermodynamic description of processes occurring in it and the analysis of engine test results in the context of its thermal and mechanical efficiency indicated the mean effective pressure and the ratio of exhaust energy recovery in cylinders of additional expansion.

Until now, relatively little space has been devoted to issues related to the toxicity of exhaust gas. Some preliminary results of experimental research in this matter are presented in previous research [40]. These results concerned the raw exhaust emissions because until now, the engine was not equipped with an exhaust-gas aftertreatment system. Only a little information is available on the subject of exhaust toxicity of a similar engine developed from scratch and tested by the Keromnes, Schmitz et al. team [24]. However, nowadays issues related to emissions from propulsion sources are at the forefront, not only in the automotive industry but also in other transport areas as well as in the energy sector. For this reason, the next, natural stage of development of the design had to be the development of the aftertreatment system because without such a system, the internal combustion engine, or a vehicle equipped with it, is not able to meet any modern emission standards. This paper is devoted to the presentation of the effects of current work in this matter.

4. Research problem and aim of work

The design of the engine with the additional expansion of the exhaust in a separate cylinder is oriented to the maximum use of the energy of the burned fuel. The use of additional expansion of exhaust gases in a separate working space causes the temperature of exhaust gases reaching the inlet of the turbine to be already relatively low, and at the turbine outlet, the temperature of the exhaust gases is even lower. Sample results obtained during the operation of the engine at a constant rotational speed of 2,000 rpm and the opening of the throttle within the range of 7 to 100% are shown in Fig. 4. It should be noted here that the presented results were obtained in the previous configuration of the research engine, without a catalytic converter and when it was equipped with a turbocharger with a waste-gate valve, but this fact does not have a significant impact on the temperature measured downstream from the turbine.

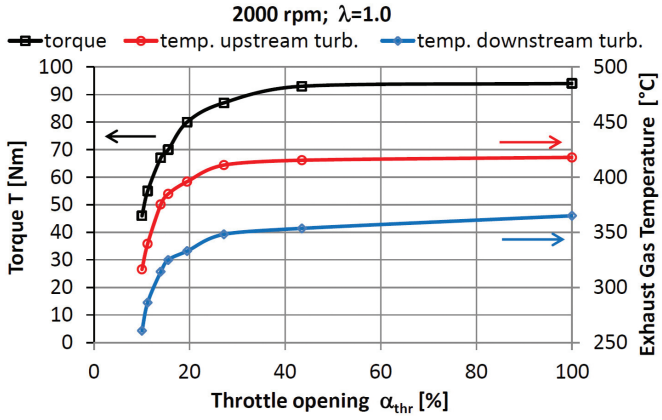

Fig. 4. Torque and exhaust gas temperature of the engine with additional expansion as a function of throttle opening

As can be seen above, in the range of a moderate load, below 60 Nm, the temperature of exhaust gases downstream from the turbine is slightly higher than 250°C, which is considered to be the temperature of the beginning of the effective operation of an ordinary three-way catalytic converter [19]. However, the values presented in the chart were obtained after a certain time of engine operation with given parameters. In the period immediately after starting a cold engine, when (mainly for the sake of its durability) it works for some time without a load, and then with a low load, the temperature of the exhaust is even lower and the warming-up of the exhaust system components, including the catalytic converter, progresses slowly. During this period of operation of the five-stroke engine, the classic three-way catalyst would not work at all.

The aim of this work is to find a three-way catalytic converter, which, on the one hand, will allow a significant reduction in the concentration of toxic exhaust components starting from the lowest possible temperature of the exhaust downstream from the turbine, and on the other hand, will have low exhaust gas flow resistance. Increasing the flow resistance raises backpressure of gases in the exhaust system, which in turn increases the pumping losses, reducing the effect of energy recovery in the cylinders of the additional expansion of the five-stroke engine [27].

5. Test stand

Tests were performed on the engine test bench with an Eddy-current dyno. The measurement of fuel consumption was conducted by applying the mass method using the system integrated with the dyno controller. The exhaust gas composition measurements were performed with the use of a Capelec CAP 3201 class 0 analyser, which allows the measurement of the volume concentration of the most important components of dry exhaust gases, such as carbon dioxide, carbon monoxide, oxygen, nitrogen oxides and hydrocarbons converted to hexane. CO_2, CO and HC are measured using the NDIR method, while electrochemical cells are used to determine O_2 and NO_x concentrations. On the basis of the current exhaust gas composition, the analyser also calculates the value of relative air-fuel ratio λ. For this purpose, the Brettschneider formula is used [5].

Fig. 5 shows a view of the exhaust system of the engine with the additional expansion of exhaust gas with an installed catalytic converter.

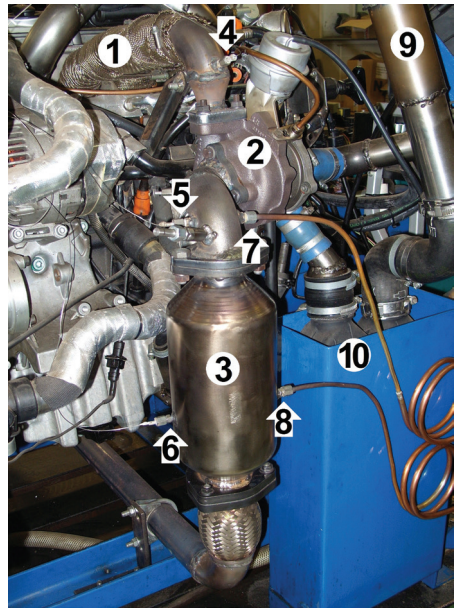

Fig. 5. Modified exhaust system of a five-stroke engine with a catalytic converter; 1 – engine exhaust manifold, 2 – turbocharger, 3 – catalytic converter, 4 – exhaust gas temperature measurement point upstream from the turbine, 5 – exhaust gas temperature measurement point upstream from the catalytic converter, 6 – exhaust gas temperature measurement point downstream from the TWC, 7 – exhaust gas sampling point for the analyser upstream from the catalytic converter, 8 – the sampling point downstream from the reactor, 9 – intake air pipes, 10 – charge air cooler

The catalytic converter was installed as close as possible to the turbine outlet so as to minimise heat losses to the ambient environment, which would delay the light-off of the aftertreatment system. The pipe connecting the turbine outlet to the inlet of the reactor is approximately 170 mm long. In order to estimate the conditions and effects of the catalytic

converter operation, exhaust gas temperature values at selected points were measured using K-type thermocouples. Measurements were made at the following points of exhaust system:

1. In the port between the fired cylinder no. 1 and the cylinder of additional expansion no. 2;
2. In the engine exhaust manifold just upstream from the turbine inlet;
3. Upstream from the catalytic converter (downstream from the turbine);
4. Downstream from the catalytic converter outlet (close to the support).

One analyser was used for the tests, thus the measurement of the composition of the exhaust gas upstream and downstream from the catalytic converter required use of a valve enabling the switching of the gas-sampling point. Exhaust gases were sampled very close to the inlet of the catalytic converter and just after its outlet (directly after the reactor's support).

6. Three-way catalytic converters used in the research

Two catalytic converters were chosen for the research. One of these was built based on a metal support, while the other was based on a ceramic support. The displacement volume of the test engine is 0.992 dm^3. The operation of the engine with the boost pressure not exceeding 0.5 bar and the rotational speed below 4,000 rpm is foreseen, as well as with the stoichiometric air-fuel mixture. The result is that the maximum torque achieved by the engine is limited to approximately 130 Nm, which in effect gives a maximum power level below 55 kW. Based on these estimates, a ceramic catalytic converter from a passenger car with a naturally aspirated engine with a displacement volume of 1.2 dm^3 and a maximum power of 59 kW at 6,000 rpm was selected. The second converter, with a metal support, is for universal application and is designed for engines with a displacement volume of 1.3 to 1.6 dm^3. The basic dimensions and technical data of catalytic converters are shown in a Table 2.

Table 2. Basic technical data of converters used for research

Parameter	Ceramic support converter	Metal support converter
support cross section shape	round	round
support diameter, mm	110	86
support length, mm	50	90
inlet/outlet inner diameter, mm	48/48	48/48
total length, mm	277	277
cell density, cpsi	576	200
area of application	underfloor converter (2nd of two) from the B-segment car,	universal converter,
engine displacement volume, dm^3	1.2, naturally aspirated	1.3–1.6, if naturally aspirated
exhaust emission standard of vehicle for which converter is intended	Euro 6	Euro 4

Both catalytic converters used were brand new. In the case of the metal converter, the adaptation for use in a five-stroke engine was to weld the flanges to the inlet and outlet pipes. In the case of a ceramic support converter, the fixing of the necessary flanges had to be preceded by the removal of the original inlet and outlet pipes and the welding of straight pipe fragments, because the used converter was part of a larger element of the exhaust which is installed under the floor of the vehicle. A general view of the selected reactors after adaptation to the test bench of the five-stroke engine is presented in Fig. 6.

Fig. 6. Three-way catalytic converters tested with the five-stroke engine; 1 – Converter with a ceramic support, 2 – Converter with a metal support

As is visible in the picture above, both reactors below the support have attached connectors for thermocouple mounting (left hand side) and for the sampling of the exhaust after the catalyst for the analyser (right hand side). Unfortunately, no further information on the wall thickness, coatings and precious metal content was available for either catalytic reactor.

7. Experimental research of the five stroke engine

7.1. Tests with the ceramic support three-way converter

In the first part of the research, a catalytic converter with a ceramic support was used. The tests were performed at a low rotational speed of 2,000 rpm because in such a situation, the exhaust gas has a low temperature, thus creating beneficial conditions for verification of the aftertreatment system. The first measurements concerned the operation of the catalytic converter depending on the engine load with the assumed constant value of relative air-fuel ratio equal to 1.0. In each of the following measurement points, the engine was operated until the exhaust gas temperature measured downstream from the catalytic converter had stabilised. Fig. 7 presents the conditions for conducting tests. The graph shows the throttle opening and the ignition timing dependent on the load of the test engine.

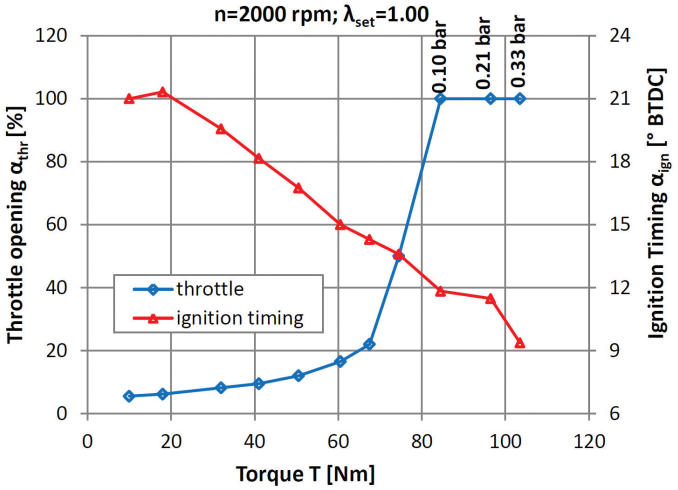

Fig. 7. Conditions for conducting tests depending on the load of the five-stroke engine

For each measurement point, the ignition timing was set so that the maximum torque was obtained for the determined throttle opening. The last three measuring points (from the right) were realised during operation of the engine with a wide-open throttle. Figures given at the points representing 100% throttle opening indicate the values of the boost pressure. The increase of the boost pressure was performed by changing the position of the turbine nozzles, which remained fully open up to the load of 84.5 Nm.

Fig. 8. presents the plots of exhaust gas temperature measured upstream and downstream from the catalytic converter dependent upon the load of the five-stroke engine. The graph also shows the course of the actual value of the relative air-fuel ratio measured by the exhaust gas analyser.

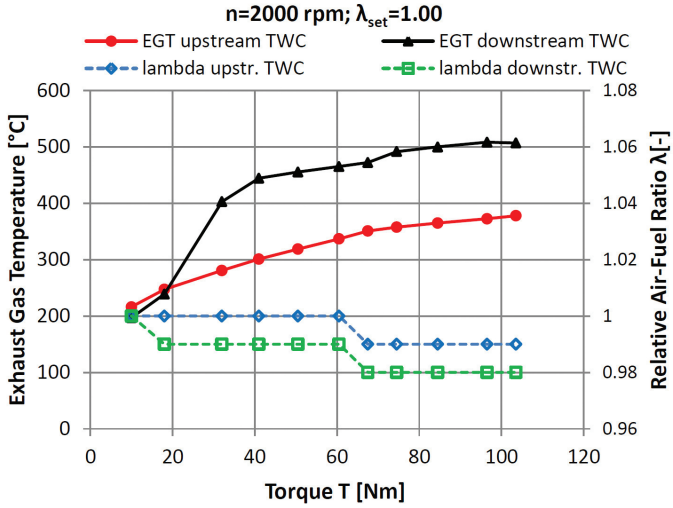

Fig. 8. Exhaust gas temperature upstream and downstream the catalytic converter with a ceramic support and the measured value of the relative air-fuel ratio depending on the engine load

For the first two operating points (from the left), the exhaust gas temperature measured downstream from the converter is slightly lower than upstream from the TWC. This means that in the low load range, when the temperature of the exhaust gas measured upstream from the converter does not exceed 250°C, TWC does not show any effect of activity. After exceeding the load of 20 Nm, exhaust gas temperature measured in the reactor inlet increased above 250°C and the converter started operating. This is characterised by the increase in the exhaust gas temperature measured below the catalytic reactor of 130°C in relation to the temperature at its inlet, which is the result of the exothermic character of reactions taking place inside the converter. The value of the relative air-fuel ratio measured on the basis of the composition of the exhaust shows a certain deviation in the direction of enrichment at a higher engine load. This is due to imperfections in the operation of the mixture composition control system in the closed loop. The error of adjusting the relative air-fuel ratio is 0.01, which can be considered to be a relatively low value.

Fig. 9 shows the courses of volume concentrations of carbon monoxide and carbon dioxide in the exhaust gas of a five-stroke engine depending on its load. Continuous lines connect the results of measurements downstream from the catalytic converter, while the dashed lines refer to results upstream from TWC (note that these line styles also apply to the presentation of results later in this paper).

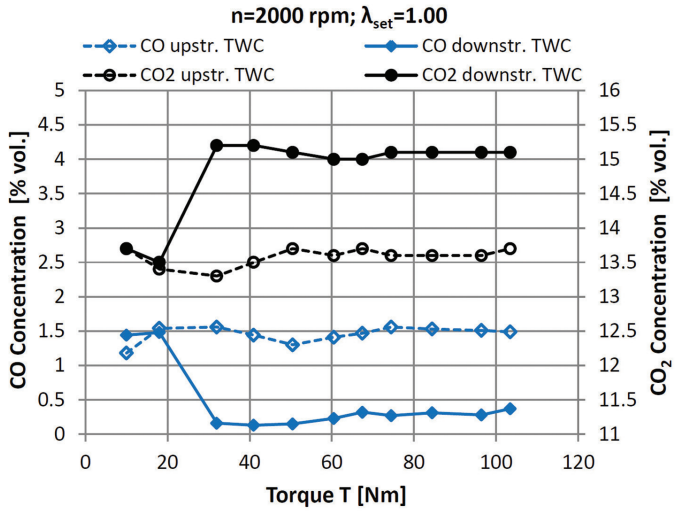

Fig. 9. Volume concentration of CO and CO_2 in the exhaust gas of the five-stroke engine co-operating with a catalytic converter with a ceramic support as a function of the engine load

The previously presented results concerning the measurement of the exhaust gas temperature are also reflected in the course of exhaust gas composition changes measured downstream from the catalytic converter. At a load higher than 20 Nm, when the TWC has reached the temperature necessary for efficient operation, oxidation reactions of combustible components occur on reactor active surface as does the reduction of nitrogen oxide. This fact is reflected by an increase in the volume concentration of CO_2 measured downstream

from the catalytic converter by about 1.5% in relation to the measurement upstream from the TWC. In an analogous comparison, the volume concentration of CO drops by more than 1%, reaching a value not exceeding 0.35% downstream from the catalytic converter.

Fig. 10 shows further results regarding the composition of exhaust gases as a function of the load of the engine cooperating with the ceramic-support converter. The figure shows the course of changes in the volume concentration of hydrocarbons and nitrogen oxides in the exhaust gases.

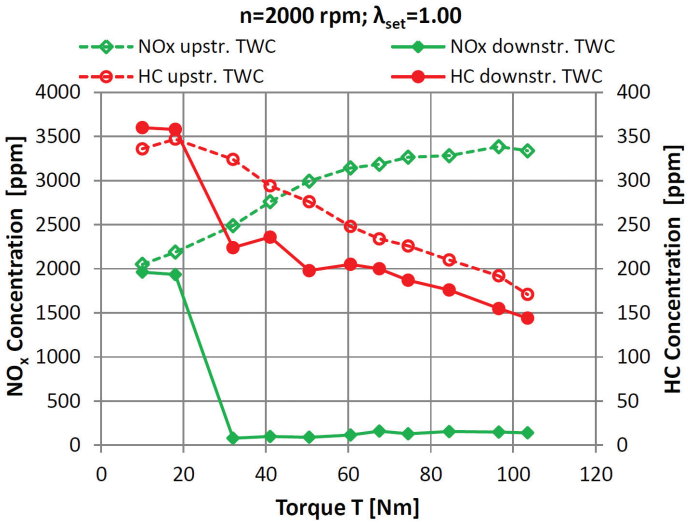

Fig. 10. Volume concentration of hydrocarbons and nitrogen oxides in the exhaust gases dependent upon the load of the five-stroke engine

In the region of the lowest engine load, below 20 Nm, the catalytic converter showed no activity. For the load higher than 20 Nm, a clear reduction in the volume concentration of nitrogen oxides downstream the catalytic converter was recorded. The NO_x concentration values downstream from the catalytic converter change with loads higher than 20 Nm from 80 to 160 ppm. The reduction in the volume concentration of unburned hydrocarbons in the catalytic converter has a much smaller intensity. The difference in the volume concentration of HC upstream and downstream from the TWC varies from 100 ppm at a load of 32 Nm, which is about 30% of the initial value, to only 27 ppm at the maximum load, which in this test is 103.5 Nm. The HC reduction is then only slightly above 15% of the initial value. The singularity consisting in registering the increase in the volume concentration of HC downstream from the catalytic converter, when it does not show normal activity, results from the NDIR measurement method used in the analyser used for the tests. A certain change in the composition of the exhaust gas occurring in a reactor functioning below light-off temperature, but heated to over 200°C results in an increase in the absorption of infrared radiation of a specific wavelength for hexane. As a result, this leads to an overestimation of the measurement of the volume concentration of hydrocarbons in the exhaust gas leaving the catalytic converter. A more accurate recognition of the mechanism of this phenomenon would require additional studies and research; this was not the subject of this study.

Fig. 11 shows plots of the conversion efficiency of a catalytic converter with a ceramic support as a function of the load of the engine with the additional expansion of exhaust gases.

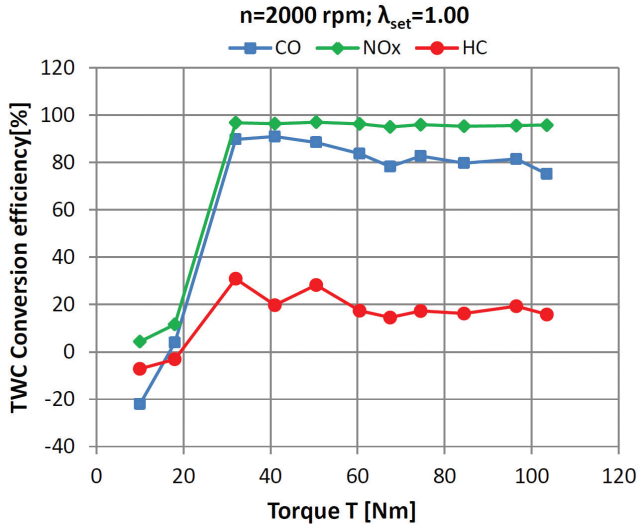

Fig. 11. Graphs of conversion efficiency of TWC with a ceramic support as a function of load of the engine with the additional expansion of exhaust gases

During the test, the highest values of the conversion efficiency of toxic exhaust components in the TWC were obtained for nitrogen oxides. In the load range in which the reactor was active, the NO_x conversion efficiency values exceeded 95%. Slightly lower conversion efficiency of the reactor was achieved for the oxidation of carbon monoxide. The conversion efficiency for carbon monoxide was about 90% at 32 Nm and showed a decreasing trend when the engine load increased. For a load of 103.5 Nm, the conversion efficiency with respect to the volume concentration of carbon monoxide was about 75%. In the conditions of the tests, the applied catalytic converter was by far the least efficient at dealing with the neutralisation of unburned hydrocarbons. The conversion efficiency of the TWC for this group of compounds at medium and high loads oscillated at around 20%. Slightly higher values, around 30%, were recorded when the engine operated with a partial load between 32 and 50 Nm.

In the next part of the work, a cooperation of the five-stroke engine with a catalytic converter with a ceramic support as a function of air-fuel mixture composition at partial engine load was investigated. A constant rotational speed of 2,000 rpm, a throttle opening of 15% and an ignition timing of 16°CA BTDC were set. Figure 12 shows the course of torque and brake specific fuel consumption of the five-stroke engine co-operating with a catalytic converter with a ceramic support depending on the composition of the air-fuel mixture.

A maximum torque of 63 Nm was obtained when the engine was fed with a mixture of $\lambda = 0.87$. The minimum value of the specific fuel consumption was 282 g/kWh and was obtained for a mixture with a composition of $\lambda = 1.10$. The values of the relative air-fuel ratio at which the maximum torque and the minimum specific fuel consumption were recorded do not differ from those obtained in the case of conventional four-stroke spark-ignition engines.

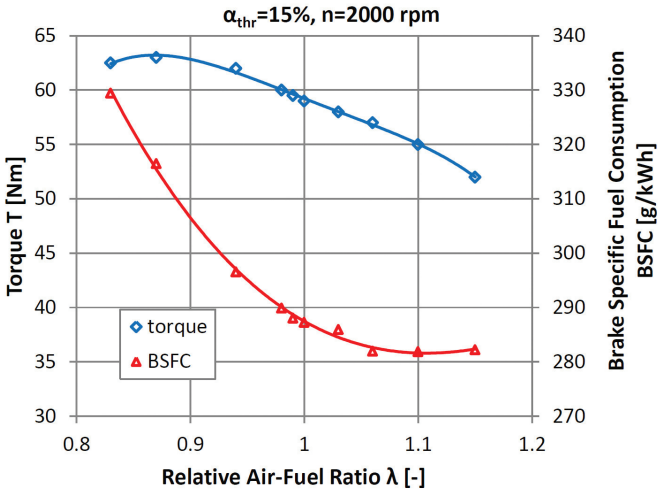

Fig. 12. Graphs of torque and brake specific fuel consumption of the five-stroke engine co-operating with the TWC with a ceramic support depending on the composition of the air-fuel mixture

Fig. 13 shows the dependence of exhaust gas temperature on the mixture composition. As before, the temperature of the exhaust gas upstream and downstream from the catalytic converter was recorded. Also recorded was the temperature upstream from the inlet of the turbine and in the port connecting the fired cylinder no. 1 with the cylinder of the additional expansion no. 2.

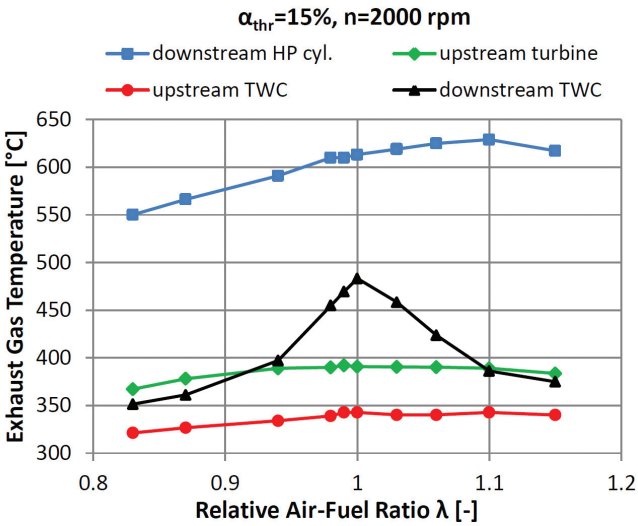

Fig. 13. Exhaust gas temperature of the five-stroke engine co-operating with the TWC with a ceramic support depending on the air-fuel mixture composition

The maximum value of the temperature in the port between the HP and LP cylinders (629°C) was recorded for the value of the relative air-fuel ratio 1.10. This temperature is higher than that registered for the stoichiometric mixture by 16°C. This is the result of

reducing the heat release rate and shifting the combustion process to the further part of the power stroke in the case of feeding the engine with a lean mixture. The decrease of the exhaust gas temperature measured upstream from the additional expansion cylinder and in the engine exhaust manifold upstream from the turbine inlet has values in the range from 180 to 240°C; the higher the exhaust gas temperature measured in the port in the inlet of additional expansion cylinder was, the higher this decrease was. This is due to the fact that, firstly, the process of additional expansion brings a stronger effect in the form of work transferred to the crankshaft, and secondly, the increase in the temperature of exhaust gases is associated with the intensification of the heat transfer process to the cylinder and exhaust manifold walls. The temperature drop between the inlet and outlet of the turbine assumes an approximately constant value of around 50°C. This is the result of the operation of the engine in the part load range when the turbine operated without load; therefore, the temperature drop is the result of heat exchange with the walls of its housing more than an expansion in the turbine. The exhaust gas temperature measured downstream from the catalytic converter had a higher value at each measurement point than that measured upstream from the converter. This gives rise for asserting that the catalytic converter at each of the measurement points at least partially fulfilled its basic function. The highest temperature increase of 140°C was recorded with a relative air-fuel mixture of 1.0, which was to be expected for a three-way catalytic converter. This is the result of the most efficient operation of the reactor, when the engine works with the mixture of an exactly stoichiometric composition.

Fig. 14 shows plots of the volume concentrations of carbon monoxide and carbon dioxide in the exhaust gas of a five-stroke engine as a function of the air-fuel mixture composition.

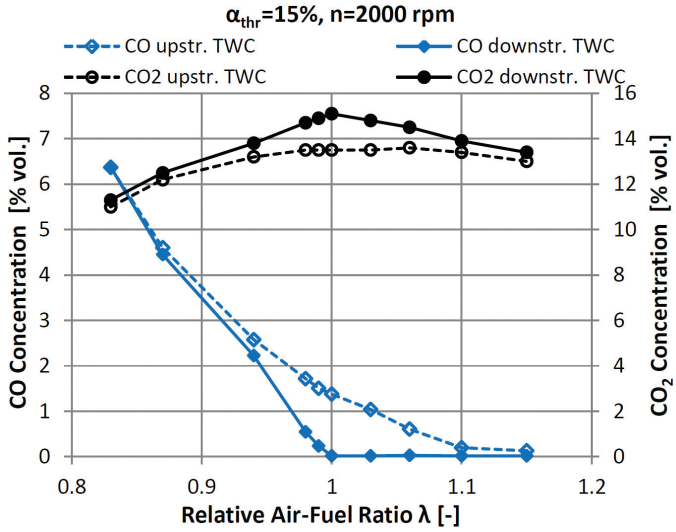

Fig. 14. Graphs of the volume concentrations of carbon monoxide and carbon dioxide in the exhaust gas of a five-stroke engine as a function of the air-fuel mixture composition

The highest reduction in the volume concentration of carbon monoxide in the catalytic converter was obtained when the engine was fed with a stoichiometric mixture. The volume concentration of CO was reduced from 1.38% to 0.02%. This is accompanied by an increase in the volume fraction of CO_2 in the exhaust downstream from the catalytic converter to 15.1%, while the concentration of CO_2 upstream from the converter was 13.5%. The ceramic support catalytic converter coped well with CO oxidation to CO_2 when the engine was powered by a lean mixture. The volume concentration of CO downstream from the TWC had a constant value of 0.02%. When the mixture was enriched more than the stoichiometric composition, the reduction of the volume concentration of CO in the catalytic converter decreased in value until the reactor no longer oxidised CO to CO_2 and the carbon monoxide concentration measured upstream and downstream from the converter were the same. It occurred when the engine was operating using the mixture of the relative air-fuel ratio of 0.87.

Fig. 15 presents graphs of the volumetric concentration of hydrocarbons and nitrogen oxides in the exhaust gas of a five-stroke engine cooperating with the ceramic support TWC depending on the composition of the air-fuel mixture.

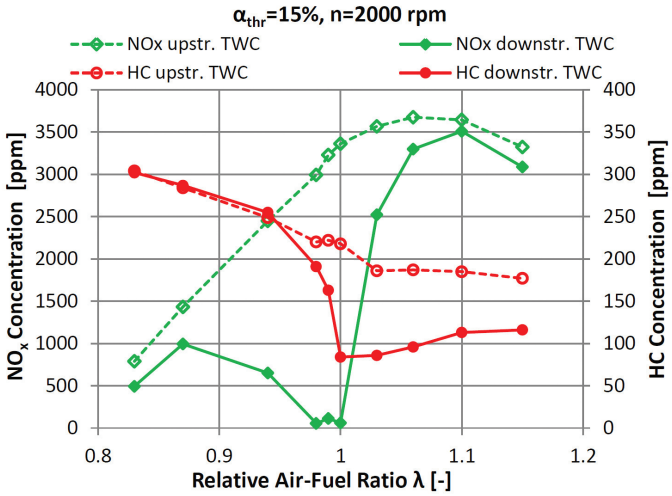

Fig. 15. Plots of the volumetric concentration of hydrocarbons and nitrogen oxides in the exhaust gas depending on the composition of the air-fuel mixture

The plot of the volume concentration of nitrogen oxides is as usually observed, with the maximum achieved for a mixture with a slightly leaner composition than the stoichiometric – $\lambda = 1.06$. The most beneficial results in the reduction of the volume concentration of NO_x were recorded when feeding the engine with a mixture from slightly enriched up to stoichiometric composition – λ from 0.98 to 1.00. The concentration of NO_x in the exhaust gases was reduced from over 3,000 ppm to below 100 ppm. The plot of changes in the volume concentration of hydrocarbons is approximately linearly descending when the relative air-fuel ratio grows. The maximum value of the HC volume concentration was recorded for the value of the relative air-fuel ratio equal to 0.87. As in the case of carbon monoxide, hydrocarbons at this point in the catalytic converter showed no activity. Oxidation of unburned hydrocarbons in the

converter only occurred when the five-stroke engine was fed by a mixture with a composition close to stoichiometric. The maximum reduction in the volume concentration of HC in the catalytic converter was recorded for the mixture with a stoichiometric composition. The volume concentration of hydrocarbons upstream from the catalytic converter was 218 ppm, while the measurement result downstream from the converter was only 84 ppm.

The plots of efficiency of conversion of the catalytic converter with the ceramic support as a function of the relative air-fuel ratio of the mixture are presented in Fig. 16.

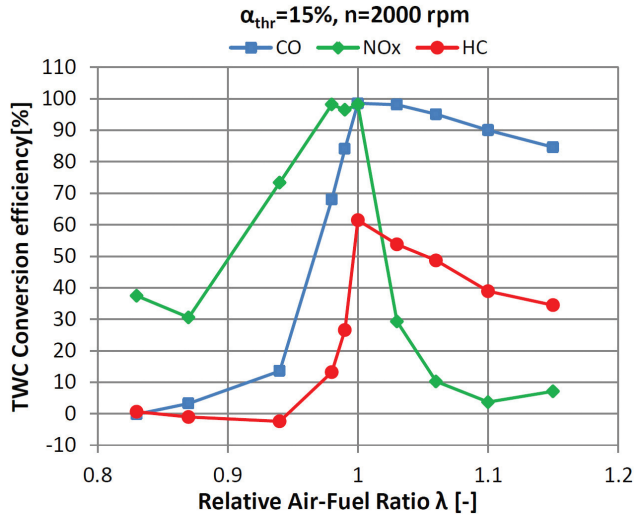

Fig. 16. Diagrams of conversion efficiency of the catalytic converter with the ceramic support as a function of the relative air-fuel ratio of the mixture

The maximum overall conversion efficiency of a catalytic reactor with a ceramic support was obtained when the engine was fed with a mixture of a stoichiometric composition. In the case of carbon monoxide and nitrogen oxides, conversion efficiency levels of 98.5% and 98.2% respectively were obtained. The efficiency of hydrocarbon conversion was considerably lower for the mixture with a stoichiometric composition – 61.5%. However, it should be noted that this was the highest of the obtained HC conversion efficiency values registered during the research that is the subject of this study. The catalytic reactor obtained an acceptably high efficiency of nitrogen oxide conversion when the engine was fed with a mixture with a relative air-fuel ratio of 0.98 to 1.00; for carbon monoxide, this value of λ was in the range of 1.00 to 1.03. In the case of hydrocarbons, a change of the mixture composition from the stoichiometric composition caused a significant decrease in the conversion efficiency of the catalytic converter from the aforementioned value of 61.5%.

In the last part of the research on the ceramic-support TWC conducted under quasi-stationary conditions, measurements were made of the influence of ignition timing on the exhaust temperature of the engine with the additional expansion process. The tests were primarily aimed at determining the range of the increase in the exhaust gas temperature measured upstream from the catalytic converter with the ignition retarded from the point

allowing the obtaining of the maximum torque for a given operating point. Increasing the exhaust gas temperature would shorten the time taken for the converter to warm up to activation temperature. During this part of the research, it was also determined what the cost of such an operation would be in the form of an increase in the specific fuel consumption. The tests were performed at a rotational speed of 2,000 rpm and with a partial throttle opening of 15%, with the stoichiometric mixture feeding. These conditions allowed obtaining the maximum brake torque (MBT) at this operating point of 60.5 Nm for an ignition timing of 17.1°CA BTDC. Figure 17 presents graphs of the exhaust gas temperature of a five-stroke engine depending on the ignition timing.

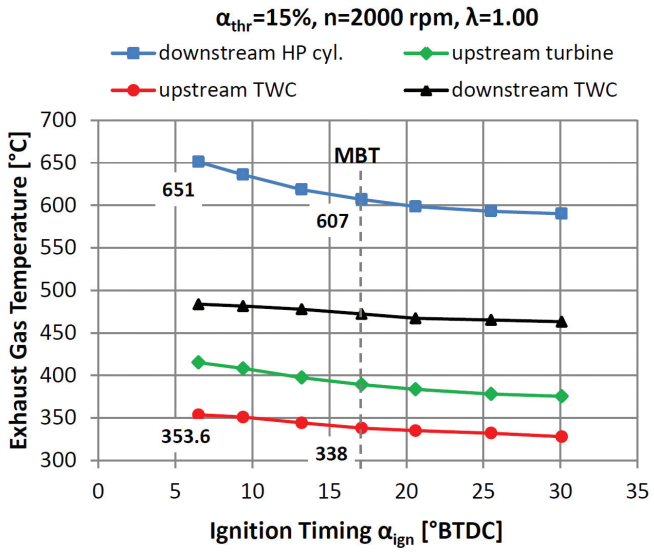

Fig. 17. Exhaust gas temperature of the five-stroke engine as a function of the ignition timing

Retarding of the ignition by 10.6°CA from the MBT point results in an increase of 44°C (from 607 to 651) in the exhaust gas temperature measured in the port between the fired cylinders and an additional expansion cylinder. An analogous comparison of the exhaust gas temperature measured upstream from the catalytic converter indicates that the temperature increased only by 15.6°C with the retarded ignition. A disproportionally low increase in the exhaust gas temperature measured upstream from the converter results from the intensified heat transfer in the additional expansion cylinders, the exhaust manifold of a relatively long length and the turbocharger. This is not a beneficial phenomenon because it hinders the use of what is basically the simplest method of accelerating the warming-up of a catalytic converter in order to shorten the period of its activation. Graphs of torque and brake specific fuel consumption of the five-stroke engine in the function of the ignition timing are shown in Fig. 18.

Shifting the ignition point from 17.1 to 6.5°CA BTDC results in a reduction of the engine torque by 6.5 Nm, i.e. by more than 10.7%. This corresponds to an increase in brake specific fuel consumption by 34 g/kWh (this is a relative increase from the initial value by 12%).

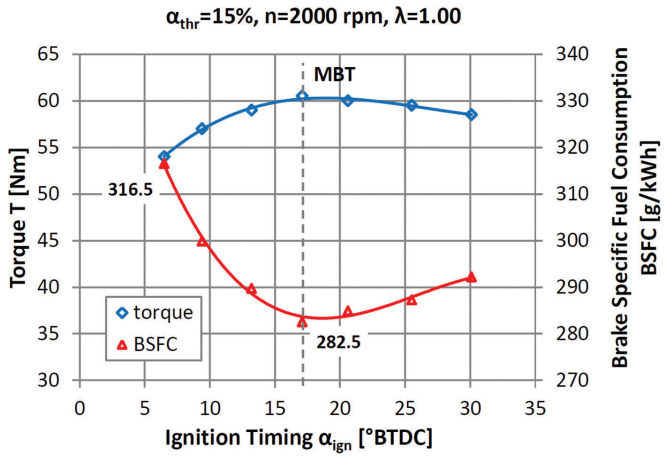

Fig. 18. Torque and brake specific fuel consumption of the five-stroke engine as a function of the ignition timing

During the tests with variable ignition timing, the composition of the exhaust gases upstream and downstream from the catalytic converter was also recorded. The nature of changes in the volume concentrations of analysed components was analogous to the results usually obtained in the case of a classic four-stroke engine. The highest sensitivity to changes in the ignition timing was of course related to the volume concentration of nitrogen oxides. For the ignition timing of 6.5°CA BTDC, the NO_x concentration was 2,400 ppm, while for the ignition timing of 30.1°CA BTDC, it was as high as 4,300 ppm. The conversion efficiency of the catalytic converter maintained approximately constant levels independently of the ignition timing setting and was approx. 98% for NO_x, approx. 82% for CO and approx. 24% for HC.

7.2. Tests with the metal-support three-way converter

In the second phase of work on the development of the exhaust gas aftertreatment system for the five-stroke engine constructed at the Cracow University of Technology, a catalytic converter with a support made of a steel sheet was tested. The research was conducted in order to estimate the impact of the use of the reactor with lower flow resistance on the performance and efficiency of the test engine and to determine to what extent the reactor with the metal support would fulfil its fundamental task. The mentioned task is to limit the concentration of toxic components of engine exhaust. The reactor which was used had a support with a cell density of 200 cpsi made of a thin steel sheet. The assumption that the flow resistance through the catalytic converter would be lower than through a ceramic support reactor with a cell density of 576 cpsi was therefore justified. However, the metal support of the reactor had a significantly smaller active surface compared to the previously tested catalytic converter with a ceramic support; therefore, there were concerns about the efficiency of the second

converter in relatively difficult conditions caused by low exhaust gas temperature. During the tests of a five-stroke engine with a metal support catalytic converter, exactly the same conditions and settings of the engine management system were maintained, as was the case with the research on a ceramic-support reactor.

The graphs of exhaust gas temperature measured upstream and downstream from the converter with a metal support as a function of the engine load represented as torque is shown in Fig. 19. The test was performed at a rotational speed of 2,000 rpm.

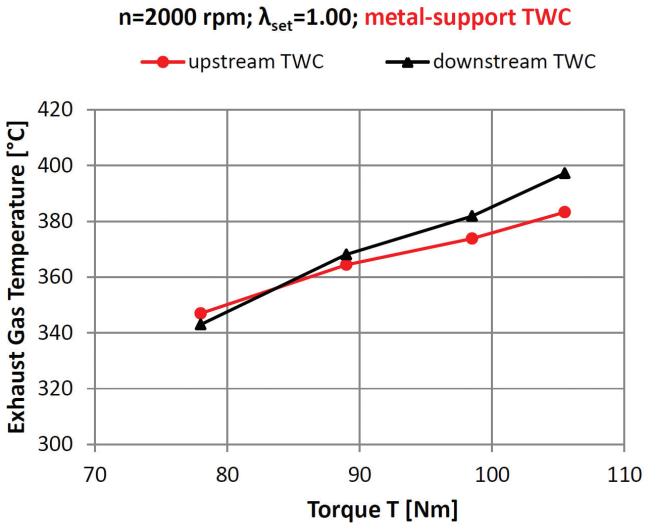

Fig. 19. Exhaust gas temperature measured upstream and downstream from the converter with a metal support as a function of the engine load at a rotational speed of 2,000 rpm

Due to the lack of any symptoms of the activity of the converter with a metal support at low and medium engine load, only the measurement results for the last four testing points were shown when the engine was operating at high load. In the first point of the chart the engine worked with a throttle opening of 50%, and in the next three, the throttle opening was 100% and the boost pressure was adjusted as in the case of analogous tests of converter with a ceramic support (last three points from the right in Fig. 7). It is evident that in the first of the measurement points, the converter with a metal support did not show signs of active operation despite reaching an exhaust gas temperature of 347°C in the inlet. At a load higher than 85 Nm, the exhaust gas temperature measured downstream from the converter started to reach higher values than those upstream from the reactor. The recorded values of the temperature increase in the converter with a metal support, however, had very low values, from 4 to 14°C, which indicates that the intensity of reactions in the converter was negligible. To confirm the last observation, the courses of volume concentration of carbon monoxide and carbon dioxide in exhaust gases of a five-stroke engine co-operating with the converter with metal support depending on the engine load are presented in Fig. 20.

The CO and CO_2 volumetric concentrations measured upstream and downstream from the catalytic converter had the same or very similar values regardless of the engine load. The difference in the volume concentration of CO measured at the last measurement point is only 0.09% (1.54% CO downstream from the converter against 1.63% CO upstream). This means that despite obtaining a temperature of around 400°C, the tested catalytic converter with a metal support does not show any symptoms of efficient operation. The values of volume concentrations of CO_2 before and after the catalytic reactor remain at the same level, which results from the resolution of the CO_2 measurement in the used analyser (0.1%). In fact, if a reduction in the carbon monoxide content was registered, there must have been some increase in the concentration of carbon dioxide measured downstream from the reactor. However, the change was so low that it did not change the analyser's indication.

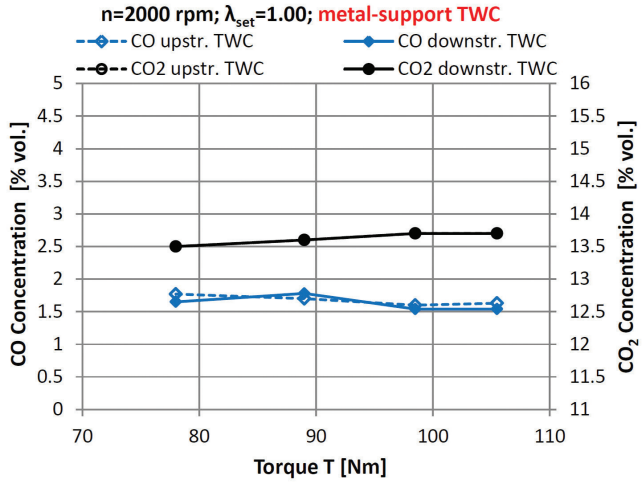

Fig. 20. Volume concentration of carbon monoxide and carbon dioxide in exhaust gases of a five-stroke engine co-operating with the converter with a metal support depending on the load

In order to verify whether the converter with a metal support will start operating at a higher exhaust gas temperature, the engine speed has been increased to 3,500 rpm. With a wide open throttle, a 17.1°CA BTDC ignition timing, a stoichiometric mixture composition and a boost pressure of 0.29 bar, the engine generated a torque of 107.5 Nm; this translates into an effective power value of 39.4 kW. A bar chart of the conversion efficiency of the converter with a metal support obtained in this test is presented in Fig. 21.

Despite reaching an exhaust gas temperature of 478°C upstream from the converter, no acceptable conversion efficiency values were obtained. For CO, HC and NO_x, these values were lower than 10%. Ineffective converter operation also occurred at increased engine speed and high load is reflected in the exhaust gas temperature recorded downstream from the converter; this was 504°C, which is an increase of only 26°C in relation to the temperature of the exhaust gas measured upstream from the TWC.

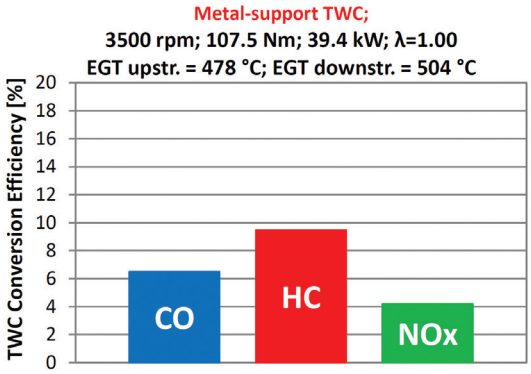

Fig. 21. The efficiency of conversion of the TWC with a metal support during operation of a five-stroke engine with a rotational speed of 3500 rpm and a load of 107.5 Nm

7.3. Warm-up process of the TWC with a ceramic support

In the last phase of the tests that are the subject of this paper, tests on the warming up of the catalytic converter with the ceramic support were performed. The research began from the cold start of the engine, through idle run and then run with various increasing partial load values up to achieving a throttle opening of 29% after 130 seconds, which allows the generation of torque of over 70 Nm. The value of the target load was selected on the basis of previously conducted quasi-stationary tests of the catalytic converter operation. The goal was to get the effect of light-off the converter after about 150 seconds after reaching the final engine load. This enabled the convenient registration of the moment of starting the reactor operation and then obtaining its target activity. A fixed rotational speed of 2,000 rpm, a stoichiometric mixture and an ignition timing set to the maximum brake torque were applied. In this test of the five-stroke engine, the composition of exhaust gas only downstream the catalytic converter was measured. The test was performed until the stable temperature was measured downstream from the converter, which occurred just over eight minutes after the start of the cold engine.

Fig. 22 shows an illustration of the conditions for conducting the test of warming up the catalytic converter with a ceramic support. The chart presents throttle opening, generated torque and engine rotational speed as a function of time.

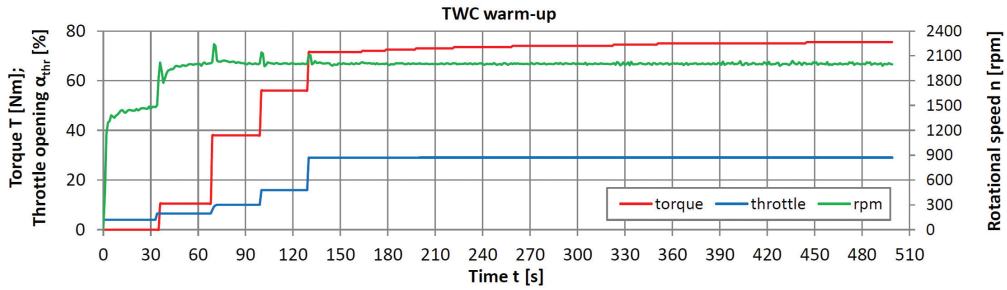

Fig. 22. Conditions for conducting the test of warming up the TWC with a ceramic support

The increase in load from the moment the engine started to the desired value was graded so as to avoid operation of the cold engine under a high load, which is disadvantageous due to durability. As with the previous tests, the engine was running at a speed of 2,000 rpm. Only in the first phase of the idle engine operation was the rotational speed around 1,500 rpm.

Fig. 23 presents graphs of exhaust gas temperature measured upstream and downstream from the catalytic converter, and oxygen volume concentration and relative air-fuel ratio in the warming-up phase of the catalytic converter.

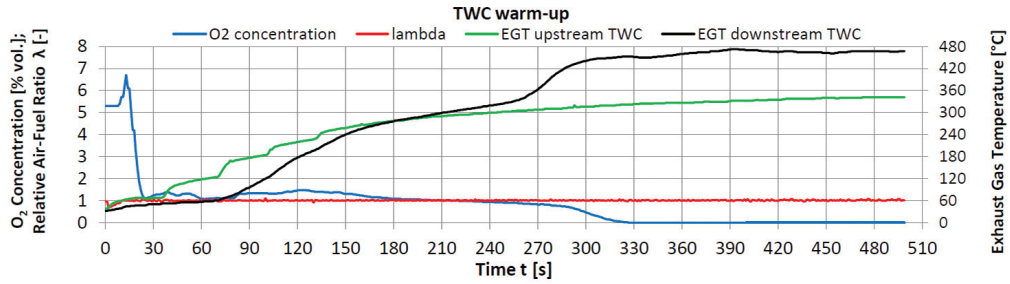

Fig. 23. Charts of exhaust gas temperature upstream and downstream from the catalytic converter, and oxygen volume concentration and relative air-fuel ratio measured in the warming-up phase of the catalytic converter

The effective work of the catalytic converter commenced around 260 seconds after the engine was started. A marked increase in the temperature downstream from the catalytic converter was then recorded. This fact corresponds with a reduction of the oxygen concentration in the exhaust downstream from the converter to a value close to zero. The oxygen concentration graph is delayed by around 20 seconds in relation to the temperature plot downstream from the converter, which results from the length of the pipe connecting the engine exhaust with the analyser and from the measurement properties of the analyser itself. After reaching the light-off temperature, the exhaust gas temperature increase in the TWC was around 130°C on average.

The plots of changes in the volume concentration of CO, CO_2, HC and NO_x in the exhaust gas of the five-stroke engine during the test of the process of warming-up the TWC with a ceramic support are shown in Fig. 24.

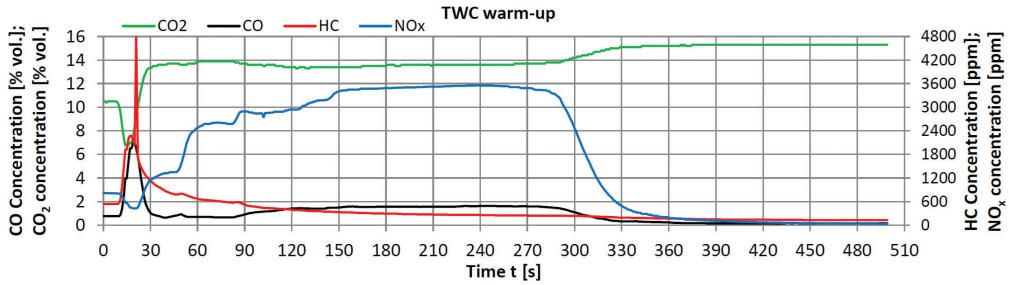

Fig. 24. Charts of the volume concentration of CO, CO_2, HC and NO_x in the exhaust gas of the five-stroke engine during the test of the process of warming-up the TWC with a ceramic support

Achieving a volume concentration of carbon dioxide in the exhaust gas equal to 15.5% downstream from the converter means that it achieved a temperature sufficient for efficient operation. As in the case of oxygen concentration, all charts of volume concentration presented in Fig. 24 are delayed by 20 seconds in relation to the temperature waveform measured downstream from the converter. The sudden increase in the volume concentration of hydrocarbons in the exhaust gas in the 20th second of measurement to over 4,800 ppm results from the misfire in the first cycle of operation after starting the five-stroke engine. The volume concentration of HC before the active operation of the catalytic converter was around 250 ppm. After the converter started to operate, the concentration of HC dropped to around 130 ppm, which means obtaining a relatively good conversion efficiency in the analysed case. The results of starting the effective operation of the catalytic converter are best seen in the course of the volume concentration of nitrogen oxides in the exhaust gas. Before activating the reactor, it was around 3,600 ppm, after light-off it dropped to around 35 ppm.

Due to the fact that the converter with a metal support that was selected for the research did not show sufficiently effective work in quasi-stationary tests, conducting the test of its warming-up process was pointless; therefore, no such test was performed.

7.4. Efficiency and performance of the engine with TWC

The converters used for research have clearly different constructional features. The differences mainly boil down to the materials of which the supports were made, and also to the cell density and support dimensions. The reactor with a metal support has a significantly lower cell density, moreover, the walls of the metal support have a smaller thickness than in the case of the ceramic-support converter. All this means that a metal-support TWC should cause lower resistance to the exhaust gas flow, and consequently, for the same engine operating conditions, the backpressure in the exhaust system should be lower. As mentioned earlier, increasing the backpressure in the exhaust system limits the effects of using additional exhaust expansion. Figure 25 presents a comparison of fuel consumption [kg/h] and brake specific fuel consumption [g/kWh] of the five-stroke engine cooperating with ceramic-support and metal-support converters. The comparison is presented as a function of the engine load represented by the torque.

Analysis of the comparison shows that the use of a metal-support reactor for the five-stroke engine allows reduction of the specific fuel consumption in relation to the values obtained with the ceramic-support converter. The entire line of the BSFC obtained with the metal-support converter is located below the line registered when the engine worked with a ceramic-support converter. The minimum recorded specific fuel consumption values were equal to 256.5 g/kWh when operating with a ceramic-support catalytic converter and 253.6 g/kWh when using a metal-support reactor in the exhaust system. The reduction of the brake specific fuel consumption results mainly from the increase of the torque obtained by the engine for the given operating conditions. The values of fuel consumption [kg/h] remained at a comparable level. The obtained results confirm predictions about the possibility of obtaining a reduction in specific fuel consumption using a catalytic converter with lower exhaust flow resistance. The lower backpressure in the exhaust system limits to a lesser extent the positive effects of additional expansion.

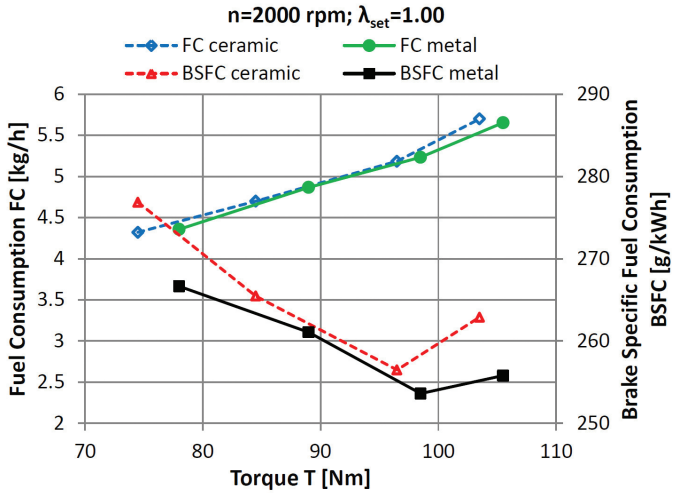

Fig. 25. Comparison of fuel consumption [kg/h] and brake specific fuel consumption [g/kWh] of the five-stroke engine cooperating with ceramic-support and metal-support converters as a function of the engine load

8. Discussion

The analysis of the research results showed that the effective exhaust gas aftertreatment at low load and low rotational speed is impossible. At medium and high loads, the acceptable operation of the TWC with a ceramic-support was observed. The applied ceramic reactor demonstrated correct operation from the exhaust gas temperature of approx. 280°C, which corresponds to a BMEP value of 2.5 bar at 2000 rpm. The tested metal-support reactor was not functional even with increased load and rotational speed when the exhaust temperature was already around 480°C. This fact gives reason for stating that the tested catalytic converter with a metal support obtained low conversion efficiency of toxic exhaust components due to the insufficient amount of precious metals used to make it. Unfortunately, the manufacturer of the converter did not reveal any data other than cell density and support dimensions.

In order to obtain an acceptable conversion efficiency of toxic exhaust components in the tested converter with a ceramic support, it is essential that, first of all, the regulation of the mixture composition occurs within a very narrow range of changes in the lambda value around the stoichiometric composition. In this situation, conversion efficiency of a high value is achieved, especially for nitrogen oxides and carbon monoxide; a lower value is achieved for hydrocarbons. The lower conversion efficiency for hydrocarbons than carbon monoxide or NO_x results from the generally low temperature of exhaust gases entering the converter. At an exhaust gas temperature of around 340 to 360°C, HC conversion efficiency may be lower than the NO_x result by 25 to as much as 40% [26]. A certain improvement in the efficiency of exhaust gas aftertreatment could be achieved by using a catalytic converter with newly developed support materials in the form of a mixture of Al_2O_3 / CeO_2 / ZrO_2 oxides. Converters with the used new support material show a significantly reduced activation temperature compared

to the previously used converters with the thus-far popular material mix of Al_2O_3 + CeO_2 / ZrO_2 oxides. Such converters are designed for use in vehicles with highly efficient SI engines with direct injection in which the exhaust temperature is significantly lower than for older engines [9, 47].

From the moment of starting the cold engine to achieving the active operation of the catalytic converter in the adopted load variability regime, more than 300 seconds elapsed. From the moment the engine got the target load to a start of converter operation about 165 seconds elapsed. The low temperature of the exhaust gases after additional expansion causes that the heating of the reactor to the light-off temperature takes a relatively long time. Shortening the warming-up period of a three-way catalytic converter requires limiting the operating period with a low load to a minimum. The limit here is mainly the durability of the engine, and the determination of the minimum allowable time for preheating the engine at low load would require wider operational tests in this regard.

The use of non-hardware exhaust gas temperature increasing techniques, for example by ignition retarding, is not very effective in the engine with additional exhaust expansion. The performed tests have shown that although the ignition retarding increases the temperature of exhaust gases leaving the fired cylinders in a similar manner to the classical engine, it does not, however, translate into a proportional increase in the exhaust gas temperature downstream from the low pressure cylinders. The effects of the ignition retarding are wasted by the intensified heat dissipation through the exhaust to the walls of the additional expansion cylinders and to the elements of the engine exhaust system. The costs of increasing the temperature of the exhaust gases by the ignition retarding are relatively high. The research indicated that the increase of exhaust gas temperature at the inlet to the converter by approx. 15°C was associated with an increase in the specific fuel consumption by 34 g/kWh, which translates to as much as 12%.

The use of the catalytic converter with a metal support of a lower cell density and the subsequent lower flow resistance resulted in increasing the torque of the five-stroke engine at the same boost pressure. The minimum value of the obtained specific fuel consumption is about 3 g/kWh lower than in case of cooperation of the five-stroke engine with the ceramic-support reactor. Unfortunately, as mentioned earlier, no symptoms of the effective operation of this metal-support reactor were found, even at the exhaust gas temperature of 480°C, which disqualifies it as a device for the aftertreatment of engine exhaust.

9. Conclusions

The low exhaust temperature of the engine with additional expansion means that the development of the exhaust aftertreatment system encounters problems which are absent in the case of conventional spark-ignition engines. The tested converter with the ceramic support fulfilled its functions in a correct manner. Acceptable levels of conversion efficiency of the converter were obtained under the quasi-stationary operating conditions of the engine. The requirement for correct operation of the reactor is exceeding an exhaust gas temperature

of 280°C, which is obtained with a load of 2.5 bar BMEP and a rotational speed of 2,000 rpm. Under these conditions, the ceramic-support catalytic converter was working properly; however, at low load after a cold start, warming up of the reactor to a light-off temperature would be extremely long. The reduction of exhaust emissions due to the reactor did not reach the nominal operating temperature requires the engine to enter the work area with a high load as quickly as possible. To obtain high values of conversion efficiency in TWC, it is also necessary to precisely adjust the composition of the mixture to a value of $\lambda = 1.0$. Deviations from this value by even 0.02 cause a significant reduction in the exhaust gas cleaning efficiency, especially in the area of hydrocarbon oxidation. The effect of shortening the warming-up phase of the catalytic converter to the operating temperature by increasing the temperature of exhaust gases internally in the engine is weakened by intensified heat exchange with the walls of the additional expansion cylinders and elements of the engine exhaust system. In order to substantially shorten the warming up time of a catalytic converter, the use of an external, hardware method, such as the use of electric heating of the reactor support, should be considered and balanced [25, 42]. Another idea is the relocation of the catalytic converter upstream from the turbine. The exhaust gas temperature is at least 50°C higher than that measured downstream from the turbine, which would contribute to a faster achievement of the effective operation of the catalytic converter [8]. In addition, an increase in the temperature of the exhaust gas in the catalytic converter resulting from the exothermic nature of the reactions occurring inside could improve the operating conditions of the turbine, which operates in a five-stroke engine at a relatively low temperature. For similar reasons, it is also possible to apply a catalytic layer on the walls of ports connecting the fired cylinders with low pressure cylinders, which would increase the exhaust gas temperature and improve the process of additional expansion [4].

The use of the metal-support reactor with reduced exhaust flow resistance resulted in a reduction in the specific fuel consumption of the five-stroke engine. The converter itself did not show proper functionality in aftertreatment due to the probable low content of precious metals used in its support; however, during the research, the potential possibilities of reducing fuel consumption by the engine cooperating with the reactor with low flow resistance were outlined. This means that further search for a suitable converter should be performed in the future.

The presented research and analysis results confirm the findings of previous works in which the five-stroke engine was defined as a source of propulsion suitable for cooperation with an electric power generator, for example, as a range-extender [34]. In such an application, the engine operates in fixed conditions with a high load. In classic vehicle drive systems, where the combustion engine is the sole source of propulsion, this character of the work is, by nature, impossible to achieve. The engine often works with a low load, which in the case of a five-stroke engine, is highly unfavourable due to its fuel conversion efficiency, as well as the conversion efficiency of the exhaust gas aftertreatment system with the TWC converter.

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