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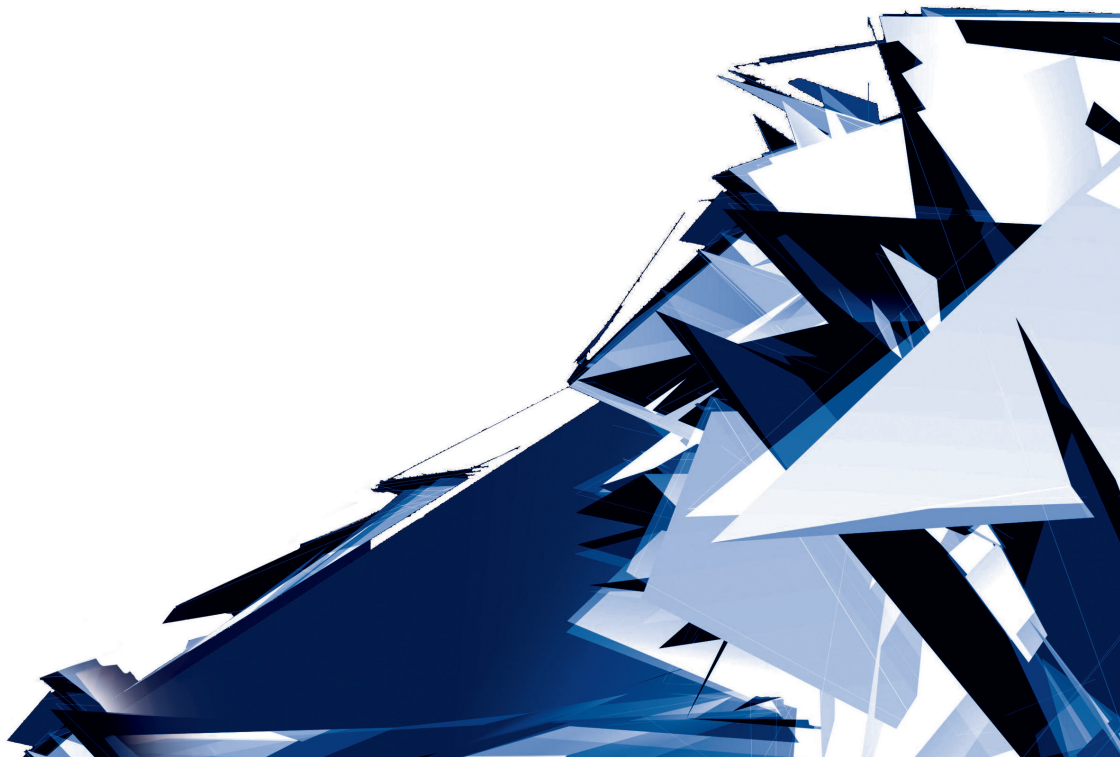

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The architectural design of light-permeable facades – a summary of recent trends and observations

Projektowanie architektoniczne fasad przezroczystych – podsumowanie najnowszych nurtów i obserwacji

Abstract

Contemporary architectural transparency, understood as the optical property of the construction material, is constantly being redefined and, over the last two decades, new design trends have developed. These trends are the result of: (i) dynamic technological progress; (ii) advancement in the field of materials science; (iii) changes in the attitude of clients and users. Transparency is no longer limited to specific functions (e.g. illumination of the interior) but has become a tool of formal expression itself. This paper defines most recent trends, which are divided into two main types: (i) optical-perceptual – relying on phenomenal effects, (ii) geometrical – that differentiate the large group of spatial transformations developed from what was initially flat planar façade.

Keywords: transparency, architecture theory, façade glazing, glass printing, glass coating

Abstract

Współczesna przezroczystość w architekturze, rozumiana jako właściwość optyczna materiału budowlanego, jest stale redefiniowana. W ciągu ostatnich dwóch dekad pojawiły się nowe nurty w projektowaniu przezroczystych elewacji w architekturze. Nurty te są wynikiem: (i) dynamicznego postępu technologicznego; (ii) osiągnięć w dziedzinie materiałoznawstwa oraz (iii) zmiany w nastawieniu klientów i użytkowników. Przezroczystość nie ogranicza się już do pełnienia konkretnych funkcji (np. doświetlenie wnętrza), ale sama w sobie stała się narzędziem formalnej ekspresji. Niniejszy artykuł definiuje najnowsze nurty, które dzielą się na dwa główne typy: (i) optyczno-wrażeniowe – oparte na zjawiskach optycznych, (ii) geometryczne – wyróżniające dużą grupę przekształceń przestrzennych początkowo płaskiej fasady.

Słowa kluczowe: przezroczystość, teoria architektury, przeszklenie fasady, nadruki na szkle, powłoki na szkle

Glück ohne Glas, wie dumm ist das,
Backstein vergeht, Glasfarbe besteht…
Sprüche für das Glashaus
Paul Scheerbart (1914)

Happiness without glass, how stupid is that,
the brick will perish, while glass will continue to exist
Sayings for the glasshouse
Paul Scheerbart (1914)

1. Introduction

Contemporary architectural transparency (understood as the optical property of the material) is constantly being redefined and, over the last two decades, new design trends have developed in relation to transparent façades in architecture. These trends are the result of dynamic technological progress and advancements in the field of materials science.

Contemporary trends in architecture are generally rooted in philosophy and reflect the prevailing social moods and transparency is no exception. It must be stressed, however, that the term transparency has been repeatedly redefined and is often metaphorically used as a tool of political discourse by various authors. Some authors also find general relationships with the current human condition, as "transparency expresses the dichotomy between the visual interconnection and the isolation of the individuals in modern society" [21]. These authors assume that certain optical characteristics of transparent envelopes can be permanent. This is not true because the visual experience connected with viewing architectural glass greatly depends on the light. Glass walls are "both reflective and transparent depending on the time of day, the angle of the sun, and the weather" [4]. Therefore, when some lighting conditions change, so do the relationships between the visual experience and architectural glass. In an attempt to bring some objectivity to the issue of trends in architectural transparency, the author of this paper presents a different point of view that is based on systematic morphological analysis. This analysis, however, might be somewhat subject to the author's personal aesthetic preference.

2. Methodology

The objective of the presented research project was to investigate and identify new trends in the architectural design of transparent façades, identify their scope and devise models that illustrate sets of typical features in each trend. The identification of new trends is crucial not only for architectural theory but also for the planning of glass production strategies and the manufacturing of glass processing equipment, which can serve as practical tools in implementing certain visual solutions. This paper is a presentation of the results of a large study of over five hundred facades located in Europe, USA, and Japan and built between 2001 and 2018.

The objective of the presented research program was to investigate and isolate new trends, identify their range and formulate models of the trends – "a group of all the features typical of the trend" [32]. The analysis of the visual performance of the building facades was performed in conjunction with the analysis of the innovative technologies used to build the façade. It was assumed that the "trend is a set of architectural objects, while the model is a group of the features typical of the trend" [31]. In order to create models of the trends, it is necessary to analyse the architectural form and the visual appeal of buildings. During this stage of the analysis, special attention was paid to the fact that the specific piece of architecture "shows usually only some of the features which are recognised as representative for the trend" [32]. The distinction of these features helped to create models of the trends and assign the selected buildings to the trends. This problem is also addressed in Section 5 and in Table 1.

Methodology is based on in-situ research of case studies, specifically, the photographic documentation of existing buildings, the conducting of measurements and field observations. Field observations are an essential component of the proposed scientific method and plays an important role in collecting data and formulating scientific insights. Originally, the analysis of individual facades as case studies was intended. After the collection of data and the photographic inventory began, it became evident that the study of each case was unfeasible. J. Gerring in Case Study Research states that the study should "include 5–10 cases" [16]. At the time this paper was written, the database had 524 entries and was growing. Because of the large number of database records, it was decided to change the methodology from a case--study analysis to a large sample analysis. As a result, it also proved to be more effective in creating models of trends of transparency in contemporary architecture. However, it has to be stated that particular façades are presented in this paper for illustrative purposes, not as case studies. This is based on the assumption that only the most representative case-studies are suited the best to present the trends in the most visible way. The presented facades have the most profound features that are characteristic of the illustrated sub-groups of trends.

All façades presented in the paper were visited and photographed by the author. Although this kind of aesthetic assessment is usually rather emotionally-driven than science-based, one must realise that a scientific method for the objective appraisal of beauty has yet to be invented. The author's emotional assessment is counterbalanced by his analytical approach focused on identifying the technique, the materials that were used, and the optical results. For each sub-trend, the morphological analysis was performed while taking into the account the following factors: (i) geometry (ii) the number of transparent layers, (iii) the depth of penetration of the eye and (iv) homogeneous or heterogeneous light transmission through the façade.

3. Background

Architects approach transparency differently depending on their own attitude and that of the client. Some solutions are well thought out and serve as architectural manifestos, others are by-products of the chosen design technologies, e.g. double façades were initially introduced

to regulate climate and handle acoustics. Furthermore, transparency in architecture remains an important tool of political discourse when used by those authorities that associate optical transparency with institutional transparency. Paradoxically, the term transparency – rarely seen in reality in the form of bonafide visual manifestation – has gained an additional meaning associated with "legitimacy, policy efficiency, and good governance, as well as a universal remedy against corruption" [15]. This politically-driven discourse is still present in architecture and – despite the fact that transparency has gained an identity of its own – is commonly used to justify the excessive use of glass in public buildings.

4. Aesthetic trends in transparency

Despite the fact, that transparency in architecture is deeply rooted in technological advancement, aesthetic qualities are of profound importance in the decision that is made by both the client and the architect on the use of glass in façade. Glass, as addressed below, carries immense symbolic meaning that seems crucial for the decision making process. The advancement of glass technology has always been pushed by human imagination and aspirations. First, people dreamt of larger glass panes, than glass walls, then whole glazed buildings. And technology has provided adequate means of fulfilling these aesthetic ideas and aspirations. As a result of the analysis described in Section 2, two main types of trends have been distinguished: (i) optical/perceptual and (ii) geometrical. These are addressed below. It is important to note that in final table of optical and geometrical trends do not sum up to 100% but frequently go above this value because the analysis on the quantitative level have been performed separately for optical and geometrical types.

4.1. Optical/perceptual trends

Perceptual and optical experiments are a new, distinctive and booming trend leading to the creation of the new styles of transparent facades that offer new experiences to building users and visitors. Many innovative techniques are used to enrich the spatial depth of the facade, multiply the observed plans and achieve the picturesque effects of blur, stratification or movement. However, as it has also been observed, many pre-existing techniques (meaning existing before the year 2000) are still used, therefore – for the sake of accuracy – they are also included in the provided analysis. A brief description of the trend's models and representative case-studies are given below.

4.1.1. Classic/clear transparency

Classic transparency is basically the use of transparent or partially coated glass. This trend was regarded as the basis for the definition and the reference of the other trends. The classic/clear transparency model is defined as the unmodified transparency of the light-transmitting material (with some possible partial use of coating on the glass). This trend is present in a total of 23.2% of optical type cases. It was a surprise to find out that only about a quarter of

the studied facades preserved the original optical properties of the light-transmitting material. However, the above-mentioned "excessive use of glass" (see Section 3) could still be found and is frequently used to emphasise the prestige of the building, for example, in the Supreme Court in the Hague (arch. by KAAN Architecten, 2015), which has recently been reviewed as "more crystalline than transparent" [24] or the well-known CDU headquarters in Berlin (arch. Petzinka and Partners, 2001). Although the former building is extensively glazed at the street level, it only enables a shallow penetration of its doubled-glazed envelope on the top floors (see Fig. 1, Fig. 2). Such glazing manifestos have repeatedly been built around Europe since the 1960s, with Stuttgart's Landtag von Baden-Württemberg (arch. Horst Linde, 1961) as the originator of this trend. The most recent trends in architectural transparency seem to have shaken off this political "transparency" burden by allowing visual and material experiments to take a leading role in the creation of architectural space and the user's impressions.

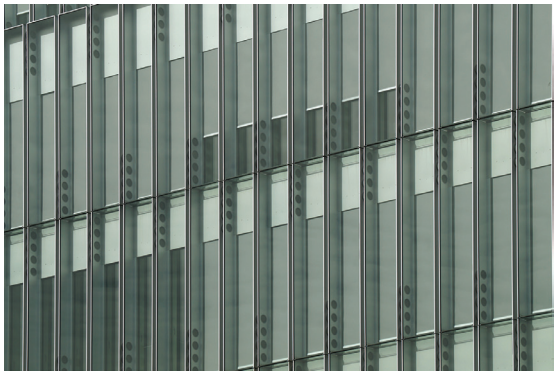

Fig. 1. Supreme Court in the Hague (arch. KAAN Architecten, 2015)

Fig. 2. CDU headquarters in Berlin (arch. Petzinka and Partners, 2001)

4.1.2. Obstruction of transparency

Obstruction of transparency is defined as an intentional significant change of optical parameters of light-transmitting materials used in the façade, and its model is defined as the local or gradual loss of the light-transmitting properties of the façade. The obstruction trend is the most numerous trend type, totalling 40.6% of optically analysed facades. Within this type, a few sub-groups (or sub-trends) were defined including (i) homogeneous obstruction (e.g. frosted glass – 7%); (ii) heterogeneous obstruction (e.g. silk printed glass or frit printed glass 11.5%). The models might be formulated as follows: heterogeneous obstruction takes place when "light transmission is blocked by elements that are randomly or evenly scattered in front of, or on the pane's surface" [12] or homogenous when a homogenous decrease in light intensity is experienced. This group of obstruction trends also includes the shading systems of different types as external/internal blinds, shutters, rollers that affect the visibility and light transmission, which in total account for 22.1% of facades.

Research has shown that obstruction is the dominant trend, denoting the enthusiastic use of prints, rasters, blinds, shutters and other systems in order to achieve other, previously unavailable visual effects (veiled transparency, visual occlusion). In many situations, the

transparent panes of glass only serve as a *scaffolding* for the creation of a specific visual *veil*. The obstruction of transparency has recently gained in importance with the emergence of innovative technologies and materials that offer new formal solutions. Heterogeneous obstruction can be achieved by printing, laminating or depositing a thin layer on the surface of the glass. Examples of such solutions include the screen-printed glass in Hôpital Jean Mermoz (arch. F.-H. Jourda, 2008), Clinique du Parc (arch. Xanadu, 2007) and small patches of reflective surface which create a pattern on the glazed façade of the Uni Carl Vogt in Geneve (arch. 3BM3, 2015) – see Fig. 3, Fig. 4, Fig. 5.

Fig. 3. Hôpital Jean Mermoz (arch. F.-H. Jourda, 2008)

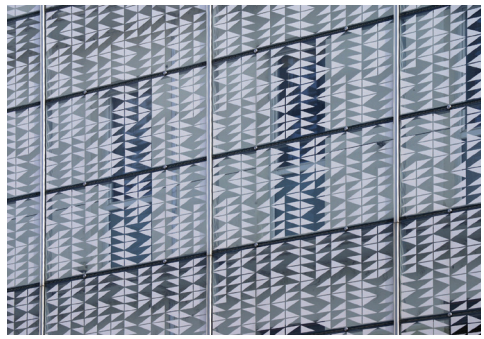

Fig. 4. Clinique du Parc (arch. Xanadu, 2007)

Fig. 5. Uni Carl Vogt in Geneve (arch. 3BM3, 2015)

Examples of *veiling* include the use of evenly translucent or foggy/ornamental glass that is embossed with a small-scale graphic or geometric pattern. This type of material distorts the image transmitted through the glass and causes the elements behind it to appear hazy and foggy. Some architectural theoreticians notice the connection between this type of transparency and postmodernism and trace the beginning of this trend back to the writings of the French philosopher Jean Starobinski, who derives a foggy translucence from the ancient and archetypical "Poppea's veil" [33]. Herbert Muschamp even says that "the skin of a building is not used to reveal but to hide" [22].

On the optical level light-scattering materials behave differently than fully transparent. The entire translucent pane emits scattered light and successfully blocks the image but lets the light pass through. This is a feature of translucent light-permeable materials that changes the quality of

light and thus gives a soft and hazy quality to the illumination. From an architectural perspective, translucency offers the unique possibility to dematerialise the building, to blur its boundaries and achieve visually different results in different daylighting scenarios. The Silesian Museum in Katowice (arch. Pysal Ruge Architekten, 2013) is a good example of the use of ornamental glazing embossed with a so-called frost-flower pattern, while the headquarters Sotax AG (arch. Itten+Brechbühl, 2013) could serve as an example of the use of a uniformly translucent façade. The new Credit Suisse Backoffice (arch. Burckhardt+Partners, 2012) offers an even more exciting visual experience as the building is equipped with "recessed ribbon windows with translucent glass balustrade elements" [23] which make the areas where translucent panes are mounted seem out of focus, see Fig. 6, Fig. 7, Fig. 8.

Fig. 6. Silesian Museum in Katowice
(arch. Pysal Ruge Architekten, 2013)

Fig. 7. New Credit Suisse Backoffice
(arch. Burckhardt+Partners, 2012)

Fig. 8. Headquarter Sotax AG
(arch. Itten+Brechbühl, 2013)

4.1.3. Reflexive coating/mirrored glass

Significant progress has also been made in the field of applying different coatings to glass. Use of reflexive coatings still remains a notable trend in the application of light-transmitting façade materials (7%). This sub-trend model is defined as both a significant reduction of transparency together with the specular reflection of a large portion of incoming light to the extent that enables a virtual image to be created that dominates the pane. Originally, silver was used for this purpose, but for the sake of cost, aluminium is now widely applied. This type of coating reduces the energy gain through the façade to facilitate the regulation of the microclimate but simultaneously disturbs the transmission of the image, usually from the inside to the outside. Reflective coatings visually turn the glass into a two-way mirror (although of course, some daylight is introduced into the building) [8].

The reflexive coating has significant disadvantages, both functional and aesthetical. It always reflects the same percentage of incident light so in the winter, the desirable greenhouse effect will not work. In architecture – after the original fascination – the reflective coatings have faced a wave of harsh criticism as e.g. "(…) the glass skin repels the city outside" [34] and were commonly associated with corporate architecture. Reflective coating impacts not only the appearance of the buildings "thereby changing the buildings into impermeable mirrored solids" [11].

4.1.4. Multiplication

The multiplication of optical phenomena in façades was initially a side-effect of the deliberate use of an extra layer of glass in order to improve the thermal performance of windows. This *doubling* trend peaked in the mid-1990s with the development of technology and methods of calculating airflow (computational fluid dynamics) and assessing the climatic performance of double facades, which in turn provided evidence supporting the choice of a given technology.

Distinctive features of this trend – those characteristics of the model – include the multiplication of optical phenomena, e.g. higher absorption (if a ray of light penetrates through more layers), the multiplication of reflections or even the loss of the contrast such as in the Lightcube Office in Zurich (Fischer Architekten, 2006, see Fig. 9) where "material transparency of the walls" is converted "into perceptual opacity" [4]. The aesthetic effect is also created by intentionally moving apart the layers of glass in the façade to achieve a chiaroscuro effect on what is basically a flat glass facade. Additionally, there can be the impression of the apparent duplication of the elements of the structural frame, as the light is zigzagging between panels, e.g. the façade of Bern Train Station (arch. Atelier 5, 2003).

This trend has been clearly visible since 2000 (10.5%) within the studied group of facades and in the architecture of transparent facades, it has been present since the 1990s. The research shows the decreasing popularity of doubling solutions in the second decade of the 21st century. This may be due to the tendency to seal the building envelope to recover heat and thus to limit natural ventilation schemes of which the double façade was a part of. Double façades also provide additional space for solar gain regulation devices (rollers or blinds) thus eliminating the need to use mirrored glass to regulate insolation. This important change in technology enabled new optical characteristics to appear. Due to daylight playing a key

role in the perception of the transparency of a building, the elusive appearance of its façade depends very much on the viewing conditions. This phenomenon has become the most interesting feature of new multiplied transparent walls. In their designs, architects have started incorporating the effects of multiplied optical phenomena, such as decreased transmission and overlaid reflections, in order to achieve rhythm, proportion, and balance.

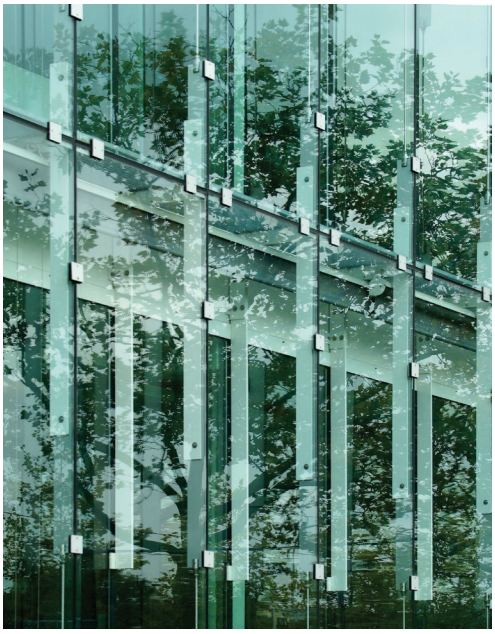

Fig. 9. Lightcube Office in Zurich (Fischer Architekten, 2006)

Notable buildings and concepts that are usually quoted by architecture critics, such as the Tres Grande Bibliotheque proposal (OMA, 1997), the Institute for Hospital Pharmaceuticals (Herzog de Meuron, 1995), and Kunstmuzeum Winterthur (arch. Gigon & Guyer, 1995), represent the multiplication trend which, at some point, gave birth to the – redundancy trend discussed below.

4.1.5. Redundant transparency

Redundant transparency is probably one of the most interesting trends, although it is not very popular (2.1% of recorded cases). It was identified and described by the author in 2014 in his paper entitled *Redundant transparency: the building's light-permeable disguise*. The sub-trend model is defined as follows: redundant transparency occurs when light-transmitting materials are used to "enrich the spatial depth of the spandrel region of a building's facade without affecting its main important function of bringing light into the building" [10]. The use of light-transmitting materials does not affect the illumination of a building but visually activates large areas of the façade that were previously relatively inert. The shallow space behind this redundant glazing adds the impression of depth to the previously flat part of the building. Originally, redundant transparency took the form of

(i) the shadow-box, and (ii) the cloche. The shodow-box consisted of a relatively shallow space behind glass, such as in the case of the Deutsche Krankenversicherung headquarters in Cologne, Germany (arch. Störmer Murphy and Partners, 2005) – see Fig. 10. This form later developed into much more complex solutions with entire buildings covered by a cloche, which describes bell-shaped glass. The cloche, defined as an additional transparent layer of the outer envelope, originated in buildings in the early 20th century e.g., the Steiff Factory (arch. Richard Steiff, 1903). However, it became very popular as it proved to be surprisingly effective in shaping the microclimate in a building by mitigating seasonal temperature differences. This was achieved by exploiting air circulation in the summer period and solar gain in the winter period. An excellent but not widely known example of this cloche solution is the glazed enclosure build over the go-cart racing track in Delft in the Netherlands (arch. Cepezed, 2001) – see Fig. 11.

Fig. 10. Deutsche Krankenversicherung (arch. Störmer Murphy and Partners, 2005)

Fig. 11. Go-cart racing track in Delft (arch. Cepezed, 2001)

4.1.6. Perceptual transparency

Small-sized meshes or perforated surfaces (although typologically heterogeneous) are optically perceived as producing a homogenous decrease in transparency. This phenomenon of perceptual transparency occurs when the openings in such meshes or perforations are so small as to be beyond the limits of the spatial acuity of the human eye. This sub-trend model is therefore defined by the phenomenon of the perforated surface/mesh becoming evenly transparent. This perceptual phenomenon is eagerly used by architects as it produces the effect of transparency without the use of materials which transmit visible light. There are many solutions that take advantage of this technology ranging from a glittering mesh, such as the one on the façade of the De Baljurk in Hague (arch. Eric Vreedenburgh, 2005) to perforated

metal sheets which not only create the effect of transparency but simultaneously produce moiré fringes. This sometimes unwanted consequence is especially visible in the expanded metal cladding of the recently refurbished Toni-Areal development in Zurich (arch. EM2N Mathias Müller und Daniel Niggli, 2014), see Fig. 12, Fig. 13.

Fig. 12. De Baljurk in Hague (arch. Eric Vreedenburgh, 2005)

Fig. 13. Toni-Areal development in Zurich (arch. EM2N Mathias Müller und Daniel Niggli, 2014)

4.1.7. Underlit facades

In the course of the research, it was also necessary to introduce new parameters that have not been defined before. One of these is the definition of the directionality of the light transmission through the facade. This parameter describes the predominant direction of light transmission from the perspective of the aesthetic outcome significant for the viewer and especially applies to the night viewing conditions. After dusk, the usual direction of light transmission is reversed as artificial lights are lit inside the building [8]. This artificial light radiates out of the building reversing the usual direction of light transmission from the inside to the outside – this defines this sub-trend model. It became evident during the research, that there is a growing trend for façades that are deliberately designed to look better in night conditions, than in the daylight. This new trend was tentatively named underlit façades and was found to be especially present in Japan (1.8% of cases in total, of which 7.3% in Japan) – see Fig. 14. The rationale behind this is the fact that predominant exposition of the façade to the client usually happens after dusk (e.g. in Tokyo in summer, twilight falls at 19:00 and in winter, at 17:00). Therefore, designers and clients focus on the attractive appearance of buildings at these times of the day when customers leave their jobs and stroll through the city.

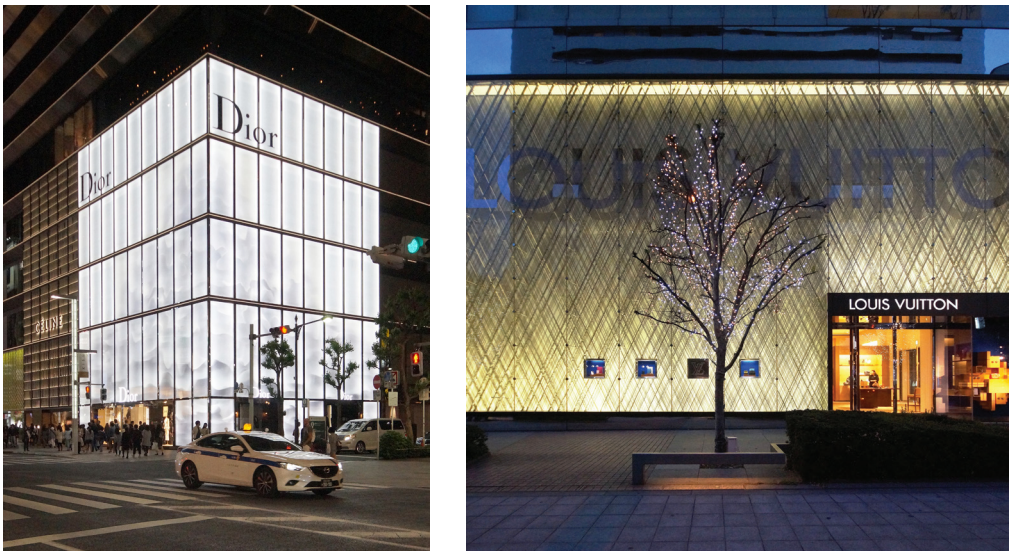

Fig. 14. Left: Ginza Six Store Dior, Tokyo, Japan (arch. Yoshio Taniguchi, 2016);
Right: Louis Vuitton Hilton Umeda in Osaka, Japan (arch. Office of Kumiko Inui, 2009)

4.2. Geometrical trends

Geometrical deformation is deeply rooted in the sculptural qualities of the building's volume. Many methods of shaping the building's volume are used. Architects tend to choose the method that best suits the functional program, reflects the relationship with the surroundings and corresponds with individual aesthetic sensitivity (the unique architectural style). Briefly speaking, transformations that vary in scale are generally made to: (i) the entire volume of a building (in 3D), (ii) in the depth of the façade (in 2.5D – relief, analogous to the double façade design) and (iii) on the flat surface of the façade – pattern in 2D – also called façade decoration. Those two sub-groups (2.5D and 3D) are described in the detail in the paper entitled *Studies on glass facades morphologies* recently published by the author [11].

The presented typology is based on façade geometry and divides facades into two groups of *spatially deformed* facades with surface continuity (and their variations), which produce various types of curves (single or double-curved), and *segmented iterations*, which consist of single facets that form a folded/serrated/protruded surface of the façade [3]. The general typology is explained in the diagrams in Fig. 15.

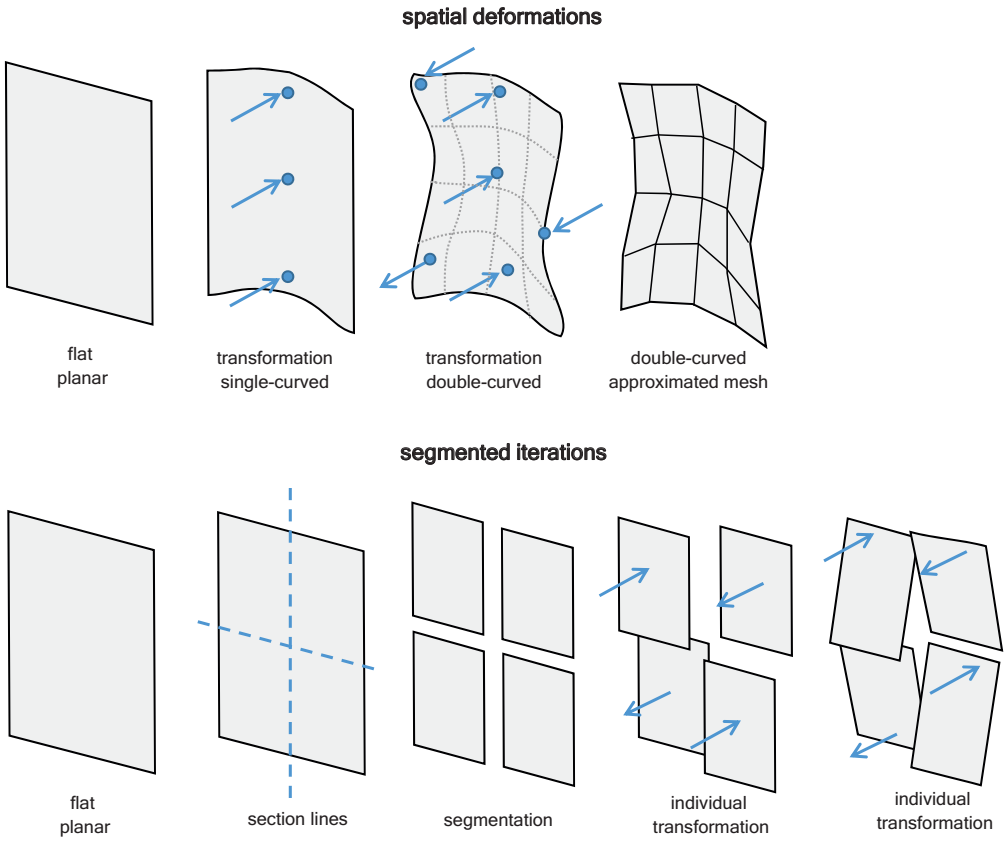

Fig. 15. Surface transformation phases (schematic diagram by author)

4.2.1. Planar curtain wall

Use of a flat glass curtain wall is the most widespread technical solution and is observed in 45.5% of geometrical cases. As with the clear transparency trend, it is used here as a reference for other geometrical deformation trends. The definition of this sub-trend model can be simply formulated as a flat, planar surface of the glass, regardless of whether it is constructed using mullions and transoms, or is, for example, frameless.

The first curtain walls were flat. This facilitated the production of mullion and transom elements and the assembly of flat glass sheets. With the application of this technology, the façade of the building has no load-bearing function and is only a thermal and functional barrier. This trend is characterised by a system of mullions and transoms, which are usually aluminium, constituting a framework for glass panels. This technology is deeply rooted in the achievements of the modernism movement, with the first cases of application in Bauhaus, Dessau (arch. W. Gropius, 1926). Curtain walls are used globally and are present in all observed locations, possibly due to the evident spread of curtain-wall technology as a part of the so-called international style. The most visible invention in curtain-wall technology is the use of timber as a more sustainable solution than aluminium. Because timber rots when exposed to the outdoor environment, profiles with aluminium on the outside and timber on the inside seem to be the most suitable solution.

4.2.2. Double leaf facades

These are thoroughly described in Section 4.1.4, which considers multiplication. From a geometrical perspective, this sub-group accounts for 12.1% of recorded façades and is described as a "system consisting of two glass skins placed in such a way that air flows in the intermediate cavity" [28]. This geometrical sub-group features intakes and exhaust for air-circulation. These are usually located on the surface of the façade. Recently, more cases of non-planar double-leaf facades have been recorded as planar façades, but curvilinear facades are also built.

4.2.3. Spatial deformations

Spatial deformations preserve the continuity of the surface. Such surfaces are characterised by smooth transitions and the absence of acute angles (mild/soft angles are more common). Spatial deformations produce both regular and irregular shapes. The former sub-group includes single-curved surfaces (cylindrical, conical, elliptical and rotational geometry) and double--curved surfaces (synclastic and anticlastic shapes, e.g. hyperbolic paraboloid) while the latter covers all free-form transformations (including twisting, bending, tapering, free-forming). The model of this trend could be characterised by the unbroken continuity of the surface.

At the technical/manufacturing level, double-curved or free-form geometry is usually achieved by using flat or curved glass. The use of flat glass requires the approximation of curved surfaces by using flat faces/panels (triangles or planar quads). Thus, a mesh is created which represents the curvature or free-from geometry of the facade. The rare example of this can be found in the case of the Headquarters of the Department of Health of the Basque Government in Bilbao, Spain (arch. Coll-Barreu Arquitectos, 2004), where "folded element produces multiple views of the city, and changing its appearance depending on the point of view, the hour and the season" [3] – see Fig. 16. The issue of mesh geometry and the definition/optimisation of mesh nodes has recently evolved and currently constitutes a separate discipline of science, both in mathematics, geometry and façade engineering. The most comprehensive lecture on the topic is provided in the book *Architectural geometry* [25].

Fig. 16. Headquarters of the Department of Health of the Basque Government in Bilbao, Spain (arch. Coll-Barreu Arquitectos-Juan Coll Barreu & Daniel Gutiérezze Zarza, 2004)

The use of curved glass in single- and double-curved facades is rare because its production costs are very high. Glass can be hot or cold bent. Hot bent glass can be bent at smaller radii, while cold-bent glass only allows much smaller curvatures and thus requires large radii – the minimum cold-bending radius is approximately 1500 times the thickness of the glass. Cold bent glass requires a rigid sub-frame to maintain its shape as this is visible in the case of the Van Gogh Museum's New Entrance (arch. Hans van Heeswijk Architects, 2015) where large panes of glass are cold bend on a lattice of vertical glass fins and rigid steel horizontal curved girders – see Fig. 17.

Fig. 17. Van Gogh Museum's New Entrance (arch. Hans van Heeswijk Architects, 2015)

The above spatial deformation might be also visible in a smaller scale, not at the scale of the whole volume, but on the scale of the façade's depth (as addressed above in 2.5D resulting in the bas-relief). These rare cases include the hot-bent glass façade elements that are later assembled to form basically planar facades but undulated on the scale of the façade's relief. These cases include the sinusoidal glazing of Casa da Música – Sala de concertos, in Porto (arch. OMA, 2004 – see Fig. 18) and a similar system was used in the MAAS museum in Antwerp (arch. Neutelings Riedijk, 2011 – see Fig. 19). The example of the Swiss Re Ltd Headquarters

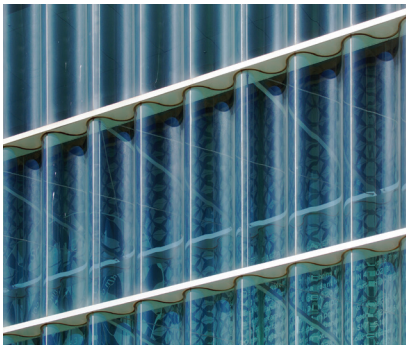

Fig. 18. Casa da Música – Sala de concertos, in Porto (arch. OMA, 2004)

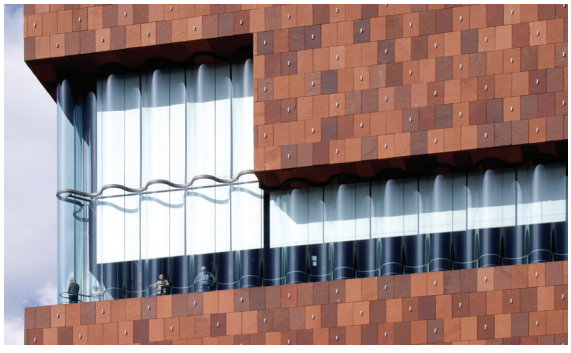

Fig. 19. MAAS museum in Antwerp (arch. Neutelings Riedijk, 2011)

in Zurich (Diener & Diener Architekten, 2017) presents an obvious transition case between the spatial deformation and surface iteration, as its glass cladding – in the form of undulating planes – is also a shingle-like arrangement along the façade – see Fig. 20.

Fig. 20. Swiss Re Ltd Headquarters in Zurich (Diener & Diener Architekten, 2017)

4.2.4. Surface iterations

Iteration breaks the continuity of the façade surface and divides it into individual facets which can be oriented in different directions (the above-mentioned approximation also divides façades into individual facets by creating a mesh, but these facets are used as smooth transitions that represent a curve). The model of this trend could be characterised by – in the opposition to the previously described trend – the broken continuity of the surface and the creation of a segmented facade. The general geometrical rule for surface iteration (general scenario) requires two consecutive spatial operations. Firstly, the fragmentation/division of the façade's surface into segments (either regular or irregular), and secondly, the geometrical transformation of the segments obtained in the previous operation (e.g. translation, rotation, scaling, skewing) – see the diagram in Fig. 15.

Among the most popular iterated solutions are facades with:

- **Protruding and retracting segments**
  Parts of the façade form oriels that project forwards and backward, e.g. Bürogebäude Haus 1 in Munch (arch. Ganzer-Hajek-Unterholzner/Louvieaux, 2010) – see Fig. 21.
- **Serrated/folded segments**
  These are basically characterised by the zigzagged geometry in the vertical or horizontal section (horizontal section serration being much more frequent) and parallel fold lines. This produces rectangular façade facets/panels. Serrated facades are also characterised by the *angle of serration* which describes the angle between the panel and the overall surface of the facade. In repetitive/rhythmic solutions, the angles are usually of the same measure, e.g. the Oskar von Miller Forum in Munich (arch. Herzog+Partner, 2009) – see Fig. 22; when arbitrary geometry is applied, the angles are random e.g. the Osaka Fukoku Seimei Building (arch. Dominique Perrault Architecture, 2010). Arbitrary serration requires much more labour-intensive detailing, as all the junctions at unique angles have to be solved/designed separately. Serration can also be applied

Fig. 21. Protruding and retracting segments. Bürogebäude Haus 1 in Munch (arch. Ganzer-Hajek-Unterholzner/Louvieaux, 2010)

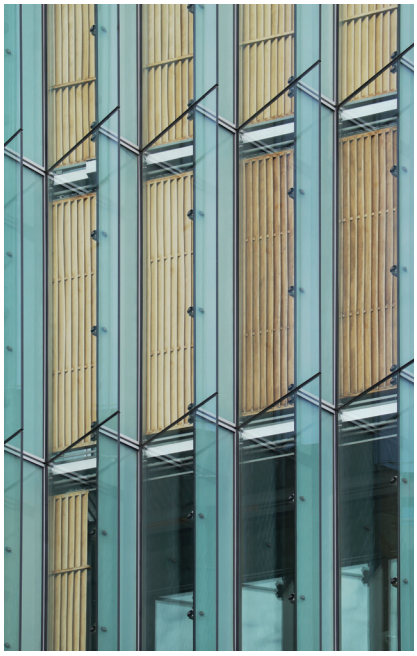

Fig. 22. Regular serrated segments: Oskar von Miller Forum in Munich (arch. Herzog+Partner, 2009)

to the entire façade or it can be limited to a single storey. Very interesting visual effects can be achieved when the serration on the upper and lower stories is different e.g. the Conservatorium of Amsterdam (arch. van Dongen – Koschuch, 2005) – Fig. 23. The issues of serrated facades – including serrated double facades – were addressed in depth in the paper entitled "Morphology of serrated glass facades: repetitive and non-repetitive serration: single and double serrated facades" [13].

- **Pleated segments**

  These are similar to those mentioned above but with arbitrary fold lines, e.g. Tokyu Plaza Ginza (arch. Nikken Sekkei, 2016), which produce arbitrary polygonal facets/panels on the façade – see Fig. 24.

- **Shingled segments**

  Panes of glass are positioned in a similar arrangement to fish scales or shingles. Glass shingles are frequently used to introduce air into the space of the façade because the manner in which panes are arranged rarely provides a tight connection between the panes (as in the case of roof tiles). Such examples of the use of shingle segments are the H 19 Office Building in Duesselfor (arch. Petzinka Pink und Partner, 2002) – see Fig. 25 – and Steiermärkische Sparkasse in Graz (arch. Szyszkowitz-Kowalski, 2006) – see Fig. 26. In Ghent's market hall (arch. Robbrecht en Daem and Marie-José van Hee, 2013) glass plates mimic ceramic roof tiles, providing improved quality of light transmission through the glazed envelope of the roof – this recent case study was analysed in detail in the paper entitled *Glass protected timber façades – new sustainable façade typology* published by Technical Transactions no 2/2019 [7].

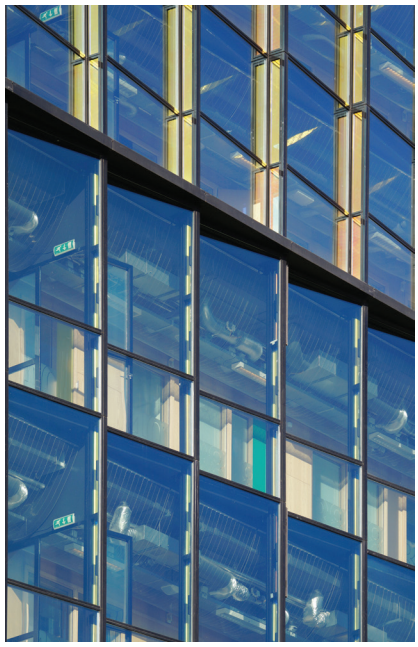

Fig. 23. Serrated segments in different directions Conservatorium of Amsterdam (arch. van Dongen-Koschuch, 2005)

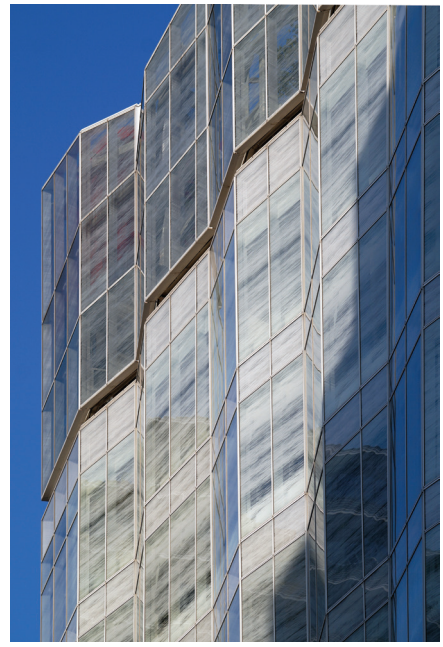

Fig. 24. Tokyu Plaza Ginza (arch. Nikken Sekkei, 2016)

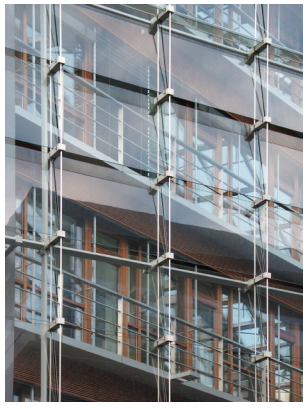

Fig. 25. H 19 Office Building in Duesselfor (arch. Petzinka Pink und Partner, 2002)

Fig. 26. Steiermärkische Sparkasse in Graz (arch. Szyszkowitz-Kowalski, 2006)

- **Finned segments**
  These are not a pure example of a segmented iteration, but, once the fins are added, they are visually divided into separate parts and alter the surface of what is basically a flat façade. The issues of glass fins were addressed in depth in the paper entitled *Glass fins – a structural and aesthetical application in glass facades* [6] which distinguished between fins that are used as (i) decorative (aesthetic enrichment of the facade), (ii) functional

(e.g. as sunshade) and (iii) structural (stiffening and load-bearing) elements of the facade. From the structural point of view, glass fins replace the opaque vertical mullions in classic curtain-wall façade systems. The first successful application of this system in buildings (e.g. Willis Faber & Dumas Headquarters by Foster and Partners, in which the façade is partially hung from above using glass fins) facilitated the spread of the system and pushed the technology for the creation of new developments. Glass fins are connected with the façade glazing by the means of patch fittings, corner connections or point mount fittings; there are numerous available systems offering fin heights of up to 12–15 meters, reaching 18 m is some conceptual proposals.

5. Quantitative results

As a result of the analysis described in Section 2, two main types of trends have been distinguished: (i) optical/perceptual, (ii) geometrical. From a methodological point of view, modern trends cannot be categorised because the analysed facades – records in the database – represent distinctive features that fall into many types and sub-groups simultaneously e.g. a façade could present both the features of geometrical serration and obstructed transparency, as is the case with the Historical Archive of the Basque Country (arch. ACXT, 2013) – see Fig. 27.

Fig. 27. The example of the façade falling into multiplied types and sub-trends: irregularly serrated and obstructed transparency – Historical Archive of the Basque Country (arch. ACXT, 2013)

Therefore, the presented approach is more "many-valued logic" [18], rather than strict categorisation. Trend developments over time was presented in the diagram of the glass trends. This diagram (see Fig. 28) is based on a similar methodology to diagrams initially created by Charles Jenks. Despite the fact, that – as Jencks claims – "architects dislike being pigeon-holed as much as do politicians and writers" [19], assigning the case-studies to trend types, and sub-trends was a necessary operation. However, finding an "evolutionary" connection between trends, as was the original aim, requires a detailed case-study of each façade. These connections certainly exist, but, taking into account the number of analysed facades, this study requires more time and effort than a simple morphological analysis, model building and a mere graphical representation.

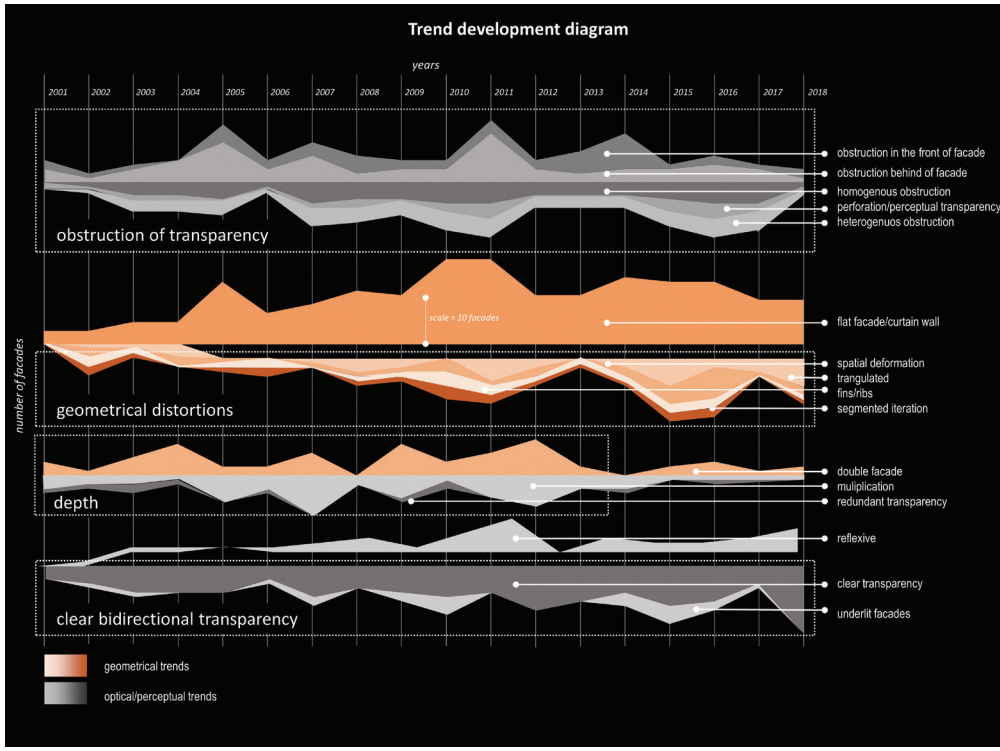

Fig. 28. Trend graph representing the development of the most important trend types (optical and geometrical) and sub-groups over time for the years 2000-2018

The interpretation of the presented diagram should be considered carefully, with respect to the fact that it represents the trend distribution of facades from the collected data pool and does not include all facades. As it was initially said, only the most representative examples are chosen that present the characteristics of the trend in the most visible way. However, some buildings still have inclusion in the database pending and therefore might not contribute to the overall image of recent trends. The presented research program is intended to be a long-range task, and the more facades that are collected, the more precise the available results will be. Analysis of the database remains ongoing and it seems that in

the future, a matrix approach would probably be used to describe the trends with greater precision, than is currently presented. Nevertheless, some results may be provided and conclusions generalised drawn on the basis of 524 cases that were collected. These results include the following:

- The algorithm for the establishment of the trend model was presented (identifying the most important characteristic features of the trend). Trend models – the characteristic features of trends are summarised in Table 1.
- The existence of the trends originating in the twentieth century was confirmed (e.g. clear transparency, reflexive glazing, curtain wall). The number of facades peaked around 2010–2011, but this might be the result of the largest amount of cases being recorded for this period.
- Previously unknown trends were described (as redundant transparency, underlit transparency, perceptual transparency).
- Geometrical study of the facades shows the visible growth of the number of geometrically complex facades (triangulated, serrated and ribbed/finned). It seems that Bilbao's building might be a starting point of the independent sub-group development, see Fig. 16.
- The optical sub-trend of multiplication and the geometrical trend of doubling the façade layers almost coincide because the optical effect of multiplication is almost always enforced with the technical operation of layer "doubling";
- A relatively constant proportion of façades with the obstruction of transparency is observed, even taking into account the significant fact that more facades completed in the years 2010-2011 were recorded.
- The chronology of facades was studied and constituted the basis for the study of the trend's development over time. Façade's form depends upon climate, prevailing local technology, and construction tradition was also confirmed.

Table 1. Trend model definitions – the most important characteristic features of the trends

Trend sub-group	**Model definition**
1	2
Optical/perceptual trends	
Classic/clear transparency	▸ unmodified transparency of light-transmitting material ▸ some possible slight use of coating on glass is possible
Obstruction of transparency	▸ local or gradual loss of the light-transmitting properties of the façade ▸ intentional significant change of optical parameters of light-transmitting material
Reflexive coating/mirrored glass	▸ significant reduction of transparency together with specular reflection ▸ virtual image created that dominates the pane
Multiplication	▸ multiplication of optical phenomena ▸ multiplication of reflections ▸ higher multi-pane absorption

Table 1 (continued from the previous page)

1	2
Redundant transparency	▸ light-transmitting materials used to "enrich the spatial depth of the spandrel region of a building's facade without affecting its main important function of bringing light into the building" [10]
Perceptual transparency	▸ perforated surface/mesh becoming evenly transparent
Underlit facades	▸ change of the predominant direction of light transmission from inside to the outside ▸ artificial light radiation out of the building after dusk
Geometrical trends	
Flat curtain wall	▸ flat, planar surface of the glass, regardless of whether it is constructed using mullions and transoms, or is, for example, frameless
Double leaf facades	▸ system consisting two glass skins placed in such a way that air flows in the intermediate cavity ▸ intakes and exhaust for air-circulation
Spatial deformations	▸ smooth transitions and the absence of acute angles (mild/soft angles are more common) ▸ triangulation possible if straight line approximation in applied
Surface iterations	▸ broken continuity of the façade surface ▸ division into individual facets which might be oriented in different directions and at a different angles

6. Discussion

Although, as stated above, aesthetic considerations have priority over technical solutions in many situations, in fact, many purely formal trends evidently find their origin in technology and design decisions that are governed by rational issues (e.g. the impression of depth that was created as a by-product of double façades). The implementation of certain rational technical solutions simultaneously creates many opportunities for visual expression. This also applies to other aspects of façade technology, which can be a source of other creative inspiration. **Drawing visual and formal inspirations from the achievements of façade technology** is a general feature of recent trends in the design of light-transmitting facades. Another notable trend in façade technology is characterised by the **increasing complexity of the facade**, not only from the technological perspective (e.g. the increasing amount of components) but also in terms of façade geometry; this trend is the high variety of the forms that are used.

The façade becomes more than a passively perceived interface, envelope, and enclosure of the building's volume. **The relationship between the interior and exterior seems be much more complicated**. Façade represents order, hierarchy, power and prestige. Symbolically it frequently encodes the transparency of the institution itself. The facades thus become

an integral part of the brand and a recognisable feature. As clients' expectations differ, the designer's attention is attracted to the other aspects of the design of transparent facades. The question arises of whether the designers' motivations are more superficial than before (e.g. in the modernist period). The answer is no. The way that facades are designed today simply demonstrates **the change in the sensitivity of both designers and users of architecture**.

Apart from the strict, countable results (as in Section 5) a conclusion requires a wider discussion on the character of the trends and their development. When trends are viewed from a broad perspective, several observations can be formulated and discussed. They apply to both optical/perceptual and geometrical trends.

6.1. The desire for depth

Elements of artificial and authentic space stratification are present in almost every analysed optical/perceptual and geometrical trend. In general, the superposition/juxtaposition of transparent layers seems to be the most prominent tendency. Surface iteration – even if not intended by the designer – undoubtedly results in a relief of the façade (2.5D transformation). As Christian Schittich notes: "superimposing layers of various kinds – printing, louvers, etc. – over a glass skin can produce further variations within the transitional zone" [29]. These new elements which constitute the transitional zone could also be recognised as a case of "additive configuration of planes" as it is addressed by A.C. Schultz in her extensive research on architectural overlaying [30]. This observation has been confirmed by many other researchers [26].

The presented research clearly indicates that the *depth of the façade* is what stimulates architects to search for new ways of utilising light-transmitting materials. Pane superposition could be one of the ways to achieve this. "The plastic effect of the facade within its immediate surroundings is essentially created by the offsetting of the individual surfaces within the facade and the resulting shadows" [17]. Nina Rappaport also observes that the "wake of postmodern discourse (…) has created a need for a visual surface simulation and depth" [26]. Paradoxically, many architects – following Mies van der Rohe's statements that glass itself provides sufficient variability to the façade – simultaneously seek additional measures to spatially activate what is commonly seen as a boring flat glazed wall. This is probably deeply rooted in the human appreciation of beauty. For the vast majority of non-expert observers, only the sculptural aspects are recognised as aesthetically pleasing – see the discussion in [36].

The optical/perceptual or geometrical 2.5D transformations enable the stratification of space and the differentiation of planes. Furthermore, the following are examples of effects that were previously absent and are now applied:

- the connection of spaces visually without providing a bonafide spatial connection thus avoiding the exchange of air that occurs with double-leaf facades,
- the establishment of space between the multiplied panes,
- the visual hanging of the element of the façade "in the air" while in technical terms fixing them firmly but enabling them to apparently float while viewed in certain lighting conditions,

- sculpting with light by creating space which is much more daylight dependent and creates the evident chiaroscuro effect; glass layering seen as a way of building up architectural space, or, as Yoshinobu Ashihara labels it, "space that is created centrifugally" [2].

Another reason for the desire for depth might be the recent change in the function of the façade. In his influential book *Complexity and Contradiction in Architecture* from the early 1960s, Robert Venturi devised a new division of a building into its "volume" and its "façade" [35]. Terence Riley described a very similar mechanism of "shifting the objects meaning from its form to its surface" [27]. This "transformed the building from the monolithic form into the act of communication – a symbol, a message bearer" [20]. thus strengthening the role of the façade itself. The other possible reason indicated by K. Kuma in the interview is that "(…) architects today are more sensitive to the fact that glass is always caught up between the various phenomena that take place on its two sides, and are eager to experiment with a new type of transparency while developing increasingly ambiguous definitions of enclosure"[5]. Kuma also says that as a result "boundaries are blurred not only between inside and outside but also between what is perceived as real and virtual" [5].

6.2. Conclusion

The façade has always been seen as more than mere protection against the weather. It has symbolised prestige and power, first with the use of stone, now through glass and technology, which perform a similar function but offers easier and more direct communication. It is no longer necessary to be an expert in Greek mythology – as it was before – to understand the message of the architect. This information can now be communicated more directly and understood by the observer. Media facades present the most recent type of information--infused transparency and, most probably, are paving the path to the future of the façade industry. New technologies also facilitate the communication of new architectural ideas to the audience, thus creating new social values and stronger relationships among people.

In the brief study of transparency provided above, the main identified trends open the way for a much more extensive study in the future. Judging from the given analysis, the increase in spatial depth of the façade is no longer an emerging trend but has become a well-established practice. However odd it may seem, this trend coincides with an equally strong tendency of both image blurring and transmission interruption. Moreover, in many cases, these trends reinforce each other or blend together. Glazed façade designs have now become more of an art than ever before. The demand for new technologies will stimulate innovation in the field, with a possible focus on smart solutions in the near future.

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The presented paper contains excerpts (less than 50%) from two conference papers entitled Recent trends in architectural design of light-permeable facades, that was presented on GDP 2017 Conference in Tampere, Finland [9] and Studies on glass facades morphologies presented in the Engineering Transparency conference in Düsseldorf in 2018 [11].

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The belly of Budapest – the Hungarian Central Market Hall from the end of the 19th century against the backdrop of selected European objects with this function

Brzuch Budapesztu – węgierska centralna hala targowa z końca XIX wieku na tle wybranych europejskich obiektów o tej funkcji

Abstract

The nineteenth century was a period of ground-breaking events in the history of humanity relating to the industrial revolution, scientific discoveries, knowledge development and social changes. It was also a time when new types of commercial buildings were being formed and transformations of those that had existed for centuries were taking place. The aim of this article is to present the problems of the Central Market Hall in Budapest by Samu Pecz and compare its architectural solutions with selected nineteenth-century constructions serving the same purpose elsewhere in Europe.

Keywords: market hall, commercial buildings, industrial revolution, Budapest

Streszczenie

XIX wiek to okres przełomowych wydarzeń w dziejach ludzkości związanych z rewolucją przemysłową, odkryciami naukowymi, rozwojem wiedzy oraz przemianami społecznymi. Był to także czas kształtowania się nowych typów obiektów handlowych lub też transformacji tych, które istniały od wieków. Celem niniejszego artykułu jest przybliżenie problematyki Centralnej Hali Targowej w Budapeszcie autorstwa Samu Pecza i porównanie jej rozwiązań architektonicznych z wybranymi, dziewiętnastowiecznymi obiektami o tej funkcji z terenów Europy.

Słowa kluczowe: hala targowa, obiekty handlowe, rewolucja przemysłowa, Budapeszt

1. Introduction

The history of commercial stalls within a single building dates back to ancient times. The first century of our era brought the new shopping district of Rome, the so-called Trajan's Hale, which formed a complex of 150 stores selling wine, olives, gain, etc. Another construction object with a similar function dating back to 1329 is the Souk El-Quattanin (Cotton Market) in Jerusalem – it is covered by a vault with closely set pointed transverse arches, protecting merchants and exhibited goods from adverse weather conditions [7]. Until the turn of the 18th and 19th centuries, the function of trade was usually combined with another function, which was often dominant, such as a town hall, stock exchange, guild headquarters or residential buildings with a store on the ground level.

Significant progress in the development of various forms of commercial facilities occurred in the nineteenth century, when the types of buildings that we are still dealing with today were distinguished such as market halls, shopping arcades and department stores. This phenomenon was accompanied by breakthroughs in the history of mankind: the industrial revolution; the development of research in the field of natural and medical sciences; the introduction of new construction technologies, which gained a clear impetus in the second half of the nineteenth century, and were initiated in England and Scotland in the eighteenth century. A characteristic feature of those times was the orientation of the economy mainly towards agriculture, manufacturing and craftsmanship leading to factory production on an industrial scale. The discoveries of Louis Pasteur and Robert Koch significantly influenced the development of knowledge on bacteriology and hygiene, which had a direct impact on the modernisation of food-selling facilities. Finishing materials for floors (clinker), walls (tile) and sales counters (stone slabs) were established, which could easily be kept clean. It was obligatory to equip commercial buildings with sewage systems, running water and cooling warehouses which were initially iceboxes, and then along with technological progress, chemical cold stores were introduced. These solutions significantly improved the quality of the food products on offer [6, p. 16].

2. Market halls – characteristics of the spatial system, definition, state of research

Market halls dating back to the 19th century were based on a spatial scheme that had already been developed in ancient times. They usually had one or three naves, often in the basilica system. The innovation was the use of the aforementioned technological and material solutions as well as, above all, iron constructions that allowed the inclusion of large spans.

Quoting Professor Małgorzata Omilanowska, the researcher of the exhibition halls, it is possible to define this type of object as a "large-space commercial building, recognizing both its architectural structure and function as a determinant, thus excluding from the definition this category of buildings which, although they perform exhibition functions, are organized in an architectural structure that is not a hall, but for example a sequence of stalls accessible from the arcade" [6, p. 22].

European market halls have not yet been included in a full monograph; however, many publications have been issued regarding selected objects with this function. Bertrand Lemoine prepared a comprehensive study on the Paris halls [3], Thorsten Knoll studied the Berlin halls [2], James Schmiechen and Kenneth Carls wrote a monograph on the British market halls [8], and the aforementioned Professor Małgorzata Omilanowska thoroughly analysed the Warsaw market halls of the metropolitan era . The publication dedicated to the Budapest market hall, which is the essence of this article, is authored by the Hungarian researcher, Gergely Nagy [4, 5].

Market halls, called the "bellies" of the city, created a substitute of the "microcosm", and at the same time, due to their dimensions and the need for a free transport service to supply them, had a very significant impact on the shaping of urban tissue. Their social and moral role was not without significance. Just as the 19th century department stores served the needs of the middle and upper classes, the market halls were a place where people from the lower social classes could buy necessary food and, at the same time, use catering services or watch the performances of jugglers [6, p. 24–25]. Thus, they perfectly fit into the ideology of positivism and were a source of inspiration for artists. The French writer, Émile Zola, the main representative of naturalism, placed the action of his novel *Belly of Paris* in one of the most famous buildings of this type – the Central Halls in Paris. Describing them, he used colourful, technical language: "the halls appeared immeasurably like a modern machine, a steam machine, some kind of pot of digestion for the whole people, a giant metal belly, fixed with bolts, riveted, made of wood, glass and iron with the charm and power of a mechanical motorbike, working there with the deafening noise, the heat of fuel and the mad spinning of wheels" [10]. Goods halls provided access to fresh food, which was also taken care of by the veterinary services employed in them on a permanent basis. The separation of products of various types (e.g. meat and fish) was employed so that no odours could penetrate each other, and appropriate natural lighting and ventilation would additionally increase the comfort of shopping.

3. The aim of the article and selected research methods

In many publications, market halls are presented in the context of other commercial facilities developed in the 19th century, such as arcades and department stores. Researchers pay attention not only to innovations that were introduced in the context of sanitary facilities but above all, to the structural solutions used in them.

The aim of this article is to discuss the problems of the Central Market Hall in Budapest and to present its architectural solutions against the backdrop of selected nineteenth-century buildings with the same function elsewhere in Europe.

4. Selected examples of nineteenth-century market halls in Europe – functional, spatial and material solutions

The first large-scale market hall was St. John's Market in Liverpool, Great Britain, designed by John Foster in 1822. The roof structure was still wooden, but was supported by rows of cast-iron columns. Over the next few years, further objects for this function appeared in Brighton (1830), Aberdeen (1842) and Newcastle (1835). In France, an important market hall created entirely as a cast iron construction was Marché de la Madeleine [6, p. 127], which was completed in 1938.

A breakthrough for technological solutions, but also for functional and spatial commercial buildings was the construction of Crystal Palace, which was completed in 1851. This magnificent exhibition facility, designed by Joseph Paxton for the World Exhibition in Hyde Park London, was an excellent example of the use of prefabricated iron construction elements, which significantly affected the time of its implementation and the introduction of glazing in large areas. Crystal Palace could today be called a huge showroom, which perfectly fuelled the desire for the products displayed within and was an inexhaustible source of inspiration. Within a few years of its completion (in 1857), the Kirkgate Market Hall in Leeds was created (designed by C. Tilney and J. Paxton) [6, p. 128], which was inspired by Crystal Palace.

Undoubtedly, one of the most significant market halls is the example of the previously mentioned Central Halls in Paris (Figs. 1 & 2), the construction history of which dates back to 1842, when the first preparations for their implementation began. A year later, Victor Baltard presented the initial project in which he set up a brick market building [3]. After a loud public debate and further modifications to the project, the construction of the first pavilion began in 1851 and two years later, it was put into use. Due to the poor ventilation system and insufficient interior lighting, the construction of new pavilions was interrupted. Napoleon III was supposed to want iron halls like "big, iron umbrellas". In 1853, forty-two architects submitted their proposals, the most interesting of which were by Hector Horeau, Eugene Flachat and Alfred Armand [9]. Finally, due to the intercession of the Prefect of the Seine Department, Georges Hausmann, the project was once again entrusted to Baltard. The Central Halls consisted of ten pavilions connected by roofed passages. Under the building, there was a system of cellars with warehouses, cold stores and sorting rooms. Each pavilion had the form of a rectangle placed on pillars and raised by a skylight above the roof, inserted into a larger rectangle. The construction framework itself was formed entirely from iron, and stone and brick filled the walls up to a height of 5 meters. Above, openwork structures in the form of arcades with a segmental arc filled with glass blinds were used [6, p. 131].

The Parisian Central Halls served as an architectural model not only in France but also abroad, mainly in warm climates, where the solution of the upper parts of the building as filled with blinds worked perfectly. As examples, it is worth mentioning Mercato Centrale in Florence, Mercado La Cebada in Madrid, and Mercado de San Antonio in Barcelona here. In regions with colder climates, slightly different architectural solutions were used to protect against heat loss in winter. In Germany, solutions were based on the construction of solid brick perimeter walls with a roof supported by rows of iron supports forming internal aisles.

Fig. 1. Halles de Paris, 1863 (source: [15])

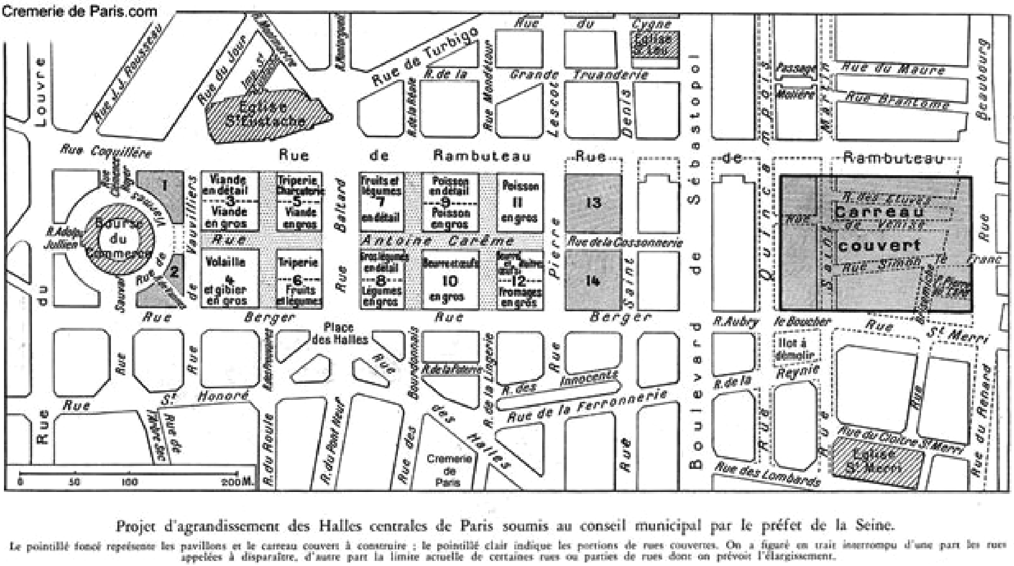

Fig. 2. Halles de Paris – site plan, 1863 (source: [16])

Their spacing and quantity depended on the planned span. Administration buildings were added to the main body along the shorter sides, and the walls were divided by a rhythmical arrangement of window openings [6, p. 134–136].

In Berlin, the system of exhibition halls was introduced at the initiative of the city, which wanted to provide residents with comfortable access to fresh products and food in hygienic conditions of sale. By 1900, a total of fourteen such structures were built, most of which were built on the basis of the plans of the city architect, Hermann Blankenstein. The designer even made a study tour around European countries to learn about the solutions applied in

other countries. The first city market hall was built in 1883–1886 in cooperation with August Lindemann at Kaiser-Wilhelm Strasse near Alexanderplatz (Figs. 3 & 4). The construction object was connected to the viaduct of the railway crossing, which not only ensured its excellent communication but also enabled the delivery of goods directly from railway platforms connected to the hall floor [11]. Cooling warehouses were located in the basement, and in the arcades of the railway viaduct, there were stores and warehouses, e.g. sales of live fish, which allowed keeping the hall itself clean [12]. In 1893, the extension of the Central Market Hall on the other side of Kaiser-Wilhelm Strasse was completed and it was called Central-Markthalle Ia or Central Markthalle II. The elevations were covered with a colourful brick cladding, creating patterns. They were designed as a system of repetitive spans covered with lisens, on which terracotta, bas-relief plates with decorations were placed in the floor level. In the lower part of the building, there are two windows topped with a segmental arch in each repetitive span. Above the arches there was an inter-story cornice, and then a large window with a full arch shape. The corners of the building were clearly distinguished from each other by octagonal towers covered with domes with triforms in each of the walls, under which a decorative cornice was placed, referring to the crowning cornice running around the whole building. On the sides of the towers, there were full plasticity and allegorical sculptures by Eduard Luerssen presenting trade in meat, poultry, game and vegetables [6, p. 137].

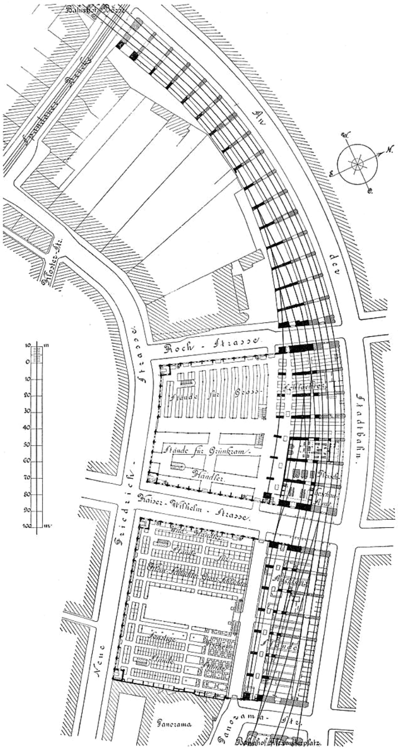

Fig. 3. Central Market Hall in Berlin – site plan, 1896 (source: [17])

Fig. 4. Central Market Hall in Berlin, 1896 (source: [18])

The architecture of the subsequent Berlin market halls by Blankenstein was subordinated to the character of the district in which they were created, and the spatial solutions were dependent upon the shape of the plot. Some of these, such as the II, III, IV, VI and IX halls, complemented the frontage; thus, the design included only the front elevation with the main entrance. As was the case with hall number one, the facades were finished with clinker bricks and decorated with yellow and red terracotta decorations, bas-relief medallions and friezes. The free-standing halls were designed in the basilica layout. An interesting example is the existing Markthalle X at Arminiusplatz, where both the nave and the side elements of the building were covered with rows of transversely set gabled roofs creating repetitive spans filled with significant glazing [2]. Above the brick section, a delicate, openwork structure based on an iron construction emerged, serving as a lightening for the sales interiors. In the front elevation, arcades have been introduced, leading to separate stores on the ground floor (Fig. 5).

By the beginning of the 20th century, exhibition halls had been built in 21 German cities, usually using a basilica layout based on a schematic diagram of a circumferential brick construction with an iron roof structure. An interesting and memorable project was executed for the central hall in Leipzig (Figs. 6 & 7). The building was built in 1889–1891 according to

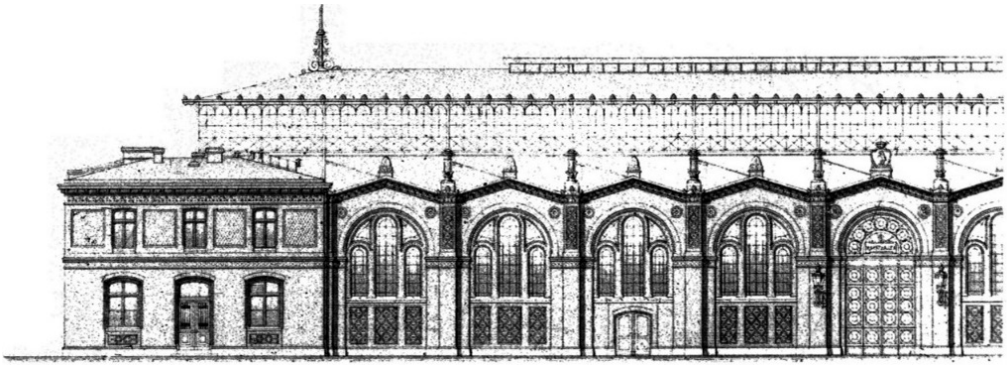

Fig. 5. Market Hall X in Berlin (source: [19])

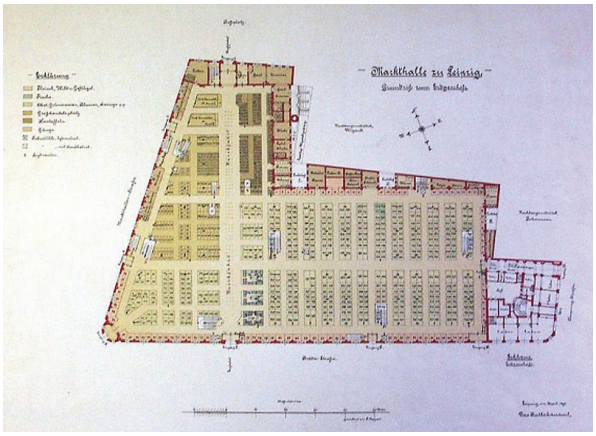

Fig. 6. Central Market Hall in Leipzig – ground floor plan (source: [20])

Fig. 7. Central Market Hall in Leipzig from Rossplatz, 1900 (source: [21])

Hugo Licht's plans on an irregular, corner plot. Its total area was 7500 m^2. On the ground floor, there was a restaurant, café, atrium, administrative rooms, 600 stands (another 160 in the gallery), a vet's office and a mushroom control station. It sold meat, fish, potatoes, vegetables, canned food, dairy and bakery products, as well as wood products, wicker, pots and barrels. In the basement, there were cold stores which were at the disposal of the traders. The facades of the Leipzig hall were made of yellow brick on a basalt pedestal. Their characteristic feature was a repetitive arrangement of triangular gables set by gabled roofs. Each of the spans had large window openings crowned with an arch. In the south-western corner, there was a thirty-four-metre-high clock tower, which makes reference to the Italian town hall buildings; it contained a water tank for operating six hydraulic cranes [1].

5. Market hall in Budapest – construction, functional and spatial arrangement and material solutions

The brick, three-naval market hall with a partially glazed roof was a popular architectural solution in central-eastern and northern Europe (e. g. Wanha Kauppahalli in Helsinki and Östermalm in Stockholm) [6, p. 139]. A commercial building based on this scheme was also created in Budapest. Formally, the city itself was quite "young" at the time, although it had had a turbulent and long history. It was established in 1873 as a result of the merger of three cities: Buda, Óbuda and Pest [14]. Already in the 1860s, there were voices in Pest about the need to build a market hall, which would enable greater control over the food sold as well as the introduction of regulations regarding retail and wholesale practices. Due to the constantly deteriorating supply conditions in foodstuffs, a plan for the entire city was developed in 1879. General Assembly Resolution No. 852 of 30 December enabled the establishment of a Food Committee, whose task was to prepare for the creation of a market hall. On 28 October 1885, the motion of committee member Lajos Nyiri to locate a hall in the 9th district on a plot between Vámház Boulevard and the Pipa, Csillag and Sóház Streets was accepted. At that

time, the plot was owned by the State Treasury, which again suspended the construction plans for a few years. Due to the steadily deteriorating state of food supplies for Budapest residents and the growing number of inhabitants (until 1900 the city was larger than Rome, Naples, Madrid and Amsterdam), the need to build a market hall became increasingly urgent. Finally, after the resolution of 1891, Prime Minister Kálmán Tisza renounced the plot of land planned for the investment of the hall in favour of another location at Alkotmány Street [13].

On 25 August 1892, a competition for the design of the Central Hall of Budapest was announced, which was to enable the proposal of a modern, fast and economical building to be separated. It was assumed that the pavilions for the sale of meat would be closed, and that in the gallery zone, there would be trading in baskets and flowers. The competition requirements also required the construction to be iron and the external façade to be brick. The final result of the competition took place on 5 December 1892. Nine works were submitted and the assessment focused on the proposed spatial and urban layout, transport services, accessibility to the Danube, equipment and lighting. The jury selected three winners who were awarded prizes of $1,000: P. Escande, J. Gourmez from Paris (15 votes in favour), S. Pécs from Budapest (14 votes in favour), Alvin Anger, P. Högner and P. Preil from Leipzig (15 votes in favour). Finally, on January 11, 1893, it was decided to entrust the design of the market hall to the Hungarian architect, Samu Pecz, who presented his plans less than a month later. He assumed that the floor would be arranged with a slope of 110 cm to connect the building with the surrounding streets without any difference in levels. He also introduced changes that included an innovative basement solution, which resulted in an increase in planned costs of up to 2,200,000 forints, which was not agreed. Disputes lasted over six months and the city's demands for further modifications resulted in a further increase in financial outlay. A chance for agreement appeared in November 1893, when award-winning French architects put forward their counterproposition in which they pledged to build and equip the entire building for around 1,650,000 forints in 18 months. The competition committee met on 30 December 1893 and during a meeting in which the mayor also participated, it was decided that Samu Pecz, together with the architectural company Escande and Gourmez, would present new proposals so that the most advantageous and economical option could be chosen. Finally, on 21 February 1894, during the session of the General Assembly, it was decided to implement the project by Samu Pecz [4, p. 8–22].

Earthworks began in June 1894, which allowed the completion of foundations and cellar walls by the end of the year. In the winter, works on the basement's iron structures and preparations for brickwork were completed. In the spring of 1895, the cellar ceiling was completed and stone plinths were built. In the summer and autumn, the walls of the hall were erected, the iron construction was completed, the installation of stone elements in the walls commenced and the windows were installed. In the spring of 1896, painting and carpentry work began. Several days before the completion of the whole investment on 30 July, a fire broke out in the hall, which caused considerable damage. Sixty metres of the roof of the main nave burned down and the losses were estimated at about 50-60 thousand forints. Samu Pecz undertook to complete the repair of the damage by October 1896. In order to improve safety, the construction of the facility had to be strengthened. The roof of the hall was divided into

three independent sections, the number of hydrants, roof manholes and climbing ladders was increased. The official opening of the exhibition hall took place on 15 February 1887 at 20.00. The final cost of the construction was 1,900,000 forints, including a tunnel, equipment for the river banks and a steam engine [4, p. 26–28].

The building was based on a longitudinal plan of 20.55 m, referring to the design of the hall in Leipzig [5]. It was connected to the railway siding and the Danube riverbank (Fig. 8). The interior was divided into two parts by a main road leading to wagons (Fig. 9). The side spans were covered with separate roofs with transversely aligned ridges, forming a rhythmic, "toothed" elevation system. Triple windows were placed in each triangular gable, crowned with a full arch, which indicated the inspiration of the Blankenstein and Licht halls. The impressive front façade was symmetrically captured by two quadrilateral towers. Its central part was occupied by a triangular wide risalit topped with a decorative entrance portal with rich sculptural decoration. Above it spread huge windows finished with a sharp arch inscribed into precisely planned brick decorations. The elevations were given a neo-Gothic costume and their ceramic detail was carefully worked out, supplemented with stone corners and numerous sculptural forms. The steep roofs are covered with colourful green-yellow-orange tiles produced at the Vilmos Zsolnay plant, which is famous throughout Europe (Figs. 10 & 11).

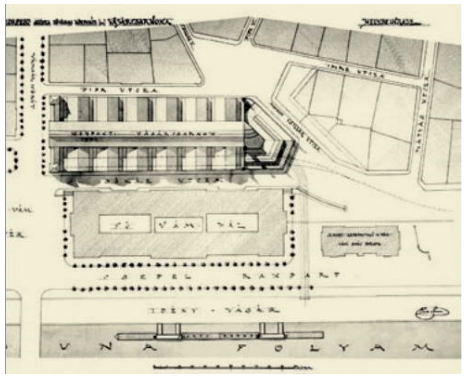

Fig. 8. Central Market Hall in Budapest – site plan (source: [22])

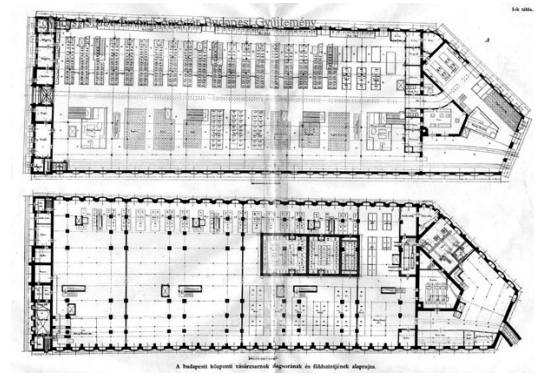

Fig. 9. Plans of Central Market Hall in Budapest (source: [23])

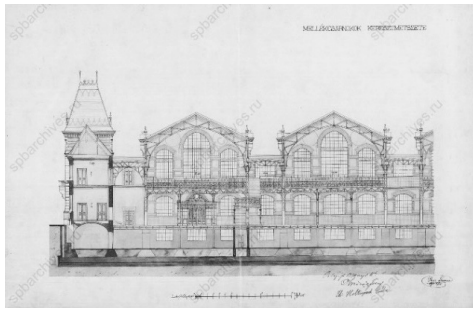

Fig. 10. Section of Central Market Hall in Budapest (source: [24])

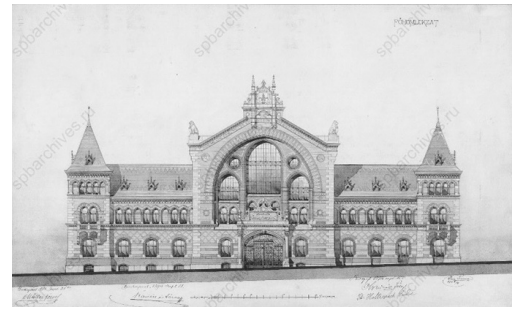

Fig. 11. The front elevation of Central Market Hall in Budapest (source: [24])

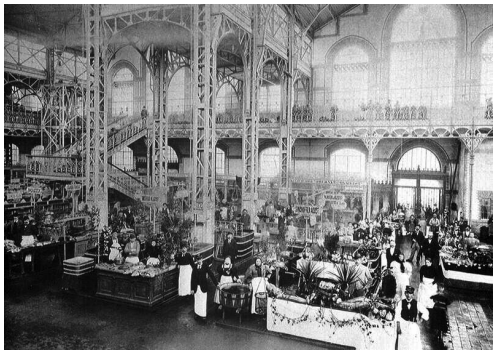

Fig. 12. Interior of Central Market Hall in Budapest (source: [25])

Fig. 13. Interior of Central Market Hall in Budapest (source: [26])

Inside the space on the east side was handed over to retailers, and the wholesalers' stands were located on the west side. Meat was sold in closed pavilions from the Pipa street side and on their opposite side on stand-alone stands separated by a wire mesh. Between the meat stalls and the central route of the wagons along the entire length of the building, there were sellers of vegetables, fruit, cheese and butter. The sale of fish from oak tanks was located at the other end of the retailers' area. The back of the building was closed by a one-storey poultry hall. A gallery ran around the high building, which was lead by seven staircases of iron construction with oak steps (Figs. 12 & 13). On the galleries and two bridges there were a total of 768 retailers' stands with an area of 2 m^2 each. Three 500 kg and five 1,000 kg electric lifts were installed in the building, as well as a public teleinformation station. Administration rooms were located in the front zone of the first floor . In order to maintain order in the exhibition hall, regulations were drawn up in 1896, which specified the system of sales and service of goods. One of the rules stated that the traders could rent more than one place in the same room, provided that the rooms were located next to each other and there was no other willing tenant who did not yet have a stand [4, p. 32–40].

Budapest's Central Market Hall was significantly damaged during World War II, when the poultry hall was completely destroyed. During the reconstruction, it was possible to use materials originally prepared for the construction of the hall, which were kept in the basement, including effective ceramic fittings. In 1977, the building was entered into the register of

Fig. 14. Central Market Hall in Budapest (photo by: Katarzyna Janicka-Świerguła)

Fig. 15. Central Market Hall in Budapest (photo by: Katarzyna Janicka-Świerguła)

Fig. 16. Central Market Hall in Budapest
(photo by: Katarzyna Janicka-Świerguła)

Fig. 17. Central Market Hall in Budapest
(photo by: Katarzyna Janicka-Świerguła)

monuments. Over the years, the iron structure became increasingly worn out, so in 1991, it was decided to close the building and subject it to general renovation. The biggest challenge was to replace the ceramic fittings, which Zsolnay eventually undertook to supply. The works were awarded the FIABCI Prix d'Excellence [4, p. 48–52] (Figs. 14–17).

In Budapest, apart from the Central Market Hall, regional market halls were also created, which were of a decidedly smaller scale and architectural grandeur.

6. Summary

The analysis of the Central Market Hall in Budapest conducted in this article shows that its design was based on experience resulting from the construction of other facilities performing the same function elsewhere in Europe. Particularly clear are the references to German halls, in which the perimeter stone walls were used and the roofs were supported by a much lighter arrangement of iron supports. As in the Leipzig hall, a system of rhythmic, triangular gables and repetitive glazing was used. Wall decoration, similar to the solutions found in Berlin, for example, was comprised of geometric arrangements of multi-coloured bricks. It should also be noted that a very important factor determining the location of the market hall was linking it with the nearby railway siding and the Danube port front to ensure the comfortable supply of goods

As mentioned earlier, many European cities at the turn of the 19th and 20th centuries could be boastful of their market halls. Their spatial and functional scheme was usually based on similar principles, and similar finishing materials were used. Aside from Warsaw, the construction of trade market halls was not impressive in the case of Polish cities, which does not change the fact that in the Mirowskie Halls we can also find clear influences of generally accepted European patterns. It is satisfactory that some of these construction objects which survived the war are the subject of proper conservation care, which will enable future generations to get to know their undeniable charmr.

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Sustainable design, modern environmental protection engineering and bioeconomics

Zrównoważone projektowanie a nowoczesna inżynieria ochrony środowiska i biogospodarka

Abstract

New trends in sustainable design contribute to prevention of the deterioration of the natural environment and they are focused on the optimisation of the indoor environment for the improvement of the human life quality. There are complementary goals of sustainable design – the comfort of architecture users,proper spatial planning, and, as a priority, taking into account the needs of both contemporary and future generations. These existential needs are connected with both local and global sozological problems. These are related to the continuing growth of irreversible changes to the environment, such as climate change, the disappearance of biodiversity, and the over-exploitation of nonrenewable sources of energy as result of shortsighted economy. These imply the necessity for the sozological education in all subjects of study and transdisciplinary training focused on the solving of problems associated with sustainable development.

Keywords: new trends, sustainable design, bioeconomics

Streszczenie

Nowe tendencje w zakresie projektowania zrównoważonego przeciwstawiają się degradacji środowiska przyrodniczego i są ukierunkowane na optymalizację środowiska wewnątrz budynków w celu poprawy jakość życia człowieka. Poza dążeniem do komfortu użytkowania architektury i odpowiednim zagospodarowaniem przestrzeni priorytetem projektowania zrównoważonego jest realizacja potrzeb zarówno współczesnego człowieka, jak również przyszłych pokoleń. Z tymi egzystencjalnymi potrzebami wiążą się problemy sozologiczne zarówno o zasięgu lokalnym, jak i globalnym. Dotyczą one nasilających się i nieodwracalnych zmian środowiska, takich jak: ocieplenia klimatu, zanikanie bioróżnorodności, wyczerpywanie się nieodnawialnych źródeł energii, połączone z rabunkową gospodarką. Implikuje to konieczność edukacji sozologicznej na wszystkich kierunkach studiów i szkolenia interdyscyplinarne pod katem rozwiązywania problemów zrównoważonego rozwoju.

Słowa kluczowe: nowe trendy, projektowanie zrównoważone, biogospodarka

A contemporary picture of the living environment of man makes us reflect on the irreversible changes that are occurring and the need to take action to prevent them. On the one hand, we the rapidly progressing degradation of the biosphere, on the other hand, there is an increasing awareness of a society sensitised to issues related to human ecology and understanding the need for the economic management of the natural resources.

Current aspirations in the field of design take into account the need to maintain a balance between the environment transformed by man, the natural environment and the homeostasis of ecosystems. Sustainable design, taking nature into consideration, fits into the existing conditions in which durability is determined by protection ecological balance – an approach also promoted by planning sozology. The importance of greenery in urban structures is widely known due to its ability to purify the air. However, as indicated by many studies, natural elements also have an impact on human health, our social lives and the economy of solutions regarding the management of the urban space [1, 2] (Table 1).

Table 1. The impact of green areas on city life (according to Terrapin Bright Green, 2012) [15]

Social life	**Healthy life**	**Sozological aspect**	**The economy of the solutions**
providing the implementation of various activities in the group	positive effects on the human psyche – the reduction of acts of violence and vandalism	human activity in compliance with nature	activation of trade and commercial services
creating a willingness to identify with the environment	reduction of stress – a positive effect on the mental condition	care for the environment and natural resources	increase of the value of real estate due to the arrangement of green spaces
improving pedestrian safety	increased physical activity/relaxation	reduction of noise and vibration levels	reduction of infrastructure costs
strengthening neighbourly bonds	increase of time spent outdoors	care for pro-health conditions	increased productivity
common spaces with elements of greenery for various functions	reduction of air pollution	reduction of the temperaturę- decreased number of heat islands	business development in green districts
improving the comfort of the housing environment by increasing the green space	creation of an attractive view outside the window – psychological well-being	absorption of air pollutants and carbon dioxide	reimbursement of the cost of each planted tree

Architectural objects which are an inseparable part of the environment adapt to its conditions, such as terrain and climate analysed both on the macro- (region) and micro-scale (urban interior including the nearest neighbourhood). It should be noted that human interference in the environment results in irreversible changes to its structure, leading to an increase in entropy. Anthropopressure also contributes to global warming, which often leads to natural disasters that more and more often impact upon the everyday lives of many people.

Contemporary design trends are not only aimed at helping in the search for measures to prevent these adverse changes but also in minimising the cost of maintaining buildings using alternative energy sources. These activities are facilitated by new technologies, including biotechnology, that are applied in design.

Planning sozology and urban meteorology have a significant application in this field because they allow rational spatial planning and locating architectural objects that remain in symbiosis with the natural environment. Planning sozology is based on the principles of sozology, which were introduced to environmental engineering by prof. W. Goetel. It has its application in the sustainable design of residential areas, which contributes to the rational management of land and natural resources in a way that complies with the requirements of environmental protection and the humanisation of technology [3, 4]. The main assumption of this design trend is to take into account and use the existing environmental conditions while minimising the use of non-renewable energy sources and energy consumption.

Sustainable architecture based on the principles of sustainable design uses the above trends, approaching the idea of *Green Architecture (GA)* [5], or bioclimate in architecture. A summary of the factors taken into account by the *GA* concept is presented in Table 2 [6].

Table 2. Table 2. The Basic principles of green architecture; own concept related to S. Lehmann Principles of Green Urbanism [6, p. 45]

Energy and materials	Spatial planning and transportation
the use of local raw materials for the production of building materials with low energy consumption improvement of traditional materials the application of new technologies the recycling of materials energy efficiency the reduction of construction waste	striving to fulfil the assumptions of planning sozology and implementation of the assumptions of sustainable urban design in: ▸ adaptation to biometeorological conditions in the area of housing planning with increased compactness and maximum use of land allocated for many functions ▸ the use of climatic conditions for the rational location of facilities ▸ the application of the BIM control system in the planning and use of architectural objects ▸ the increase of biodiversity ▸ the reduction of water consumption ▸ the improvement of pro-health conditions ▸ economical land management ▸ the reduction of the intensity of car communication for green transport (walking and cycling) and collective transport using vehicles with electric motors ▸ the elimination of the nuisance of communication solutions (vibrations, noise, air pollution)

Many contemporary developments in residential areas prove the effectiveness of the above ideas. It is not a major problem in friendly conditions or those that become "natural". However, it should be noted – as indicated by the study of J. Ramanowska and M. Brzezicki [7] – that as a result of climate change, extreme conditions are increasingly occurring in areas of human residence, which means that people will be forced to adapt to changing conditions. Thus, in the extremely cold zone buildings are located on permafrost. Igloos with rounded

blocks made of cut snow blocks enable the minimisation of loss of heat and the pressure of air mass (–wind). In extremely dry zones, objects are frequently made of straw or clay, covered with a stake. In extremely hot zones, inhabited by Berbers among others, houses are either carved in sandy clay sedimentary rocks or are underground, where appropriate thermal conditions are maintained – they provide some coolness during hot weather. In extremely humid zones, traditional architecture is erected on platforms based on piles, and in the case of stoney terrains, on concrete foundations built under construction poles. In addition, the structure is stiffened with transverse beams, which allows free airflow [7].

It seems that an important role in shaping architecture in such difficult climatic conditions is attributed to the bioclimatic form of objects [8]. It allows architecture to adapt to the prevailing climatic and meteorological conditions in order to achieve parameters responsible for a comfortable living environment.

The modern environment of human life is not only affected by climatic changes, such as the weather. Growing air pollution, excessive waste production and high energy consumption are all serious problems. Other negative phenomena include the growing intensity of communication traffic and shrinking biodiversity. All these circumstances not only lead to a change in the image of cities and the lives of their inhabitants but also directly affect humans with regard to their health and functioning. Therefore, paying due consideration to this subject seems even more justified.

1. Contemporary tendencies in the shaping of the housing environment

Modern architecture and spatial planning must not only keep up with the changing conditions and lifestyle of man and the principles of functioning. New trends in design oppose contemporary problems related to environmental degradation. The impact of unfavourable phenomena on human health is the subject of continuous research. The impact of road noise on the well-being of people began to be analysed relatively recently. It has been found that it causes irritability, and in extreme cases, disorder, impairment or even loss of health (Table 3) [9].

Table 3. The influence of noise on health and human well-being [9, p. 23]

Effect	Measured factor	Acoustic indicator	The threshold value of the health effect	Influence in time
1	2	3	4	5
annoyance nuisance	psychosocial, quality of life	L_{DWN}	42	long-period
sleep disorder based on self diagnosis	quality of life, somatic effects	L_{N}	42	
learning, memory	efficiency	L_{Aeq}	50	
stress hormones	stress indicator	L_{max} $^{3}L_{Aeq}$	lack of data	

1	2	3	4	5
sleep (polysomnographic sleep)	agitation, mobility, sleep quality	$L_{max,\ wewnątrz}$	32	
reported awakening	sleep	SEL_{insde}	53	
self diagnosis of the health condition	well-being, clinical health (clinical symptoms)	L_{DWN}	50	
hypertension	physiology, somatic health	L_{DWN}	50	
coronary heart disease	health (clinical symptoms)	L_{DWN}	60	

Limiting noise by means of acoustic insulation, including green walls, is just one of the important contemporary activities improving the living conditions of modern man [10].

The use of new solutions and new technologies in the design process allows us to increasingly control the life cycle of architectural structures and introduce the ability to adapt buildings to changing climatic conditions. This is provided by intelligent construction implemented with the use of appropriate software that manages the way objects operate. The functioning of the building in its surroundings is influenced by an in-depth analysis of the full life cycle from the first idea (concept), through the planning and design of the building, its construction, exploitation and utilisation. The BIM process is helpful in this respect, as it enables control of all stages of the building's construction and operation. It also allows us to reduce energy consumption and avoid errors occurring during its design. A detailed analysis of the life cycle of objects – LCA – confirms that construction is responsible for the inefficient energy economy as it consumes around 40%. Another problem includes the excessive production of waste related to mistakes made during the design and construction of new buildings, their operation and subsequent utilisation. Therefore, it is important to select the right building materials not only in terms of the optimal time of their use but also the prospects of recycling – the so-called technical death of the object. In the future, the minimisation of waste will be ensured by the use of 3D printing technology.

In the implementation of such important challenges of the present day, greater inter-university cooperation of specialists from complementary fields of science is necessary, including the adjustment of education to the needs of the labour market. This would allow the broadening of knowledge on, among other things, the application of sozology principles, not only in modern environmental engineering based on biotechnologies and ecological engineering but also in the planning of architectural and urban solutions [11]. The future direction is to use methodological experiences the 50 years of inter-university training for thousands of students interested in sustainable development based on eco-innovation to train the staff and develop the so-called Municipal Agriculture, in particular, the Underground Centers of Environmental Biotechnology (for the in-situ cleaning of sewage and waste treatment). Such centres might be combined with the production of non-contaminated food

products (including mushroom and vegetable cultivation) in underground greenhouses that use bioenergy from waste biomass and new energy-saving lighting systems for plants. This kind of personnel training will contribute to the broad implementation of the principles of sustainable development, the bio-economy, as well as the stabilisation of the labour market [12–15].

2. Conclusions

The main goal of the new tendencies in the field of architectural design is to minimise the effects of the economy that exploit the natural environment. It is also an attempt to reduce energy consumption and waste production. Life cycle analyses (LCA), often supported by the BIM process, are helpful in this respect.

The use of modern tools enables the more accurate design of investments and the operation of buildings, including their renovation and modernisation. New technologies improve traditional building methods, the value of which is increasingly appreciated. Thus, traditional technologies and materials are characterised by new properties that allow adaption of the building to the prevailing climatic conditions. Similarly, the intelligent architecture, quipped with a management system supports the reduction of energy consumption by adapting to the weather conditions.

Regardless of the accepted methods and technological possibilities, urban sozology supporting the principles of sustainable design requires special attention. This can be applied in spatial planning at various scales. The rational planning of facilities and their appropriate localisation with respect to the natural environment that also takes into account climatic factors are perceived as striving for sustainable development promoting pro-health conditions.

The problems presented in this paper require analysis and the search for remedies due to their global scope and the consequences resulting in irreversible changes in the natural environment, which is also not indifferent to human life and health.

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Contemporaneity – Zakopane-ness – the heritage of Zakopane. The Zakopane style in the space of the confrontation of national styles Stanisław Witkiewicz's Zakopane style and its *differentia specifica*

Współczesność – zakopiańskość – zakopiańszczyzna. Styl zakopiański w przestrzeni konfrontacji stylów narodowych. Styl zakopiański Stanisława Witkiewicza i jego *differentia specifica*

Abstract

This paper is an attempt at reconstructing Stanisław Witkiewicz's creative method on the basis of his scattered writings. The Zakopane style has become a phenomenon across a broad spectrum of Polish national styles. The inspirations for classical national styles were typically arbitrarily selected sets of forms taken from a specific historical style associated with a given nation or state. It was often an eclectic set – enriched with elements derived from other styles. Stanisław Witkiewicz consistently avoided borrowing and copying, confining himself solely to drawing inspiration from the folk art of Podhale. In the methodology of his architecture, rational elements (exposing the structure, stressing hygiene) interweaved with ornamentation, predominantly featuring floral themes and elements of a specific mythology.

Keywords: national style in architecture, the Zakopane style, folk art, vernacular architecture, Podhale

Abstract

Artykuł jest próbą zrekonstruowania metody twórczej Stanisława Witkiewicza dokonaną na podstawie jego pism rozproszonych. Styl zakopiański stał się fenomenem w szerokim spektrum polskich stylów narodowych. Inspiracją dla klasycznych stylów narodowych na ogół był arbitralnie dobrany zbiór form zaczerpniętych z określonego stylu historycznego związanego z danym narodem, bądź państwem. Często był to zbiór eklektyczny – wzbogacony o elementy pochodzące z innych stylów. Stanisław Witkiewicz konsekwentnie unikał zapożyczeń i wtórności, wykorzystując wyłącznie inspiracje z ludowej sztuki Podhala. W metodologii jego architektury elementy racjonalne (eksponowanie konstrukcji, nacisk na higienę) przeplatały się z ornamentyką, głównie o tematyce roślinnej oraz elementami swoistej mitologii.

Słowa kluczowe: styl narodowy w architekturze, styl zakopiański, sztuka ludowa, architektura ludowa, Podhale

1. An apotheosis of a nation or of a people? At the source of the Zakopane style

The genesis of the Zakopane style substantially differs from that of classical national styles. The sources of the inspiration for the remaining national styles were architectural forms associated with specific historical styles. A specific catalogue of selected forms was typically created in an arbitrary manner, defining the precepts of combining them together. Eclecticism – the borrowing of forms from other styles – was allowed to an extent (e.g. Jan Sas-Zubrzycki, apart from the Gothic forms that were essential to the Vistulan style, also used elements of the Romanesque style in the bottom sections of his churches; Franz Schwechten used Byzantine forms in the interiors of the Imperial Castle). The "national" character of those styles was also defined arbitrarily.

From a long-term perspective, the notion of national styles has proven to be a controversial idea. The theses formulated by their authors currently appear enigmatic, and sometimes have not stood the test of time altogether. The fall of the notion of national styles was largely caused by the principle of the arbitrary selection of historical forms.

Stanisław Witkiewicz created the Zakopane style as a national style by referring to the architectural forms of the vernacular architecture of the Podhale region of Poland. During a long-term process, he cooperated with local Gorals, scholars and artists. The methodology of the creation of the style adopted by the architect was comprehensive, logical and consistent. There was no place for arbitrary choices. The selection of forms and reference systems performed by the architect always had a proven origin derived from local forms of vernacular architecture. All of the solutions were verified by practical on-site application, with descriptions performed *ex-post*, after completion.

Witkiewicz's pursuit of a clear and purist deduction of forms solely from Podhale's architecture can be proven by comparing his creative method with that of Dušan Jurkovič, a Slovakian architect who operated on the other side of the Tatra Mountains.

Jurkovič created his own style based on Slovakian vernacular architecture, although without the ambition of creating a national style. In his work, this architect combined the elements of folk art with elements of Viennese secession and English patterns. The integration of these elements is particularly visible in the architecture of his own house in Brno Žabovřesky, called the "House under the Hill" (1905–1906). The architect's villa hosted exhibitions of architecture and applied art. References to Art Nouveau were also present in other works of the Slovakian architect: the tourist shelter complex on the ridge of Pustevna near Radhošť (1897–1899), in the design of the Way of the Cross on mount Hostyn near Olomouc (1903), in the regional house in Skalice (1905), and in the "U Rezku" villa (1900–1901). Witkiewicz ostensibly avoided borrowing from architecture that presented other styles or that had roots in other countries.

In his scattered writings, Stanisław Witkiewicz strived to explain the selection of Podhale's folk art as the reference point and source of inspiration for the architecture he was creating. Initially, this architecture was meant to be a local style of functional, comfortable and hygienic architecture for tourists and resort patients. The creation of a Polish national style later became his long-term goal.

2. The methodology of the creation of Witkiewicz's Zakopane style, reconstructed on the basis of his scattered writings

Witkiewicz did not describe his methodology in a holistic manner anywhere. However, we can reconstruct the architect's train of thought from each of his scattered writings. It would be good to investigate them, as they are written in a characteristic style, which gives off the atmosphere of the enthusiasm with which the architecture of the period was being created. This is why I have taken the liberty of quoting long passages from his works.

The reconstructed disquisition would begin by justifying Witkiewicz's choice of the vernacular architecture of Podhale as a reference point and a source of inspiration. This description of Goral architecture as a source of inspiration is preceded by a poetic characteristic of the Gorals themselves. In his work "Na przełęczy. Wrażenia i obrazy z Tatr", Witkiewicz described the uniqueness of Podhale's Gorals. According to Witkiewicz, this uniqueness was a product of two qualities. The first factor that gives them their remarkable qualities is their constant contact with the untamed wildlife of the Tatra Mountains. Second: the Gorals have always been free people and have never been serfs. In the aforementioned story "Na przełęczy", Witkiewicz wrote: "This peasant had never been anyone's subject. He grew free and wild, and he maintained personal dignity and a strength of spirit in all forms of courtesy. He gave and demanded respect, singing to those who wanted to impress him with the habits of serfdom:

> Oh lords, oh lords, lords you shall remain,
> But lord over us – that you never will.

In truth, the period of the Gorals' rise in popularity coincided with a lively stirring of democratic notions. It became fashionable to "be closer to the common people". What can then be said of becoming closer with a people whose intellectual and social qualities, and whose life and image were so original, and so different from common, everyday phenomena? "People who were one with such a remarkable land, [...] a people that had many excellent racial characteristics in general" [9, p. 39].

Witkiewicz's description has the character of poetic prose, in some fragments coming closer to a panegyric in honour of the Gorals. Witkiewicz discussed the relationship between the Gorals and visitors at length. An atmosphere of mutual fascination between the two so starkly different social groups was prevalent at the time. In another fragment of his story, he described the legendary characters of the highland robbers – *zbójnicy*. They constitute a quintessence of the characteristics of the Gorals – of their courage and ability to deal with nature.

Architecture created by a people with exceptional qualities should also possess exceptional features. The Goral cottage was, according to Witkiewicz, the archetype of the dwelling. Its timeless features have been defined by: simplicity and functionality, its general proportions and Goral ornamentation. The furnishing of a Goral cottage constituted a stylistic whole with the remainder of the building. Decorative motifs covered the cottage's structural elements as well as its furniture and household utensils. The exceptional characteristics of the Goral cottage were described in the novel *Na Przełęczy* in the following manner:

> Even at first glance, the Goral cottage appears something that is full of character – this element of personality that sets both special people and special things apart from the crowd.
>
> The skeleton of the edifice is a box in which man finds shelter, this part of every thing that is used for practical ends is almost equally simple and uncomplicated as in any other cottage. Four walls, two gables, the two inclined surfaces of the roof, with a slight departure from symmetry on one side, underneath which there are additional chambers – such is the entire cottage.
>
> However, all of its parts bear the mark of a certain style, of a certain line motif. From the incision of the beam to its pointed gable, from the pazdur (a form of roof ridge decoration) to the ornaments carved inside, everything has the same character of lines that intersect at quite a sharp angle" [9, pp. 17–18].

The period's Goral cottage was dominated by dark spaces that were almost devoid of light, the inside of which was messy and dom-inated by chaos. However, the main room was the so-called *white chamber* – which fulfilled the role of the living room. The Gorals cared for this chamber. It was typically filled with memorabilia and paintings. Witkiewicz, while expanding the concept of the Zakopane style, turned the white chamber into a sort of model of a modern, hygienic dwelling. In his methodology, he used the principle of the maximum preservation of the value of Podhale's vernacular architecture, although he did eliminate chaotic and unsanitary elements. Witkiewicz expressed his high regard for the white chamber in the following words:

> "The chamber to the right, the day room, or the white chamber, is the Goral living room. [...] One of the walls is entirely covered with paintings – horrible, yet original paintings, painted on glass, which stand out from among the neighbouring screaming crumminess of German lithography with their grimness and naivety. [...] The white chamber, almost unchanged, can be relocated to even highly sophisticated and rich dwellings and constitute an excellent dining hall" [9, pp. 21–22].

Stanisław Witkiewicz described the inspirations and principles behind the Zakopane style in greater detail in his *Pisma tatrzańskie I*, in the chapter *Styl zakopiański, Zeszyt II Dom*. He presented his search for a source of inspiration for a national style. It was to be an architecture that was original and without ties to influences of the art of foreign nations. Following these assumptions, Witkiewicz rejected the architecture of old Polish manors as a model for the Polish style in architecture. He believed that their formal expression featured too many elements that were borrowed from foreign architecture. It should be clearly stressed here that Witkiewicz did not condemn the influence of foreign art on Polish buildings, he simply did not want these influences to be visible in the architecture that was to be a source of inspiration for the national style. On the other hand, Witkiewicz eliminated works of vernacular architecture other than those of the architecture of Podhale. They are undoubtedly tied to Polish culture, but, according to Witkiewicz, they had too few compositional qualities to become an inspiring element for a national style. The vernacular architecture of Podhale remains closely tied with Polish culture, having remained in a form of isolation from foreign influence because of its mountainous surroundings. The second factor that predestined it to become a source element for the national style were its links with the primal landscape. The third factor was the high technological and compositional level of this architecture. Combined, all of these three factors led to a situation in which the vernacular architecture of Podhale became the sole bearer of

the potential qualities that made it fit to become a driving force behind the creation of a Polish national style. Let us quote the words of Stanisław Witkiewicz himself here:

> Where then is the source of the Polish style in architecture, if this style is not to be and will not be the product of individual creativity, if it is to develop from already existing architectural elements? […] If we cannot find these forms in the o l d manor, then if we turn to the old cottage in pursuit of them, can the cottage from the valleys – with its thatched roof and structural forms, smeared with clay and doused with lime – be the starting point for the Polish style in architecture? Hardly. The Podhale cottage has in it the structural and ornamental elements of a higher type, which were also prevalent in all of timber Poland, spreading to adjacent lands along with its culture. This cottage has common characteristics with the Czech architecture of Moravia. However, this type disappears in areas where native German culture has appeared. This makes it west Slavic architecture, whose eastern reach goes as far as that of the influence of Polish culture. Therefore, when developing this building element, we can be sure that we are headed to a source of genuinely Polish historical architecture, while if we had started at the "old manor and the granary", we would have dressed Poland in a Franco-German style, or have covered it with a flat parochialism in the Biedermeier style [8, p. 313].

In his *Pisma Tatrzańskie*, Witkiewicz described the process of the shaping of the Zakopane style through the construction of successive villas and houses. The basis for this process were modifications of the pattern of the Podhale cottage. They headed towards a direction of designing a functional, sanitary and comfortable architecture. The model of the representative section of the cottage, called the *white chamber*, was used to this end. Witkiewicz wanted to prove the folk, highlander origin of the modifications that he had introduced. When describing the construction of the "Koliba" villa for Zygmunt Gnatowski, he highlighted the comprehensive character of the inspirations derived from the model of the Goral cottage:

> "All the architectural, structural or ornamental elements were found in vernacular architecture, either in a state that had been completely developed and fit for higher requirements, or in incipient forms. From the foundations to the ridge, all that a house needed, could be found in the c o t t a g e " [8, p. 292].

The shape of the roof was an essential element of Zakopane style architecture. The attic had to house additional living spaces. This required a modification of the form of the roof and its structure. However, the essential shape, along with its distinct steep incline, was preserved. The roof modifications included: the *wyględy*, which have been discussed in greater detail further in the text; verandas, glazed verandas – the so-called *pajty*; the *przyłapy* (porches covered with an extended eave, with the most beautiful specimen found in the "Pod Jedlami" villa), roof gables with balconies (first used in the "Pepita" villa). However, the essential massing, with its characteristic steep roof inclines, has remained. According to Stanisław Witkiewicz, the roof of a Goral cottage was the archetype of the Polish roof. He wrote of the remarkable qualities of the Zakopane roof using the following words:

> The Zakopane roof is not a m o u n t a i n r o o f – it is a P o l i s h r o o f, just as the entirety of this architecture, which used to predominate all of P o l a n d . The proportions and form of this roof are a result of the need to give it strength to resist wind pressure, bear the weight of snow and the incline needed to ensure water runoff. Perhaps the Gorals, when faced with the climate conditions of P o d h a l e, reinforced it to a greater extent and perfected it by following their sense of beauty, but in essence, this roof is not the exclusive property of the Podtatrze region [8, p. 300].

During the numerous construction projects and theoretical deliberations, Witkiewicz encountered the necessity to design new elements that had not existed in the peasant cottage. The architect wanted even these completely new elements to be linked with the tradition of Podhale. One example of this mode of operation is the creation of the famous *wyględy*. Witkiewicz adapted the pattern of a primitive technical device – a sort of a roof hatch that was used to throw out hay. This device inspired the architect to create dormers that would jut out of the roof surfaces and be covered with shed roofs. The *wyględy* made it possible to significantly expand the usable space of the attics, to a level comparable with traditional dormers. Gabled dormers have a limited width, while shed dormers, like the *wyględy*, can be considerably wider. The side walls of the *wyględy* were decorated with a radial ornament, referring to the archetypal Goral *słonecko* (a solar ornament). On the other hand, this solar ornament could be read as a metamorphosis of the still prototype of the *wyględy* – an opening roof hatch. As an additional justification of the form of the *wyględy* and their link with Podhale folk culture, Witkiewicz described the fact of the first, primitive adaptation of the roof hatch for residential purposes that had been performed by one of Zakopane's Gorals. The *wyględ* was first built to Stanisław Witkiewicz's design in the "Koliba" villa (1892–1893). The architect described the genesis and advantages of this architectural detail in the following manner:

> Apart from smoke hole windows, we have introduced the w y g l ę d y to the Zakopane roof. In the roofs of their barns, the Gorals have a section that can be lifted and supported by a pole so that hay or straw can be thrown out. With this intent in mind, one *gazda* on Kościeliska Street, in order to fit a room for living in in the attic, tilted a portion of the roof upward to let the light in, creating a sort of a balcony covered from the sun, rain and wind. We took this motif and, after giving it a more fleshed-out shape, introduced it into new homes, primarily the K o l i b a, in which almost all of the elements of Zakopane's architecture have been tested and adapted to new conditions. The *wyględ*, as an improvement of the dwelling, is an extraordinary addition. It expands it as it becomes another room during days with warm weather, full of air and in an area where there is always something to look at, and providing the means of looking; it serves as an excellent place for the ill to recline in, as a place of rest for the infirm and for the placement of plants and flowers [8, p. 300].

One of the distinct characteristics of the Zakopane style is the formation of relatively tall ground floors enclosed with a wall made of unsquared or river stones. Thanks to a ground floor formed in this manner, it was possible to increase the volume of the entire building while preserving the proportions typical of a villa. In this case, Witkiewicz also attempted to link the genesis of the tall stone bases with vernacular architecture. He referred to the case of cottages on Mount Gubałówka:

> The building of porches, verandas and galleries that encircle the house and rest on stone arches was also observed in the cottages on the slope of Gubałówka and resulted in picturesque elements and, in harmony with the character of the entirety of the structure, in which the roof frame so evidently steps forward and rises to prominence, forming one of the constituent parts of the sensation of the beauty of a Zakopane house [8, pp. 292–293].

The saturation of architecture with ornamental forms became a fundamental characteristic of the Zakopane style. It was one of the manifestations of the intensification of symbolic messaging – a typical phenomenon for national styles. In the case of the Zakopane style,

decorative motifs mainly covered furniture and household utensils (including the famous spoon hangers). Floral motifs were the most common. When employing Goral ornamentation, Witkiewicz used the famous lithographic tables included in the work entitled *Budownictwo ludowe na Podhalu* by Władysław Matlakowski. This book was published in 1892 by the Academy of Learning in Krakow. Of note is the fact that Goral dress was also ornamented. Thanks to this ornamentation, a uniform stylistic space was created in the Zakopane style, integrating architecture, design and interior decoration.

Ornamentation also became an element of building the concept of the Zakopane style as the national style. Witkiewicz wanted to expand the spectrum of floral motifs, traditionally confined to the plants of the Tatra Mountains, to include floral motifs from other parts of Poland. The architect, when discussing the ornamentation introduced in the "Koliba" villa wrote of it as follows:

> The railings of stairs, verandas, balconies, the encircling of the first floor with a decorative belt, as in the Koliba, all of these are places where all manners of motifs from the openwork of spoon hangers are scattered, all sorts of stars, *parzenicas*, crosses, cut-outs, animal motifs or chevrons, or where the large visually expressive branches of stylised cut-outs intertwine. We have enriched this folk ornamentation with a number of motifs featuring the plants of the Tatra Mountains, such as those of the *asphodelus*, the *karlina*, the fern and a number of other flowers, whose wealth in the Tatras can provide many other formal elements. The fact that, when initially building in the Tatras, we have used the plants of the area, does not exclude the further development of this ornamentation by introducing plants typical of the lowlands, as the architecture itself, called the Zakopane style, is not meant solely for Podhale and has not originated here [8, pp. 301–302].

The tendency to integrate the arts was a characteristic phenomenon of the period's artistic trends, primarily those of the Secession. Of note is the fact that a breakthrough was to happen in the art of the early twentieth century – the emergence of a countertendency to eliminate the ornament. In 1908 Adolf Loos published his famous essay *Ornament and crime*. The argument about the role of the ornament, so fundamental to the art of the beginning of the twentieth century, became reflected in the writings and architectural work of Stanisław Witkiewicz. He tried to reconcile his position, close to that of the Secession, of striving for the maximum possible saturation of architecture with ornament, with that of ostentatiously highlighting the structure of a building. He believed that the role of the ornament was to accentuate the structure. He strived to employ this principle in his Zakopane style buildings. He explained this principle in his *Pisma Tatrzańskie*. It is one of the more beautiful descriptions of the Zakopane style:

> The fundamental characteristic of the Zakopane style is its structural character – it is the exposition of the roof frame and the pursuit of highlighting it through ornamentation. Those lacking a sense for structure, those who do not feel the spirit of this struggle against the inertia of matter, the fight against the force of gravity that every structure personifies – cannot create the forms given to us by folk art. Another characteristic of the Zakopane style, which is the product of applying this structural character to timber, is its orthogonal and straight character – with very rare exceptions to this universal, distinct form [8, p. 286].

In essence, Stanisław Witkiewicz did not engage in politics or broadly understood social matters. The architecture he had created through the Zakopane style could have been read as a manifesto of the connectedness or rather the community of the different social classes.

This understanding is compliant with the principles of solidarism that has been ascribed to Witkiewicz. Solidarism, according to the PWN New Encyclopedia, is "a branch of socio-political thought stating the natural community of interest that links individuals regardless of their place in the social structure" [6, p. 935]. Stanisław Witkiewicz defined the social mission of the Zakopane style in the following manner: "The social ideal of every element of culture is for it to encompass all of society, it is bestowing common civilisational characteristics upon all social strata, it is the creation of perfect links between souls, above the crevasses of terrible material inequalities and opposites. The Zakopane style has succeeded in this task" [8, p. 287]. It appears that this statement only applies to the visual layer of Zakopane style architecture. By ennobling the traditional cottage, it has also ennobled the common Goral folk. Witkiewicz never took up the challenge of creating genuine social architecture.

When we list the essential characteristics of the Zakopane style and its methodology in a highly condensed form, we can observe the style's rational foundations. This rationality, in my opinion, set this style apart from other national styles.

1) Proper architectural design was preceded by in-depth studies and ethnographical analyses – devoted to studying the Goral folk and analyses of the vernacular architecture of the Podtatrze region.
2) The style's methodology is based on modifying the pattern of the Goral cottage.
3) The initial goal of the modification of the Goral cottage pattern was to obtain a functional, comfortable and sanitary architecture, largely of a residential character. The long-term goal was the creation of the Zakopane style as the Polish national style.
4) The pursuit of the creation of a comfortable and sanitary architecture led to the necessity of increasing the volume of the buildings when compared with the original pattern of the Goral cottage. The expansion was largely performed by:
   a) transforming the roof: introducing verandas, glazed verandas, the so-called *pajty*, *wyględy* and *przyłapy*.
   b) the introduction of a tall ground floor enclosed by a base made from unsquared or river stones.
5) The material used in the construction of Zakopane-style buildings was predominantly timber, with stone used to build the bases. Masonry structures were also used during the mature phase of the Zakopane style.
6) Rational elements intermingled with elements of a sorts of mythology within the methodology of the Zakopane style. This phenomenon was typical for national styles.
7) The saturation of architecture with ornamentation, predominantly featuring floral motifs. According to Witkiewicz, the ornamentation highlighted the structural characteristics of the architecture.

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Contemporaneity – Zakopane-ness – the heritage of Zakopane searching for urban reserves. The potential of underground spaces. Designing in a narrow and demanding location

Współczesność – zakopiańskość – zakopiańszczyzna. W poszukiwaniu rezerw urbanistycznych. Potencjał podziemia. Projektowanie w ciasnej i wymagającej lokalizacji

Abstract

Zakopane is a regional tourist city that is unique on the national scale. It is a one of a kind mountain resort with an exceptional history and atmosphere. It is a fashionable place where visitors can both rest and test themselves. It currently requires not only sustainable development but also that the effects of negligence and its deficiencies in spheres required for it to comfortably function be addressed, in addition to the supplementation of its offering both in terms of use and culture. The small-scale architecture of the Podhale region must rise to contemporary challenges. Presenting underground projects from all over the world aids in raising awareness as to the development potential of the area, demonstrating one of the paths to solving the problems of overburdened cities. Examples show means of relieving the pressure of current needs, simultaneously relieving the above-ground service programme of cities and increasing the amounts of greenery at their disposal.

Keywords: the case of Zakopane, the overburdening of cities, pro-environmental solutions, global underground projects

Streszczenie

Zakopane jest regionalnym miastem turystycznym unikalnym w skali całej Polski. Jedyny górski kurort o wyjątkowej historii i klimacie. Modne miejsce wypoczynku i wyczynu. Wymaga obecnie nie tylko troski zrównoważonego rozwoju, ale naprawy zaniedbań i wyrównania braków dla komfortowego funkcjonowania oraz dopełnienia oferty zarówno użytkowej jak i kulturalnej. Drobna w skali architektura Podhala musi sprostać wyzwaniom współczesnym. Uświadomieniu możliwości rozwoju tego miejsca sprzyja prezentacja realizacji podziemnych z całego świata jako jednej z dróg rozwiązywania problemów przeciążonych miast. Przykłady wskazują sposoby rozładowania presji potrzeb, odciążając równocześnie naziemny program usługowy miast i zwiększając zasoby zieleni.

Słowa kluczowe: casus Zakopanego, przeciążenie miast, rozwiązania proekologiczne, podziemne realizacje światowe

1. ZAKOPANE – the baggage of the place on the scale of needs

The phenomenon of the heritage of Zakopane is primarily associated with the exceptional character of nature. It is a charming place amidst rocky mountains, a small area of the Tatra Mountains that has remained within Polish borders and whose beauty and unquestionable appeal of its rugged landscape are the pride of the Polish people. However, it is primarily the Highlanders – the inhabitants of Podhale – who take pride in it. Zakopane, first discovered and utilised for the purpose of restoring health and later for sports and broadly understood tourism – is currently "bursting at the seams". Contemporaneity has brought with it greater needs not only in terms of lodging and technical infrastructure, but also circulation, sanitation and general needs concerning an equalisation of the quality of life in the difficult local terrain and climate conditions. It also requires an immense amount of specialised services – in order to ensure attractive and diverse forms of recreation. The once-quiet resort, which used to attract the artistic bohemia, whose members sought inspiration at the source of its remarkable folklore, cultural values and a specific philosophy of survival, has turned into the go-to place for the more and less ambitious, as well as simply those who follow trends. Among them are those who pursue attractions, otherness, in addition to Polishness and regionalism, but also those who want to test themselves and experience survival, which is currently very popular. The more comfort one has in one's everyday life in the city – the more impressed one is with the challenges of a trapper's life.

As hosts, the residents of Zakopane want to provide everyone with an appropriate quality of service. After a period of the town's uncontrolled growth, which has led to a rapid growth of chaotic development – Zakopane is currently aiming to regain control of and restructure its development. This sudden growth has become damaging to the valuable elements of the area's culture, and in the face of oft-crossed liminal urban values and an increase in the incidence of unacceptable phenomena such as smog at the foot of the Tatra Mountains and climate change in general – growth has turned out to be dangerous and alarming.

Centres of cultural life, including the Tytus Chałubiński Tatra Museum which operates here and has been a focal point for scholars, activists and local culture enthusiasts, follow this trend of making development more sustainable. Professionals, academics, artists, mountain climbers, collectors of Zakopane-related artefacts, connoisseurs of the culture of the place and activists have been cultivating and archiving the traces and stages of the area's cultural wealth for years. The museum's collection grows, as do the needs concerning securing, exhibiting and presenting it, in addition to those associated with education and giving the collection a contemporary message. At the same time, the Tatra Museum is making plans to open a Contemporary Art Gallery in order to refresh the formula of its operations and to fill in a gap in its efforts towards the development of culture and progress in social life. So far, Zakopane, an area that is so eagerly and gregariously visited, has lacked an area that would "set the tone" and formulate leading cultural standards. It lacks a cultural institution that would be open to new trends in the arts and that would create local fashions, creating a focal point for dynamic creative groups and attracting individuals who revolutionise their environment and create new art. There is a lack of a qualified space for artistic messages and discussions,

one that would centralise the weight of the obligations associated with the development of such a movement. Success is, without a doubt, conditioned by the presence of such persons and organisers of cultural life who would fulfil similar roles to the one that Zofia Gołubiew has played in the operations of Krakow's National Museum or Maria Potocka in the case of MOCAK, but there is also a need to provide appropriate facilities and equipment. Taking care of the remarkable work of, among others, Władysław Hasior, and having inherited his artistic trademark, including an entire villa and a collection that can be considered the mark of artworks of the highest quality – the Museum can be *de facto* acknowledged as having potential and a complete set of branding resources to this end. Following models such as those of New York's MoMA, the Guggenheim Museum in Bilbao or such commercial brand powerhouses like Louis Vuitton which open museums and galleries, or even global corporations like Benetton, Nike or Adidas and many others – the Tatra Museum has the capacity to name an entire philosophy of living "Zakopane style", profiting not only from the museum's admission fees, but also by expanding the formula of its operations and competence, for instance through branded products offered on its premises or elsewhere. The Museum has already organised a competition for souvenirs that would be true to Zakopane – that would refer to the tradition of the place and would not be mass-produced in some manufacturing plant on the other side of world.

We are all well-aware of the uniqueness of Zakopane. We are aware of the unique aura of this place, which has continued to charm Podhale enthusiasts, artists who are sensitive to the beauty of nature, hikers and mountain climbers, as well as crowds of tourists, including foreign ones, who – enchanted with the local atmosphere – return here over and over. The mental potential of "Zakopane-ness", which is comprised of the area's otherness in a rich profile of its offering of uses and meanings, is sufficient to create a valuable image of local high art, not only in the form of regional and stylised products offered by CPLiA artisans, but also both sublime local art and the most elite modern art.

...

Modern, cutting-edge contemporary art is unpredictable. It is not confined by subject matter, format or the matter from which it is made. All procedures, citations and combinations are allowed. Purity of technique has ceased to be a requirement. What counts is the semantic expression, innovation and a non-conventionality of message. The pro-social orientation of action has taken on a particular significance. Art has become an advocate of the user, of society, of the individual as a separate entity and as a part of nature. Therefore, as an answer to a specific need, the needs of the museum as an institution that organises cultural life and exhibitions – have changed as well. The most flexible and least-limiting exhibition spaces are required. Spaces with the capacity for the arrangement of all manners of exhibitions, presenting objects of varying size, action-art spectacles, multimedia displays, performances, events, artistic gatherings, etc. These requirements also include the costs of maintaining cultural facilities, whose income is nowhere near spectacular. The cause of this state of affairs is the lower interest of society which is not used to a permanent contact with art. There is also a need to reduce the prices of admission to cultural events – in order to attract attendees – and

to conduct affordable educational community-oriented campaigns. The sum total of all of this leads to immense difficulties in conducting cultural operations with this profile.

Nevertheless, as always, the status and quality of culture are a mark of a society's class and determine its overall and community awareness, a high level of which is required in the current period of globalisation and international and intercontinental exchange.

Cutting its coat according to its cloth, the Tatra Museum is preparing to introduce changes to its image that are necessitated by contemporaneity, as well as to build new facilities meant to host contemporary art exhibitions and new spaces for the storage of already existing collections. The urban planning determinants of Zakopane prohibit extravagance, leaving only the currently-owned land reserves of the Museum at the disposal of designers. This includes its immediate vicinity, or rather the areas around the historic buildings – facilities that are the property of the Museum. This is practically the only non-developed fragment of its plots. Land dearth is not the only design constraint. Chiefly, all of Zakopane is an area of low-height development that is largely scattered, with small-scale architecture. Therefore, operating using an advertising, visible, large form of monument-type architecture that is akin to a sculpture, and which is typically associated with buildings that house arts galleries all around the world – is absolutely out of the question.

2. THE UNDERGROUND – an unexplored potential of space

Where should we look for land reserves? Where should we look for a space capable of providing the unrestrained development of contemporaneity, the provision of an effective infrastructure, an extensive variety of services and – in this wide array of needs – how do we find the appropriate conditions that will be free of limitations to the artistic development of all cultural disciplines, particularly contemporary art, which is particularly demanding? The situation is all the more troubling when we look at the constantly increasing amount of people flowing both into and through cities, whose target liminal size has largely already been reached. It is further constrained by the environmental necessity of preserving the remaining wildlife reserves and burdened by the duty of rebuilding those parts of nature that have been exploited and damaged.

We want to restore the necessary direct contact with nature to both humans and all biological life – providing land on the surface of the Earth that can be used to freely enjoy contact with nature, clean air, sunlight and a dark night sky, unpolluted by artificial light. The sole general direction of the development of architecture and urban planning appears to be the pursuit of freeing up green spaces and giving them back to pedestrians. The placement of housing functions, which require full contact with nature, typically involves tall above-ground buildings. Meanwhile, the functions of infrastructure, circulation and even services – can be hidden and placed underground. This is no longer a utopian trend. The initial experimental projects featuring the construction of underground infrastructure, shelters, multiple-level underground railways, road tunnels, water reservoirs and tanks, commercial and shopping malls, and even large public spaces illuminated with natural light, as well as museums and

galleries, have become a model that is being implemented and copied increasingly often. This proves that the underground, which has been used almost solely for mining purposes until relatively recently, can be used for everyday human occupancy over a very broad range of activities which can be housed at considerable depths. Contemporary research, engineering and the constantly growing experience in the construction of underground structures provides the perfect equipment, an increase in safety and the constant improvement of the implementation of increasingly bold solutions, as well as lowering the cost of such projects.

Of course, just as the current sustainable and planned urbanisation, as well as urban and territorial policy, the management of underground spaces requires effective construction law and other legislative provisions. It requires provisions that will regulate the problems of ownership and the conditions of new development and use – analogously to surface--based ones. In addition, legal matters concerning underground projects are always tied with applicable rights pertaining to surface problems. This is because the large-scale development of a city's underground is not possible without precisely defining the size, levels, depths and mutual multi-dimensional relations that support each other, although they can also sometimes cancel each other out – e.g. in the case of infrastructural grids and functional and technical pathway sequences of various types. We can, however, investigate examples of already functioning "underground cities" from around the world.

Why do we search for space underground?

It is hard not to agree that removing the presence of inconvenient spaces occupied by parked cars and the entirety of the noisy and troublesome vehicular traffic from our immediate vicinity would be a desirable solution. It would mean dealing away with transit that splits urban areas with insurmountable barriers and occupies precious square kilometres of agglomerations and consumes both innocent and guilty victims of vehicular traffic. Would it not be healthier in every possible way to assign the surface of the Earth for biological life, and in urban areas – to devote them to public spaces with a significant preference for pedestrian use? Housing buildings with service zones would become the main visible image of urbanisation. The entire infrastructure of the city could become invisible – it would blend into the background, housed primarily underground. Infeasible? On the contrary – it can already be widely implemented today.

This is but one of the methods of combating climate change, which is our regrettable civilisational achievement – change that can lead to the doom of life on Earth. Any increase in the average temperature of the Globe, no matter how minimal, leads to a decrease in the quality of life and a worsening of human health, in addition to geographic changes that will result in mass migrations once the most urbanised oceanic and sea coastal areas become flooded. We are already experiencing increasingly frequent and intense weather anomalies that cause unforeseen cataclysms and result in irreparable damage. We struggle to breathe in the smog, suffer from burns caused by the sun, which affects us through layers of greenhouse gasses, we fall ill because of spreading pandemics borne by microbes that multiply in disastrous quantities, insects perish, ceasing to pollinate edible plants and breaking the

natural chain of biological dependencies of many species of animals, including humans. Even if we do not clearly experience it yet, each and every one of us has observed the change and remembers colder winters, longer springs, more flowers, fruits and a greater biodiversity. Without a doubt, the projected consequences of the heating up of the planet that are reflected in all manners of studies appear decidedly catastrophic. It is our duty to society to stop this increase in temperature, which is associated with an entire range of measures that change our habits and amend our understanding of the increase of comfort of use. However, this is not associated with limiting our comfort by any means – quite the contrary – an appropriate selection of solutions and the replacement of obsolete elements of infrastructure is conducive to improving the necessary parameters. It is a long-term endeavour, but the heat we are feeling suggests immediate interventions. Ones that should be taken now.

3. SETTING COURSE underground

This is not the only alternative form of reparative action, merely one of the means of stabilising the current alarming situation. What is at stake here is not only the mere improvement of human health, but simply saving lives and ensuring our survival. Only by choosing a model that features many simultaneously conducted reparative efforts meant to address the damage that has been done to nature and restore lost reservoirs of wildlife to bring back balance can we prevent the complete destruction of nature and the end of life on Earth. Only by choosing synergic solutions and multi-directional reparative actions can we achieve a general improvement of the global situation. We do not analyse the causes and effects of the inconveniences that have already affected us every day. We live in our own present. Only in the global dimension – which is debated on by scholars, activists, politicians and government authorities who are familiar with overall readings – can we see the totality of the damage, its current consequences and further long-term effects.

We have justified ambitions to meet the highest standards of living. However, if we observe the experiences of leading and more affluent countries, we will have a chance to avoid their mistakes. As we are a large central European country, we are not allowed to ignore the consequences of the economic boom. We belong to a community of countries that are also equally responsible for the highest increase in pollution and destruction – and, therefore, are even more obligated to search for ways to reverse their pernicious consequences. [7] No matter how the situation unfolds – if we do not find ourselves in the intellectual lead – we will always remain in a definitively losing position.

...

This is why, regardless of the global scale of the problem, starting at the grassroots, as teachers and designers, we strive to face the smallest tasks just as responsibly, with said tasks presented analogously: in the spheres of housing, services, society and culture, but perhaps most importantly – that of education. We analogously strive to think of ways to solve design problems, both on the go and in a systemic manner. In this case this concerns narrow urban plots.

In the case of Zakopane, in order to approach the ambitious spatial task that is the design of a contemporary arts gallery in such a demanding town – we reached to the underground, which is a still-untouched reserve of the area's development potential. It offers the possibility of obtaining space for numerous service functions in a manner that is "invisible" to users, particularly in the case of functions of significant size, which are required by the needs of contemporaneity and do not fit the categories of the traditional heritage of Zakopane and its spatial capacity.

4. MODELS from advanced countries

In order to familiarise ourselves with the experiences and pursuits of the most advanced countries, all we have to do is to look at a presentation of civilisational changes which were summarised and had their conclusions formulated during an open session of the ITA (currently ITA-AITES – International Tunneling and Underground Spaces Association), which took place in Singapore in May 2004 and was moderated by the ITA vice-president Jean-Paul Godard from France.

The basis for this discussion was the projected growth of the global population to 5 billion in 2030. Forecasts project that the global population will double relative to the state seen in 2007. This dramatic population growth primarily pertains to poorly developed countries, as the population of developed countries increases at a significantly slower pace. Economically leading countries are more prone to experiencing a population decline. Nevertheless, the main population pressure concerns the urbanisation of cities as the most well-developed form of residence. This is the root of the greatest amount of civilisational problems and the most important concern pertains to urban life.

As can be generally observed, the traditional life of major representative urban spaces, which are open urban interiors that have always been at the centre of attention and have focused and been the site of the organisation of all major events – all activity has relocated itself to new, functionally alien places. The central administrative spaces of cities, the beautifully composed and designed squares, promenades and the official foregrounds of monumental central buildings have become deserted. The entire pedestrian traffic has relocated itself to circulation spaces, accompanied by often improvised gastronomic and commercial buildings. It is there that meeting places are organised, as the busy contemporary life is determined by ease of access by car or motorcycle, and these areas must be economically feasible – cheaper to use, flexible and not too demanding. At the same time, major urban arterials have become multiple-carriageway transit barriers, full of cars that block the flow of traffic, tearing cities apart and dividing them into poorly accessible sectors. The river of cars is accompanied by the constant hum of engines, exhaust and the quite frequent sounds of car horns and the sirens of emergency service vehicles, which are becoming particularly noisy. Noise has become the second-worst curse of large cities, right after smog. Convincing others to travel by bicycle does perhaps make arriving at one's destination quicker, but at the cost of inhaling additional doses of poison and the troubles of squeezing past car bodies. The panoramas of historical cities,

once proud of their meticulously fine-grained tissue interspersed with church towers serving as orientation points and place icons, have become "enriched" by housing block estates and the smokestacks and cooling towers of heating plants almost everywhere. Silos that mark industrial districts release clouds of smoke, either constantly or at night, leaving us without air that is free of particulate matter and toxic substances. These settle in the lowest parts of the atmosphere, at the height occupied by pedestrians and animals, in addition to forming an impassable gas barrier in its upper parts – resulting in the so-called greenhouse effect. It is not the dense matter of the city and the density of development itself that are *de facto* the most inconvenient. The greatest enemy of city residents is the infrastructure of city life: traffic, deliveries, all manners of service infrastructure and the heating and air conditioning of nearly all facilities. The users' favourite cars have become their greatest enemy. This achievement of our times, which gives us an ease of travel, a feeling of freedom and the fulfilment of many dreams and ambitions, even allowing us to reach previously unattainable goals – has become a health trap and a burden. This is why living in central districts and mass transport that make us independent of the car are eagerly being returned to. Nevertheless, it is difficult for us to abandon the ease and comfort of the use of our own cars. And it is essentially not about removing the freedom of city residents and taking away their pleasure of free travel. More and more urban circulation tunnels and parking garages that have been built underground hide constantly growing traffic. It is also a fact that it is the new and increasingly effective arterials that generate a greater flow of cars. It is easy to see how surface overpasses – built in key areas of cities to facilitate a smooth flow of traffic – are full of practically immobile cars that barely move forward, particularly during rush hour. A similar situation can be observed in the tunnels and on the highways and city diagonals that are successively being opened (Los Angeles, Seattle), but at least they remain unseen, they do not burden public spaces, which is why they do not cause inconvenience or opposition from pedestrians.

Interest in building in underground spaces is becoming increasingly high. The benefits that can be gained from it appear to be indisputable. [1] First, the increasingly dense and rich amenities grid that forms the infrastructure of the entire city can be restructured. During every construction project, every replacement or renovation, grid connections are discovered, systematised and every receiver's access to the grid is remodelled, forks are linked into new trunklines, assuming not only their development and extension, but also securing permanent access to them – which is needed by supervision and maintenance services. This accessibility is also used for other goals that can be useful in providing infrastructure to the city, e.g. in watering the root mass of city greenery, including both newly-planted greenery and the many old or solitary large trees located in heavily paved areas. It is easier to fit and hide surface runoff collection and storm drain reserve tanks or to reroute the beds of rivers that often weaken the foundations of endangered areas of the city. The placement of large infrastructural structures underground makes it possible to avoid their associated interference with the landscape and the skyline of the city, as well as to use the land on the surface in a different, more suitable manner – for instance by placing large multi-level parking garages underneath the paved surfaces of city squares.

The benefits of using underground structures – which are hidden beneath the surface – appear to be obvious: They include the procurement of new urban and facility spaces without

visibly expanding cities, safeguarding against disasters which traditionally endanger surface buildings – as experiments and studies have indicated at a much greater safety of underground buildings owing to their lower sensitivity to shocks and the effects of disasters that affect the surface of the earth. Typhoons, floods and building collapses are not felt underground. Underground spaces are new reserves of space that can be procured for the needs of the city.

The specificity of locations in which underground solutions are searched for is varied. This diversity of individual situations inspires designers similarly as it does above the surface, even if it is not associated with a visible, impressive image and has a more engineering-related character, as it is built using tunnelling technologies rather than traditional construction--related ones.

5. LEADING PROJECTS from around the world

At present, the French and Dutch thought is in the lead. It is the source of the best experts on underground space engineering. Of course, the entire engineering and academic world is also interested in underground spaces, and its projects concern – as usual – the most affluent countries, those that face danger or those that are in a difficult, demanding situation – and who take the risk of innovative solutions and can afford large experimental construction projects. At present, it is China and the Far East who are in the lead in terms of both quantity and quality, and who cooperate with and purchase technologies and know-how from the West. But Poland also has its contributions to global engineering achievements, e.g. the historical fortifications by Tadeusz Kościuszko, which played a part in the American War of Independence, while in South America there was Ernest Malinowski, the famous builder of 50 of Lima's tunnels and bridges, who is best known for building the highest ropeway in the world in terms of elevation – the Central Trans-Andean Railways. When we look closer to home, we will find the former vice-rector of the Cracow University of Technology, Sylwester Oleszkiewicz, who conducted the renovation and upgrading of the CN Tower in Toronto, which has a rotating restaurant platform. Both the former and the latter were also patriots of their respective countries: Kościuszko of the United States of America and Malinowski of Peru, particularly after the heroic defence of Callao. A statue devoted to Malinowski stands at the highest point of the railway in the Andes, authored by another Pole, sculptor Gustaw Zemła. In all probability, every sphere of creativity has its heroes in various corners of the world, people who we still consider to be Polish, just as nearby Argentina considers Witold Gombrowicz to be one of its leading twentieth-century writers. This discrepancy between one's place of birth and their greatest lifetime activity is proof of the universalism of thought and the community of existence. As we can see, it is the contribution to global achievements that counts, which, irrespective of nationality and one's geographical location, spurs on intellectual development, the awareness of life on Earth and engineering thought in the common direction of a sustainable civilisation.

Tunnelling engineering and technologies have often proven to be of aid in difficult situations, not only in atypical locations, such as, for instance, the opera building in Sydney,

which, on account of being located on an isthmus, had to house all of its complicated and multi-level infrastructure underground – including a multi-level parking garage for its guests – so that its iconic massing, that of a building extending into the sea, could be exposed without being burdened by unsightly views and the necessarily large area of its supporting facilities.

From among European cities, Paris, for instance, has supported its needs with the construction of tunnels numerous times. It did so primarily through the design of underground railway lines that intersected at multiple levels while running through the entirety of the expansive historical section of the city. Apart from the underground railway, a commuter railway was introduced in the form of the Regional Express Network, the so-called RER, which is a railway that partially makes use of the same tracks as its underground counterpart, but is supported by an additional track. Furthermore, the RER has been expanded to include express railways outside of the city. The deepest RER tunnel reached a depth of as much as 30 m already at the turn of the century. The network's large capacity and extensive stations make it possible to expand and increase its density, as well as the number of trains, without burdening the surface spaces of the city. In some areas a line can run on the surface and sometimes, for instance in the case of line C, even along a bridge above the Seine. However, the most comfortable spaces, which house all the necessary services in their monumental interiors, such as the Auber station, can be found underground. Contemporary technologies make it possible to fully secure the underground from water and damp. Railway lines have been built underneath the Seine, as in the case of line "7" Sully--Morland, or in parallel to riverbeds, like the METEOR line; fully automated lines are also being built, as in the case of the latter, which is being built using a system developed by Siemens.

The former Place du Trône, the contemporary Place de la Nation, houses a multi-level safe intersection of the city's circulation routes underneath its surface. The immense circulation node is invisible to pedestrians. The square is often used as a place of mass gatherings, as marches and demonstrations have traditionally culminated here.

It is obvious that hiding such a large amount of circulation routes underground protects the pedestrians who walk on the surface, leaving the views of the city untouched and pro--environmentally protecting the already urbanised surface.

Engineering associated with underground exploration tunnelling has a historical dimension for Paris. It is no coincidence that the French specialise in this branch of research. The Parisian catacombs – underground corridors and spaces that house invaluable relics of the past – are well-known to underground enthusiasts and common tourists alike. They are dated to the Roman times, as former quarries used as a source of limestone for the building of roads and fortifications, and later as a place of isolating the bodies of plague victims during epidemics, a refuge for the city's poor (we will find such images even in the belles-lettres, see *Les Misérables* by V. Hugo), finally, a place the resistance used for their hideouts during the Second World War. Contemporary cultural life was likewise shocked towards the end of the previous century (1989) by tunnelling underneath Paris' largest and most precious museum facility – the Louvre Palace. We all know the appearance and history of the famous "pyramid", which, having grown like an "Egyptian alien" from underneath the ground in the centre of a historical courtyard in the very heart and "command centre" of the Empire, divided all interested parties, ultimately simply saving the reason for the museum's existence.

From among the latest underground projects, it is the Chinese who are currently in the lead. As the beneficiaries of over 50 % of global manufacturing revenue, amounting to 37 billion euro per year, they are the largest development market in terms of the construction of new underground railways, stations and roads that connect the country's expanding cities. Another 50 Chinese cities will soon become equipped with new underground railway systems, and the growth of their populations necessitates the construction of rapid transit rail and road connections, which have been placed underground because of the goal of conserving surface space. However, coming from the opposite side, it is also the Chinese who have been building the largest dam in the world, on the Yangtze River, since 1994. As scientists have discovered, the enormity of its engineering structure, which converts the flow of enormous volumes of water, has disrupted the previous angle of the Earth's axis of rotation and has slowed down its movement, which has caused days to become longer, the equator to extend in length and the poles to flatten. The Three Gorges Dam has caused an environmental and cultural disaster, irreversibly destroying many biological species. It has resulted in the flooding of 13 cities with invaluable heritage sites, as well as over fifteen hundred villages and towns, causing migrations, floods and earthquakes because of its placement in a seismically active area. It has also turned rivers that once carried drinking water into barely flowing streams of refuse and wastewater that poison biological life. The political decision to construct the massive hydroelectric power plant with the aim of satisfying the country's gigantic development needs has given affordable electricity to some, while outright taking or breaking the lives of others (an estimated 70 thousand have died, with many others suffering from homelessness, expropriation and disease). All of us have also indirectly felt the consequences of this drastic interference with naturally-shaped systems and relationships.

It appears that operating in the underground is much safer – when it is based on the current state of scientific and engineering knowledge and using tried and tested tunnelling technologies [1]. However, there is no doubt that global cooperation – based on spreading knowledge and popularising achievements, exchanging experiences and propagating well--performing solutions, cooperation and the mutual support of global expert centres and the consulting of particularly large and risky projects that can affect changes in the environment – is necessary. There can be absolutely no doubt that the most important thing is to ensure that decisions about planned initiatives are not subjected to political considerations. Governments, particularly those of developing countries, make populist decisions that are based not as much on short-term gain, but the desire to consolidate their power much too often and without due consideration. Decisions are often made in an unscrupulous manner, without analysing future long-term consequences or considering the interest of not only all of a country's own citizens, but even leading to damaging the good of the community, its neighbours, various stakeholders and all who are indirectly involved. Typically, the long-term consequences of the thoughtless actions of governing circles are attributed to the successors of these decision-makers, as they sort of inherit the extant situation from them and it is those successors that must make unpopular reparatory decisions, for which they must then take responsibility.

At present, China is in the economic lead. As a very large country with an immense potential based on natural resources and manufactured goods, with a wealth of historical culture not

only in terms of what has already been studied, but also of what is being discovered during the exploration of underground spaces, as well as with an immense human resources potential – currently also including their own academics who have graduated from the best western universities – the Chinese display capabilities far beyond those of the Old World. It is for this simple reason, as well as because of their participation in making difficult decisions and taking responsibility for the fate of the entire world, that academic and engineering circles, along with broadly understood urbanists, who are responsible for the future functioning and form of our cities, are engaging in cooperation with China. Cultural differences and the many years of political isolation should no longer prove to be an obstacle in engaging in such contacts.

In 2018, the fourth international conference devoted to the presentation of successive designs and projects from the field of global tunnelling presented for the ITA Tunnelling Award [8] took place in **Chuzhou**. The projects submitted for the prize speak for themselves. The vast majority of the projects were Chinese. Below is a list of the contenders for the prize. These are as follows:

1. An undersea tunnel connecting the dynamic centres of the Chinese economic zone, Shenzhen, which is its largest port, and Zhongshan, on two sides of the Pearl River estuary (China)
2. A large and innovative tunnel boring machine (TBM), with the largest drill (15 m tunnel diameter), built in order to bore a tunnel for the Jiajiang road, exiting a bridge on the Yangtze River (China)
3. A 34-kilometre-long railway tunnel with the largest cross-section to date – Ganligongshan (China)
4. A large religious complex on the experimental grounds of an environmentally-friendly processed waste deposit site in a post-mining area – the reinforcement of a 150-metre-deep excavation, the restoration of the terrain's geomorphology and topography, landscape reconstruction and the placement of the support structure of a lotus flower-like structure with a diameter of 38 metres – which functions as a rotating stage. The project included a covering composed of aluminium frames with a tall tower, made using space technology (China)
5. The Honggu underwater road tunnel across the Ganjiang River in Nanchang (China)
6. A new border tunnel between Austria and Italy along Brenner Pass (Austria and Italy)
7. The Grand Paris Express, an extension of the RER underground and commuter railway system which includes additional lines connecting Arc Express loops (lines 11 and 14, line 18)
8. The Fehmarn Belt Fixed Link undersea road and railway tunnel linking central Europe with Scandinavia via an expressway (Denmark and Germany)
9. A two-level replacement tunnel for the Alaskan Way Viaduct (after the viaduct was severely affected by an earthquake), the so-called SR99 Tunnel, running diagonally underneath the entire city of Seattle (USA)
10. Line 4 Amarilla – an automated underground railway line in Sao Paolo, South America's most advanced line (Brazil)
11. The MRT (Mass Rapid Transport), a hi-tech rapid railway network (Singapore)

The previous editions of the conference hosted over 750 guests and received 234 submissions. The latest project of the year title winners for 2018 were:

1. A Chinese bridge and tunnel crossing connecting Hong Kong, Zhuhai and Macau, between island stations that link the sections of the route. With a total length of 29 kilometres, the crossing includes a 6,7-kilometre-long tunnel, 5.6 km of which is under the surface of the sea. Built over a period of 8 years and delivered in 2018, its cost was over 500 million euro.
2. The Chinese Queershan Tunnel, along the northern China National Highway G317, linking the Sichuan province with Tibet via a two-route tunnel, shortening the Sichuan–Tibet highway, whose entirety runs through a dangerous mountainous area that has a cold climate, which has earned it the title of a high-risk road. The 7-kilometre-long tunnel was opened for use in 2017 and was built at an elevation of 4,5 thousand metres above sea level. The construction took 5 years to complete, with the total cost being in excess of 160 million euro.
3. The Zarbalizadeh Shallow Tunnel in Tehran, connecting the east and west of the densely built-up city underground. It has been built below the level used by the railway network, which was operating during the entire tunnelling procedure – as a normally functioning underground railway. The tunnel will reduce the time it takes to travel across the city and reduce traffic in Iran's densely-developed capital. Completed in 2017, its cost was 6.5 million euro.
4. Technical project innovation of the year – this award was given to the Chinese TBM machine with a horseshoe-shaped EPB drill, which had been used during the construction of the Baicheng tunnel, which links Western Mongolia with Central China. The new drill shape is cheaper to manufacture and offers better performance. Its cost is 60 million euro.
5. Technical product/equipment innovation of the year – this award was won by a luminescent material that collects energy and offers a variety of uses, ranging from energy-efficient lighting, to covering tunnel walls or information signs. It is safe and environmentally-friendly (China).
6. Safety initiative of the year – this award was given to ROBY 850 (Hong Kong, China) – a semi-automatic drilling robot that can replace human workers during drilling and the assembly of installations and platforms in tunnels. It increases work safety and effectiveness.
7. Innovative underground space concept of the year – this title was bestowed on the Norwegian Rock Blasting Museum. It is probably the only one of its kind. Founded 25 years ago in 1992, it presents the history of tunnelling and road engineering using multimedia, also showing contemporary TBM machines – the museum itself is housed in an underground semi-circular tunnel. The stone cavern also features a restaurant, as the museum's special attraction.
8. The title of young tunneller of the year was given to the Italian Giuseppe M. Gaspari (1983), who holds a degree in Civil Engineering and a Master's Degree in Geotechnics and a second level Master's Degree in Tunnelling and TBMs. He currently holds

a management position (for a sewage servicing tunnel) in Toronto (Canada) and is a Project Design Manager for the Suffolk Outfall in New York (USA).

20. The lifetime achievement award in the field of tunnelling was given to professor Evert Hoek from Zimbabwe, who holds a degree in mechanical engineering from the university of Cape Town. He specialises in the problems of brittle fracture associated with rockbursts in very deep mines in South Africa. He is a Fellow of the Royal Academy of Engineering (UK), a Foreign Associate of the US National Academy of Engineering (USA) and of the Canadian Academy of Engineering (Canada). He has published over 100 articles and 3 books and has worked on large civil and mining projects, including dam foundations, hydroelectric power plants and tunnels in 35 countries.

Poland has been represented in the ITA by the Subcomittee of Underground Construction of the Polish Committee of Geotechnical Engineering since 1978. The International Tunnelling Association – the ITA – renamed ITA-AITES soon afterwards (International Tunneling Association-Association Internationale des Travaux en Southerrains) and presently called the International Tunnelling and Underground Association – was founded in 1974, connecting the best experts on tunnelling – western experts who jointly consult innovative projects. Since then, their operations have gone beyond Europe to include all continents, with China and the Far East being in the lead in terms of the quantity and size of projects. Among the abovementioned countries particular attention should also be given to **Malaysia**, a dynamically developing country that readily adapts the latest technical solutions, particularly those that facilitate sustainable development. An experimental tunnel has been built there, constituting a part of the ring road of the country's rapidly expanding and growing capital of Kuala Lumpur, which used to be affected by frequent flooding during the storms of the rainy season. The tunnel periodically serves as a surface runoff reservoir. The effective two-level high-capacity tunnel, which dives underground at a section above the city, where the waters of nearby tributaries typically caused flooding – slowly reduces and shuts down vehicular traffic when there is a threat of flooding, successively becoming filled with water. The excess surface runoff is collected there, increasing the water level inside the tunnel and filling its enclosed reservoir. In the lower, southern portion, which is located outside of the city, an open outfall slowly releases the excess water, regulating and easing its flow. It has been called a smart tunnel and not without reason, as it fulfils the criteria of smart or so-called intelligent structures, which operate in a pro-environmental manner, facilitating sustainable development and preventing disasters.

6. UNDERGROUND RESERVES of urban space

The underground has been a refuge for runaways and the excluded for centuries, with corridors dug to evacuate places that were under siege, or otherwise intended to be secret and private. During wars, the underground facilitated survival, protection from enemies, disasters and the elements and – ultimately – from chemical weapons and gasses from various

munitions and bombs, from nuclear radiation, blast waves, etc. Underground bunkers for the military, the general population or state governments are adapted and stocked with appropriate supplies even today. For instance, in Los Angeles, a city constantly under threat of seismic shocks and the collapse of its built tissue, there are entire "underground fortifications" – numerous bunkers for various purposes, including sheltering the general population. The city hall building alone has a fully equipped and constantly operating multi-level control centre with monitors displaying camera feeds from all areas of the city. During peaceful times they are used to regulate traffic and track any irregularities on the streets. All we are left with is to trust that what we perceive or perhaps even feel as surveillance or the stripping of our privacy and independence, is just an automatic record of city life, facilitating an increase in everyday safety, and merely provides information about various threats without interfering with the privacy of residential and semi-private interiors. This is *de facto* the case, unless a precedent allowing the release of this information as if from Pandora's Box occurs.

Nevertheless, surveillance records provide data about the city that is invaluable to the various services, scholars and urbanists. It is provided by increasingly automated devices, including fully digital data that is more and more compatible with various forms of use, suitable for processing for any need or regulation, including the optimisation of the use of appropriate materials, energy or the optimisation of the state of the atmosphere. We have become capable of providing fully comfortable housing conditions underground. The wealthiest possess not only underground shelters but also comfortable residences, hidden from the sight of the overly curious, providing nearly complete safety. Nothing stands in the way of successively incorporating underground spaces into large-scale use.

The greatest problem that urbanists currently face is creating a system of mutual relationships between the underground and the surface. We know from our current experience that the urban layout of buildings, their surface composition, as well as that of all receivers of building service grids, does not need to correspond to the layout of installation grid lines found beneath the surface. Even when the main trunklines follow the pattern of surface circulation, individual recipients typically lay their installation branches using shortcuts. When we increase the density of development we often find surprises and chaotic nodes that need to be restructured and – perhaps most importantly – reliably documented. In order to appropriately utilise the potential of the underground, it needs to be surveyed (geomorphology) and planned. Surface networks must correspond to underground networks. The new underground tissue must cooperate with the extant and planned surface tissue. Spatial dialogue between all of the stakeholders of this space is also necessary. A vision of a new city and a strategy of building it is necessary. This vision should take into consideration all of the needs of its stakeholders and target users. While drafting a new urban code fit for this vision, we have the opportunity to foresee all of the benefits the city will enjoy and minimise the effects of neglect. The new underground tissue should be comparable with its surface counterpart. But most importantly, it must possess error-free circulation links with the spaces on the surface. At present, when we discuss **circulation**, we must have not only surface-based circulation in mind, but also the one on multiple surface and underground levels, in addition to vertical circulation between various levels and depths – appropriately to the needs of the

functional programme. The planning of the future of the underground is not only a balance of needs and possibilities, but also the close cooperation of planners, urban designers and architects, in addition to close multi-disciplinary cooperation, as it is the beginnings – the initial decisions – that set the patterns and directions of underground development that will determine its ultimate shape[1].

Original text based on the author's participation in the Ninth session of the World Urban Forum (WUF9) in Kuala Lumpur, an architectural thesis design workshop in Zakopane in 2018 and the book published by WUF9 participants Han Admiraal and Antonia Cornaro [1].

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[1] Quote: „A New Urban underground paradigm, in our opinion, is based on participation, collaboration, understanding, and innovative multi-use solutions. In this way, the final urban frontier could well prove to be an urban asset that contributes to creating the resilient, sustainable, inclusive and liveable cities we need" [1, p. 19].

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Specific features of designing educational centers in the areas with challenging landscape in Ukraine

Szczególne funkcje projektowania ośrodków edukacyjnych na obszarach o wymagającym krajobrazie w Ukrainie

Abstract

This article is aimed at providing a rationale for the need to introduce a new type of educational institution in Ukraine today, namely educational centers in the areas with challenging topography. This article identifies specific features of construction, given the difficult geographic topography and architectural environment of the educational institutions, and lists conditions impacting the volume and planning of educational facility construction. It defines how urban planning of school centers influence the areas with difficult topography and establishes their location type. The authors analyzed architectural and construction solutions for school centers in areas with challenging landscape. They have also identified form-shaping types of buildings and established the best slope ratio for each of the types.

Keywords: educational institution, educational facility (school center) on difficult geographic terrain (challenging topography), architectural construction solution, space and volume arrangement, space and planning design of the building

Streszczenie

Artykuł ten ma na celu uzasadnienie potrzeby wprowadzenia dziś na Ukrainie nowego rodzaju instytucji edukacyjnej, a mianowicie ośrodków edukacyjnych na obszarach o trudnej topografii. Określono szczególne cechy konstrukcji, biorąc pod uwagę trudną topografię geograficzną i środowisko architektoniczne instytucji edukacyjnych, oraz wymieniono warunki wpływające na wielkość i planowanie budowy placówki edukacyjnej. Tekst określa, w jaki sposób urbanistyka ośrodków szkolnych wpływa na obszary o trudnej topografii i definniuje ich typ lokalizacji. Autorzy przeanalizowali rozwiązania architektoniczne i konstrukcyjne dla szkół w obszarach o trudnym krajobrazie. Zidentyfikowali także kształtujące typy budynków i ustalili najlepszy współczynnik nachylenia dla każdego z tych typów.

Słowa kluczowe: placówka edukacyjna, placówka edukacyjna (ośrodek szkolny) na trudnym terenie geograficznym (trudna topografia), architektoniczne rozwiązanie konstrukcyjne, układ przestrzenny, projekt przestrzenny i planistyczny budynku

Currently Ukraine is facing changes and undertakes reforms in many areas. One of the major reforms is the education reform under the "New Ukrainian school" and "New educational space" programs. Educational reform is of crucial importance, since it is the education of the young generation that defines the future of the state. Unfortunately, current school educational and material resources do not fully meet modern public demand and personal development expectations, economic needs or world trends. Therefore, it requires research of the world`s best practice and its introduction to change approaches and attitudes pursued at school and streamline tuition. Educational reform also involves changing the educational facilities and their spatial organization, therefore, it provides for the development of new types of educational hubs complying with revised technological requirements, improving the range and planning parameters of the premises.

Architectural environment is one of the crucial factors that have a key role in shaping personality. It serves as the basis for developing a new means of teaching and methods. The main objective of an educational center's architectural environment is to create the most favorable environment for people using it, assisting educators in shaping students' world outlook and promoting students` abilities to master knowledge. The factors contributing to the philosophy of efficient educational centers include encouraging a creative environment of inclusivity that meets technological and energy efficiency requirements. The space and equipment of school facilities reflect modern architectural trends and technical needs of educational institutions. Special attention is paid to the environment there that can be transformed into multifunctional open space. This is achieved with the help of partitioning, glass walls, large windows that create an impression of an absence of any boundaries, etc. Premises that can change their floor space and configuration is a new trend for educational institutional architecture in Ukraine that is gaining in popularity. Its main advantage is to enable students and educators to get engaged in free communication and socializing; this space organization allows for effective group work and leisure activities. Thus, it develops students' communication skills which are important for social and community life and motivates them to study as well as giving the feeling of freedom, encouraging their development.

The architectural solution for educational institutions is the intrinsic combination of construction and design methods, ensemble of the development area and modern scientific research in pedagogics.

Research of educational institution architecture and their chain in the build-up area, developing the architecture of educational institutions with non-traditional methods of teaching in an information age in all spheres of our life including science and architecture, are covered in the works of scholars/architects Leonid Kovalskiy [3], Helena Kovalska [2], Serhiy Syomka, Iryna Merylova, Tatiana Ernst. Elements of building organization and construction was the subject of research by Volodymyr Krogius, Yuriy Kurbatov and Ladislav Gorniak. Oleg Sleptsov specifically focused on modern educational institutions [4] as well as studying school construction in complex geologic and engineering terrain [5].

Research on general theoretical issues of modern education development, history of pedagogics, psychology and philosophy are of particular importance for new educational center development. These issues were covered in the works of the following scholars:

Myhailo Levkivskyi, Vasyl Madzigon, Valentyna Dorotuk, Lubov Tarabasova, Hans Bruggelmann and Ken Robinson.

Educational (school) centers in an area with difficult topography are multipurpose multi--sector educational development centers intended for functions related to education, the bringing up of children, leisure, physical development and sports, cultural development and entertainment, catering, health care, administrative and maintenance services. This type of institution is very important to develop in Ukraine now, since, on the one hand, they are an alternative to the educational institutions existing now, and on the other, Ukraine has a shortage of even land for construction.

Areas with difficult (rugged) topography are less attractive for large scale residential development or agricultural use. Thanks to the development of construction and structural opportunities and approaches, challenging terrain no longer causes considerable difficulties for architects, and with new approaches to space and design it might be turned into an advantage. Challenging terrain (slopes, hillsides, ravines, rakes) are widespread in Ukraine. Here, the land plot price is normally lower than that of an even land piece, therefore, it makes it more affordable for developers, however, the complexity of the construction work needs more investment and effort than the construction of buildings on even areas. South, south east and east facing slopes have sufficient insolation and visibility conditions that allow for the construction of energy efficient buildings. Therefore, it saves money on electricity and heating bills and the construction costs pay off in the course of building upkeep. Additional advantages here are green terraces and unimpeded surface water outflow. A sloping area influences architecture and design works, scope and spatial arrangement and building construction, resulting in a unique architectural solution.

The area of influence and organization design of school centers in the areas with challenging topography in Ukraine depends on their location. The centers should rather be located in areas easily accessed by public transport or on foot to best meet the needs and conditions of the following aspects (environmental, climatic, social and demographic). The centers could be located in the outskirts of cities – local situation or within a residential area – directly in the urban structure. The centers are meant to be used by children from the surrounding residential area where the educational institution is located. School centers in the areas with challenging topography can also be built in rural areas. There they automatically become an alternative to the hub schools that are currently being introduced in Ukraine. Hub schools are reorganized secondary educational institutions established by joining educational institutions as branches (divisions) to one educational institution (hub) [7]. School center development in rural areas plays a special role in Ukraine, since most of the schools in Ukraine are rural; where almost two thirds (67.8%) of Ukrainian students study [6]. These schools are outdated and in need of revival.

The architectural and construction solutions for such school centers should look like an integrated composition of forms cooperating with each other. These forms can be divided into smaller sized rooms (classrooms, offices, labs), large format community rooms (concert halls, gyms and catering facilities) and large open spaces (stadiums, gardens, sports fields and playgrounds).

Classrooms and offices are constructed as a terraced type of development along the slope. Then every classroom would be provided with sufficient insolation and good visibility and would have a roof leisure facility on top of the building constructed at the lower level.

Large community rooms take up a lot of space and should be located horizontally. Thus, it is best to use an even piece of land for them, however, there is an option of using cantilevers and truss or to make the building caved into the slope.

Large open spaces can be divided into the ones that should be built on level area: stadiums and sport grounds; those that can have some grade of slope: playgrounds; and those that can be constructed on any type of geographic terrain: gardens, parks (they can be developed on terraced areas).

The grade of slope for the set of buildings and facilities should be acceptable for construction. Based on Volodymyr Krogius' research [1], it has been established that the grade of slope should mainly fall within the acceptable range of 335–100% (185–45°). This range is considered to be appropriate for the main construction. Areas with a grade of slope of 33.5% should be used for sports fields and playgrounds. In case of the building being adjacent to the slope or caved in, 45–90° is believed to be acceptable.

There are two stages in planning and designing school center architecture and construction work in areas with challenging terrain. The first stage involves identifying a spatial solution. It shapes the construction and landscape arrangement of the buildings in the hub. This stage is focused on the overall appearance of the center, its urban location and spatial arrangements on the slope. The second stage is focused on the design and planning of buildings, defining their size, forms and positioning.

Space and town planning construction of school centers can be of various types: pre-engineered, pavilion, line, compact centralized and combined. Pre-engineered means arranging separate building blocks with rooms used for similar purposes; these facilities are not connected by heated passages. A pavilion type is aimed at dividing functional groups of buildings into separate blocks linked by heated passages. A line type of construction lines up the buildings along the slope. A compact centralized type arranges compactly located buildings into squares or circles linked by passages. A combined type is a combination of several types of composition options.

Space and planning structure allows one to single out buildings by chamber type, enfilade layout, hall type, perimeter and corridor-ring type. Chamber type involves positioning functional groups of buildings along the main communicative block of corridor or gallery – like type of space. Enfilade layout positions premises one after another and links them with a passage. General type is aimed at arranging integrated space to comply with functions that do not require large undivided areas. Perimeter type consists of functional blocks of premises that have an entrance to a common area uniting them (atrium, foyer). A corridor-ring type of layout positions functional blocks of premises around one large space (hall, atrium) through a passage or corridor. All space and planning structures can be combined in one school center to create a combined appearance.

Building space and planning structure is an integral part of the space and design solution; they are interdependent and shape each other.

To choose the best solution of space and design layout of the buildings making up the school center in an area with challenging topography, it is necessary to take into consideration the construction territory configuration, slope orientation, ratio of grade (angle of the slope), built up area, horizontal and vertical division of the construction area, transport accessibility from nearby residential areas, convenient access, utility services arrangement, environmental factors, erosion, if any.

Globally and in Ukraine, more attention is being paid to efficient land use and preserving their natural uniqueness. It is especially pertinent for urban areas where challenging terrain is the last piece of land to be used for residential buildings due to the complexity of construction work. However, these plots of land could have valuable recreational and aesthetical features and create unique distinctive views. Buildings constructed on complex terrains tend to dominate the skyline and shape the entire image of the area. Areas with challenging terrain have lots of potential in Ukraine. Building up these areas will contribute to the development and expansion of existing residential areas and will support progress in architecture and construction. Landscape chosen for school center construction will enable us to have more options for effective and unique architecture, planning and designing the space as well as artistic solutions.

In the modern world, education is one of the most decisive factors in developing personality. It plays a significant role in any state: it is education that serves as one of the major means of revival and development of the culture, intellectual and professional potential of its society. It is the basis and foundation for community development and improving quality of life. It enhances the competitive ability of education and its integration into the global educational space.

School centers in the areas with challenging topography are technologically unparalleled educational institutions. They not only comply with the standards, needs and general purpose requirements under the education reform objectives, but also offer more opportunities and choices for children to meet their individual needs. School centers in the areas with challenging topography contribute to raising conscientious active citizens capable of providing for the economic growth and cultural development of the country.

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Urban sprawl and smart growth versus quality of life

Urban sprawl i *smart growth* a jakość życia

Abstract

One of the key reasons behind the urban sprawl process is the desire to increase the quality of life by living in "better" conditions. "Smart growth" is an alternative concept for the extensive development of the city, integrating different ways of land development in a compact manner. The main current of the work is to reflect on the quality of life in the urban areas. The aim of research is to determine ways to "heal" the spatial development of urban and suburban areas under the existing conditions of increasing urban chaos. The interpretation of living conditions for particular social groups is needed to find solutions that increase the quality of life. The background to the research is an analysis of literature on the subject, the consideration of good examples and own observations.

Keywords: quality of life, urban sprawl, smart growth, compact city

Streszczenie

Jednym z kluczowych czynników powodujących proces urban sprawl jest chęć poprawienia swojej jakości życia poprzez zamieszkanie w „lepszych" warunkach. Smart Growth jest koncepcją alternatywną dla ekstensywnego rozwoju miasta integrującą różne sposoby zagospodarowania terenu w zwarty sposób. Głównym nurtem artykułu jest zastanowienie się nad jakością życia na terenach zurbanizowanych. Celem badań będzie określenie sposobów „uzdrowienia" zagospodarowania przestrzennego terenów miejskich i podmiejskich w istniejących warunkach narastającego chaosu urbanistycznego. Interpretacja warunków życia jest potrzebna do zastanowienia się nad sposobami rozwiązań polepszających jakość życia. Tłem do badań jest analiza literatury przedmiotu, dobrych przykładów oraz obserwacje własne.

Słowa kluczowe: jakość życia, suburbanizacja, *smart growth*, miasto zwarte

1. Introduction

The possibility of shaping an urban environment that exhibits high functional values in an active and conscious fashion and consists of satisfying the needs and expectations of local residents has been becoming increasingly important in the modern world due to urban tendencies and the growing demands concerning man's habitat. Living conditions in the urban space determine the quality of life of its numerous inhabitants and depend upon many different factors, which must be properly shaped by administrators of the urban space. Improvement of the quality of space in the existing urban tissue plays a key role in striking a balance between appropriate economic, social, and cultural measures.

According to Chwalibóg [4, p. 48], the limits of freedom in creating space should be determined by means of requirements relating to safety, accessibility, and friendliness, taking into account the needs and well-being of individuals who occupy the particular environment. Today, we start to comprehend how diversified an average population can be, and consequently, how diverse its needs are. Research on the significance of the quality of the environment in the hierarchy of human needs has demonstrated that the quality of the closest environment is the second most important determinant of the quality of life – right after family happiness – and the presence of natural elements and spatial structure consistent with our expectations can be considerably helpful in increasing this quality, fostering the improvement of local residents' health and well-being [16].

Niezabitowska and Masły [13] propose a thesis on the quality of development associated with 'a good building' as a token of sustainable environment, creating a safe and healthy work and living environment, causing no pollution of nature, having low maintenance costs, providing its users with satisfaction through occupying it and giving passers-by and the public pleasure by being in contact with it. The concept of a home, a building, and residence is closely associated with urban development. The home constitutes man's natural living environment – an individual's territory. Augustyn Bańka [1, p. 247] observes that the notions of a home and a house in western culture are intermingled. In many cultures, the notion of a home has nothing in common with the concept of a building (…); for some, it is a place of their origin, for others a place of their birth, and still for others a town they live in on an everyday basis or their neighbourhood.

According to Abraham Maslow, satisfying higher needs is preceded by satisfying lower, physiological ones. A subsequent fundamental need is the need of security, and the next needs (those of a psychological nature) refer to affiliation and territorial identification. Jan Gehl [5] emphasises the functions of a home as being crucial. Therefore, it can be stated that a home is the only element able to satisfy fundamental human needs and that it constitutes a fundamental territory for meeting such needs.

2. The quality of life

The term 'quality of life' has a long tradition. It appeared for the first time after World War II, and in the 1960s, it started to emerge in the context of all sorts of programmes of welfare and systematic social transformation aimed at helping people to shake off poverty, shortages, and helplessness [14].

Initially, quality was associated with material well-being only; over time, the term was extended to include intangible assets. It was observed that improvement in terms of material well-being and satisfying fundamental needs does not have to be equivalent to the increase in prosperity. Extending the notion of the quality of life from the areas of 'to have' to those of 'to be' entailed the need to introduce new criteria associated with objective living conditions and their subjective perception. A multifaceted and ambiguous nature of the evaluation of the quality of life became a necessity and one of the most important aspects of the contemporary reality.

When investigating the relationship between man and space, one observes that one of the fundamental elements for quality of life is man's habitat, which encompasses a home/dwelling, along with its closer and more distant material and social surroundings. The level of the quality of life is closely correlated with housing standards: the better the quality of life is to be, the better the housing standards that need to be provided in order to shape a decent, comfortable, and friendly housing environment, fostering our self-actualisation. The quality of this environment is expressed in the evaluation of the extent to which it is saturated with properties and features desirable from the perspective of its user [2].

Considering the above, as well as how diversified the average population is, we observe different choices with regards to housing patterns, satisfying the very diverse needs of residents. A lack of satisfaction with living in the city and the willingness to fulfil a natural need of 'a home' results in moving beyond the city limits and getting a dream house with a garden.

3. Urban sprawl

Mierzejewska [12] states that the pursuit of the proper form of a city may also be conducted emphasising those properties which testify to spatial disorder and which will consequently not contribute to the sustainable development of the city. Such properties identified in Polish cities in the period of real socialism have been discussed by Jałowiecki [8], who mentioned the following:

- the existence of large housing estates in the suburbs – the size, urban layout, and architectural form of which were dictated predominantly by requirements of construction companies; the monofunctionality of housing estates located increasingly far from city centres generating growing transport-related needs;
- the large scale of housing construction increasing the maintenance costs of buildings, aggravated by enormous energy losses resulting from the adopted technology and sloppy workmanship;

- the low standard of apartments and lack of the necessary services in large-scale construction, which is the source of dissatisfaction of residents and creates circumstances fostering pathological behaviours, hindering social relations necessary for individuals and communities to function properly [9];
- the decapitalisation of old buildings in the city centre, bringing about the deterioration of living conditions in inner cities and the pressure to build new apartments, which has contributed to social segmentation;
- the underdevelopment of city centres in terms of the functions of services as well as symbolic functions.

Nowadays, spatial disorder is evidenced by uncontrolled urban sprawl, an aversion to earlier spatial solutions, and the spatial policy with documents at a local level of administration. The tasks of the commune are comprised of spatial order issues in planning documents, and it is the commune's statutory obligation to define the local spatial policy in a study on development conditions and directions, as well as to implement such a policy by drawing up local spatial development plans. A lack of precision of social planning regulations has allowed communes to interpret the act quite subjectively, and consequently, it has caused the broadly criticised spatial chaos and urban sprawl.

Initially, urban sprawl was perceived as the expansion of the city towards its adjacent areas. Harvey E.O., Clark W. [6, p. 4] identify three forms of urban sprawl: low density continuous development; ribbon development; leap-frog development. As has already been mentioned, today, the term 'urban sprawl' is often used to address negative phenomena, usually associated with the phenomenon of low-density suburbanisation and ineffective development. Sometimes, the term 'sprawl' refers to harmful, unsightly, or inefficient development. Definitions based on land use identify 'sprawl' with the spatial separation of forms of land use and with the extensive monofunctional use of land associated with the development of one-family houses, free-standing shopping malls, and business/industry estates, as well as a dependency upon automobiles. In a broader sense, uncontrolled urban sprawl generates losses which could be apparent by the limited use of the remaining undeveloped land. Furthermore, additional environmental and social costs are identified, and in the course of time,it will generate higher and higher economic costs for local governments and local communities, which are associated with the technical infrastructure necessary for residents to live in a specific location. The subject literature points to other significant costs, such as the costs of commuting to work and the costs of lost time [11]. Increasingly often, such costs influence decisions on the place of residence as they constitute a direct burden for household budgets. It is also observed that young people return to cities with their school-age children due to the poor educational and cultural facilities available outside the limits of the city.

4. Smart growth

Many things we deem important in our lives are influenced by our main development decisions, e.g. how we choose to live, how much time we are ready to spend travelling to work, our accessibility to the services we deem the most necessary, etc. Our choices determine the quality of our everyday lives, which take more and more time and also have a direct influence on our personal lives. Therefore, while pursuing our dreams, we more and more frequently consider everyday life amenities, and the principles of smart growth[1] [17] turn out to be the key to our success.

Smart growth is proposed as an alternative to extensive urban development – urban sprawl – as a concept of a compact city. Smart growth is also one of many model concepts of sustainable urban development which regards the process of urban development in a more comprehensive way, taking into account ecological, spatial, and social aspects more than only economic factors. Integrating solutions contributes to limiting the unfavourable effects of external urbanised areas, as well as securing a high quality of life in the city, social justice, and favourable management conditions [12].

The objective of developing a concept for urban space development is to secure the spatial order and sustainable development of cities. The smart growth model is intended to limit suburbanisation and contribute to the revitalisation of cities. At the local level, the most popular instrument is the urban growth boundary.[2]

Residents who opt for a metropolitan lifestyle desire such values as density, intensity of contacts, and diversity, which foster the development of innovation and creativity. Residents are focussed around public transport hubs and local outlets of basic services, including new functions associated with new lifestyles, new forms of recreation, and new workplaces. These functions are easily inscribed in the urban structure and do not cause any visible changes in the physical structure of the city.

The beneficial economic aspects of a dense urban tissue most of all result from the more effective use of available resources, such as space, energy, and time. Use of local services supports local entrepreneurs and saves time. Small distances resulting from the vicinity of places of residence, workplaces, and services encourage walking and cycling and thus have a positive effect on health. Enhanced safety can also be observed due to more people observing and using the space around them. The economic advantages of good urban planning have a positive effect on local residents and, in a broader sense, on not only society on the whole but also on local authorities, investors, developers, and designers. Furthermore, a dense and multifunctional urban tissue is fairly resistant to crisis phenomena and can be relatively well adapted to the changing conditions.

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[1] 10 principles of smart growth: 1. mixed land uses; 2. taking advantage of compact building design; 3. creating a range of housing opportunities and choices; 4. creating walkable neighborhoods; 5. fostering distinctive, attractive communities with a strong sense of place; 6. preserving open space, farmland, natural beauty and critical environmental areas; 7. strengthening and direct development towards existing communities; 8. providing a variety of transportation choices; 9. making development decisions predictable, fair and cost effective; 10. encouraging community and stakeholder collaboration in development decisions

[2] See chapter III, Harasimowicz A., *W kierunku rozwoju zrównoważonego: granice wzrostu miast* (in:) [3], pp. 51–62.

5. Contemporary concepts of designing high quality spaces in cities – good practices in Vienna

Ideas of model concepts for sustainable urban development, designing a compact, multifunctional urban tissue in the aspect of smart growth have been a feature of large urban projects. This chapter focuses on selected examples of current urban projects representative in terms of different types of design: continuation, completion, or experimenting with compact urban structures using the example of Vienna. In respect to different possible classifications of such projects, a simplified division into four types of new structures is adopted herein as alternatives to chaotic suburbanisation:

- large urban projects, new districts;
- 'city within city' concepts, complex housing estates;
- suburban housing estates;
- concepts in the urban context, projects focusing on the densification of the urban tissue on a smaller scale.

One of the clearest examples of projects focusing on the creation of a new urban district is *Aspern Die Seestadt Wiens* [18] (Fig. 1). This new district of Vienna is designed on a surface area of 240 ha within the perimeter of a former airport, as a contemporary residential town (8500 housing units for 20,000 people), workplace (20,000 jobs), and place of leisure. The idea emerged in 2005. Johannes Tovatt, Swedish architect, as a result of his close cooperation with specialists representing Vienna authorities and residents, created a conceptual design of *Seestadt Aspern*. In May 2007, the Vienna City Council unanimously accepted the concept of the new district. The plans were constantly developing. In 2010, they were completed with a more detailed public space study and design guidelines were published in the planning guide "Partitur des öffentlichen Raums" from Gehl Architects. All this was accompanied by foundations for research projects NACHaspern, such as the transport guide, the general energy concept, and the action plan for sustainable development of urban areas. Local residents participated in the development of the conceptual plan and have been involved in its development and implementation, e.g. in City Labs. The project is to be implemented in 2028 in three stages. The geographical heart of the new town is a 5-ha lake in a 9-ha park. All the public spaces – streets, squares and parks – will constitute 50% of the total surface of urban areas. Man and quality of life are the main priorities in this project.

The concept of a city within the city has been implemented in many housing estates in Vienna. The first of these was a housing estate built in the 1970s, catering for the needs of over 3,000 people, Alt-Erlaa[3] in the 23rd district of Vienna. The main architect of the project, Harry Glück, planned to create a self-sufficient estate embedded in greenery. The concept of overlapping one-family houses with gardens created a terraced structure with a particularly extensive social infrastructure. Another concept, commenced in 1992, is Donau City in the 22nd district of Vienna. Apart from office buildings, towers, a school, a church, nurseries, and

[3] An interesting film by Reinhard Seiss depicting life in a housing complex Alterlaa: *Häuser für Menschen – Humaner Wohnbau in Österreich.* Ein Film von Reinhard Seiss, Müry Salzmann, DVD, Wien 2013.

Fig. 1. Aspern Die Seestadt Wiens, 22 district, Vienna (Source: [19])

Fig. 2. Housing Estate Pilotengasse, 22 district, Vienna (Source: [20])

stores, numerous residential projects were completed on the basis of the masterplan by Adolf Krischanitz and Heinz Neumann. In the direct vicinity, there is a park housing estate, Neue Donau und Alte Donau. New districts in the southern part of the city have a similar character to the development area of Donau City to the north, including: Winerberg City with terraced houses and tall apartment buildings; Monte Laa erected on a platform above the motorway; Kbelwerk[4], where a new participation model was trialed. Furthermore, one of Europe's largest adaptation projects, Gasometer City, has been implemented here.

Since the mid 1980s, increasing attention has been paid to urban expansion into suburbs. In contrast to the large housing estates of the previous decades, this is more diversified in terms of architectural form (the result of one- and two-stage competitions) and it integrates different designers within one investment. Its goal was urban and social diversity. These requirements are satisfied by the majority of projects of experimental housing estates (Fig. 2) designed in such a way.

The main assumption of the Pilotengasse housing estate in the 23rd district of Vienna is to organise its space in compliance with a series of principles: their beginning and end; their curvature; their course perpendicular to the radii; their distribution into individual structures. Whereas the lengths of the lines constitute physical parts of buildings, spaces between them create a field of relations, and eventually specially designed edges. The range of distances for pedestrians opens up an important area of perception and experience amongst the growing and shrinking central garden space, which is limited by rows of houses. Distances, proximities and widths constitute the main theme of this housing estate. Terraced houses organise their surroundings as dense residential spaces in a cyclically rotating manner, and in doing so, they secure the constantly changing view of the façade.

Another example is Traviatagasse (Fig. 3) in the 23rd district of Vienna. Its characteristic urban rigidity and severe geometry applied in the layout of the buildings constitute a definite contrast to the shapelessness of the suburbs. A high degree of privacy of spaces in this housing estate is guaranteed by the diverse housing typology (houses with balconies, buildings with front yards, stepped buildings, and mixed housing forms) and by the introvert nature of the space between buildings.

The objective of the projects in the urban context was to continue the tradition of housing estates with low, dense development and a wide range of different housing units in the existing urban tissue. A good example in this respect is the Oresteig Housing Complex in the 21st district of Vienna and forms of community housing in Frauen Werk Stadt II (Fig. 4), which constitute a continuation of the thematic Frauen Werk Stadt I housing estate. Besides the context of women in the planning process, one of the most important objectives was to create favourable conditions for the development of neighbourly contacts and the support of senior citizens. An important element was to complete the development block in such a way that it was smoothly connected with the surrounding area so that the buildings could form frontages of streets and public spaces.

[4] Housing complexes Neue Donau, Wienerberg City and Gasometer City were described in Joanna Giecewicz's book *Konserwatywna awangarda. Wiedeńska polityka mieszkaniowa 1920–2005*. Professor Jacek Gyurkovich in his article *W poszukiwaniu miejskości – przestrzeń przyjazna* refers to the examples of the Kabelwerk and Monte Laa housing complexes.

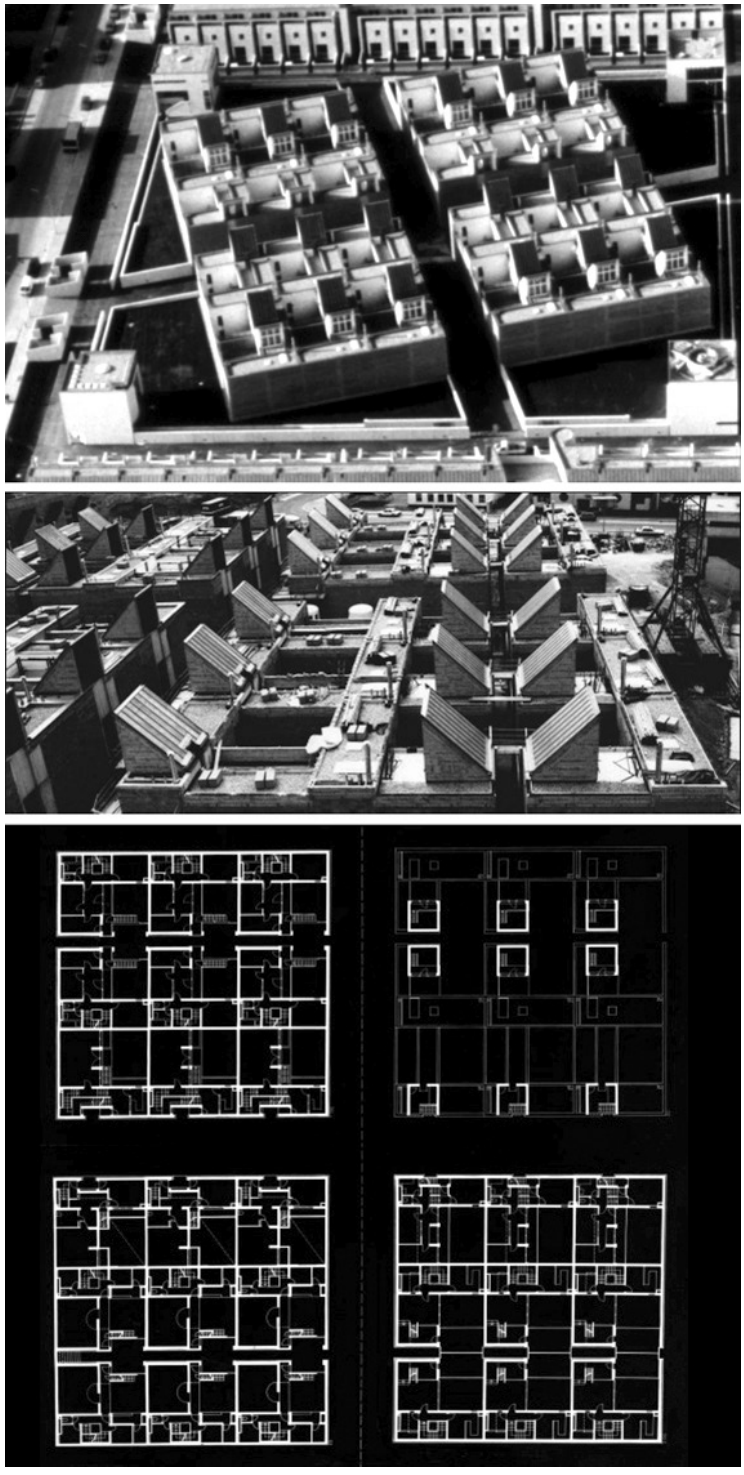

Fig. 3. The Traviatagasse housing estate, 23 district, Vienna (Source: [21])

Fig. 4. The Frauenwerkstatt II housing estate, 10 district, Vienna (Source: [22])

6. Conclusion

The diversity, functional differentiation, and integrated design of spaces in the city constitute the core of the future-oriented development of urban areas. Multifaceted quality of life in the city is comparable with the diversity of spatial structures and is closely connected with them. The interest in spatial conditions of the quality of life has been growing; thus, there is a need to heal the urban space and to introduce relevant tools for creating it. Owing to the significance of the spatial order as an inseparable element of sustainable development and quality of life, rationalisation of spatial processes becomes increasingly often perceived. Integrated spatial order can constitute another step towards integrating the tools of spatial planning, which will enable the implementation of integrated concepts in cities based on a coherent multifunctional structure and a high quality of life, and most of all, preventing costly suburbanisation.

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Ecotoxicological aspects of the use of parabens in the production of cosmetics

Ekotoksykologiczne aspekty zastosowania parabenów w produkcji kosmetyków

Abstract

Parabens are synthetic preservatives that are used on a large scale in the cosmetics, pharmaceutical and food industries. Their task is primarily to prolong the shelf life of selected products – cosmetics, medicines or food – by maintaining their microbiological purity. Parabens protect products against deterioration and microorganisms, extending their durability by up to several months without interfering with their composition and operation. Parabens do not change the aroma, taste, density or other characteristics of cosmetic or food products. However parabens, which occur in most cosmetics with a creamy or liquid formula (face creams, body lotions, foundation, tonics, lipsticks, deodorants, perfumes), are becoming increasingly worse because of the prolonged list of side effects that they may cause. The presence of intact paraben esters in human body tissues has now been confirmed by independent measurements in human urine, and the ability of parabens to penetrate human skin intact without breakdown by esterases and to be absorbed systemically has been demonstrated through not only ***in vitro*** studies but also in vivo investigation using healthy human subjects.

Keywords: parabenes, toxicity, transformation, occurrence in environment

Streszczenie

Parabeny są syntetycznymi konserwantami, które wykorzystuje się na szeroką skalę w przemyśle kosmetycznym, farmaceutycznym i spożywczym. Ich zadaniem jest przede wszystkim przedłużanie trwałości wybranych produktów – kosmetyków, leków czy artykułów spożywczych – poprzez utrzymywanie ich czystości mikrobiologicznej. Parabeny chronią produkty przed zepsuciem i drobnoustrojami, przedłużając ich trwałość nawet o kilkanaście miesięcy i nie ingerując przy tym w ich skład oraz działanie. Parabeny nie zmieniają zapachu, smaku, gęstości oraz innych cech produktów kosmetycznych lub spożywczych. Parabeny, które występują w większości kosmetyków o kremowej lub płynnej formule (kremy do twarzy, balsamy do ciała, podkłady, toniki, pomadki, dezodoranty, perfumy) cieszą się jednak coraz gorszą sławą ze względu na wydłużającą się listę skutków ubocznych, które mogą powodować. Obecność estrów parabenów w tkankach ludzkiego ciała została potwierdzona przez niezależne pomiary w ludzkim moczu, a zdolność parabenów do penetracji nienaruszonej ludzkiej skóry bez rozpadu przez esterazy i do wchłaniania ogólnoustrojowego wykazano w badaniach nie tylko ***in vitro,*** ale także ***in vivo*** u zdrowych ludzi.

Słowa kluczowe: parabeny, toksyczność, przemiany, występowanie w środowisku

1. Ancient cosmetics

From the beginning of time, men and women have strived to increase their attractiveness in the eyes of the opposite sex. Primitive peoples were already revealing tendencies to beautify bodies through various types of treatments and decorations. In as early as 10,000 BC Egyptians used fragranced oils and ointments to clean themselves, soften their skin and mask body odours. Essential oils were vital in their belief: that "cleanliness is next to godliness". Hygiene was very important for primitive peoples. Trends have changed considerably. Archaeological excavations performed in Sumerian areas (southern Mesopotamia) resulted in the first body dyes and lipsticks being excavated in caves from the Ice Age – their origin dates back to around 3000 BC [1]. It can be said therefore that cosmetics have existed from time immemorial, and the very origin of the word is closely related to embellishment. The term comes from the Greek word *cosmeo*, meaning to adorn. The adjective *cosmeticos* defines the art of beautifying. One of the first fields of cosmetology that developed in ancient times was the production of perfumes [2]. Their were made from fragrant resin known as myrrh, and from selected species of shrubs and trees mainly from sandalwood. For the same purpose, flower petals, aromatic plant leaves and animal substances such as musk and ambergris were also used. For cosmetics, commonly used plants, known for their medicinal properties, were myrtle, various flowers, herbs and fruits and garlic and onions. They were not only intended to promote health, but also to improve mood and appearance. The first civilisations usually arose in warm climates, in which it was easy to get sunburns. Thus, there was a great need for soothing balms and various moisturising agents that soothed the skin irritated and dried by the sun and desert sand. Cosmetics in Ancient Egypt were based on two basic ingredients [3]. These were pigments of vegetable or mineral origin and oils (from almonds and the fruits of moringa plants) or ointments based on animal fat. To obtain the cosmetic, the minerals were first ground to a powder, and then on pads specially designed for the purpose were mixed together to obtain a paste, which was applied to the face, eyes or mouth. The green pigment was obtained from a mineral called malachite (copper ore) and black – was obtained from galena (lead sulphide), pyrolusite (manganese oxide) or coal [4, 5]. The mixture of powdered galena, soot and copper ore was called kohl. From ocher (a kind of clay) a yellow to brown pigment was obtained [6]. In addition to minerals, the Egyptians also used dried leaves of the shrub known as "defenseless lawsonia" pigment obtained from this plant is also a henna that is popular today. A wide range of plant ingredients was used, oils were made from olives, moringa tree nuts, safflower or castor oil. Interestingly, in today's pharmacies products made from the same ingredients can be bought. Moringa oil is recommended in softening and moisturising the skin and hair. It is also often used in massages. Safflower is used in the production of soaps. Castor oil, on the other hand, has even more applications, among others, we use it in the care of the skin and hair like the ancient Egyptians.

Another example of a cosmetic used both in Ancient Egypt and today is alabaster powder which is made of sodium carbonate and so-called salt of the north mixed with honey [6]. Specific components of alabaster powder are supposed to firm the muscles, and they also find application in masks that purify and reduce imperfections, as well as in treatments for

firming around the neckline. The composition of today's creams also contains honey and milk to rejuvenate and nourish the skin. Bathing in goat milk was famoously initiated by Cleopatra VII herself [6]. In fact goat milk contains alpha hydrocarbons which smooth and elasticise the skin. We can encounter these compounds in today's creams. The Egyptians also used marigolds in creams, which they considered a rejuvenating herb. This belief is not without truth, because the extract of this plant has astringent properties – it smooths the surface of the epidermis and additionally has a bactericidal effect.

Ancient Egyptian cosmetics in some respects tower over contemporary products. The Egyptians used natural ingredients: – such as minerals, herbs and other plants [7]. For example, the base for the creation of perfumes was not alcohol, but fats: oils and resins. As a result of this, the perfumes of that time were characterised by a strong and long-lasting fragrance. By contrast, today's popular perfumes leave the scent of alcohol at first, after which the proper smell is released, but it is short-lived. The contemporary cosmetics industry, based on recipes of the ancient world, adds many other ingredients. Unfortunately, these additives can cause harmful effects. The health-adverse chemical compounds found in current cosmetics include phthalates, sodium lauryl sulfate and, in particular, parabens (parahydroxybensoates). The latter are by-products of crude oil and can be found in almost all cosmetics. They are designed to extend the shelf life of the product.

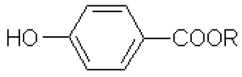
2. General characteristics of parabens

Cosmetics typicallyconsist of substances that are an excellent medium for micro-organisms (bacteria and fungi), e.g. amino acids, peptides, protein hydrolysates, polysaccharides, plant extracts and vitamins. Cosmetics that have not been protected by a preservative quickly spoil, resulting in a change in the aroma and appearance of the product [8]. To prolong the durability of cosmetics and prevent the development of microorganisms, antimicrobial ingredients are added during production. Preservatives can be divided into those that inhibit the growth and development of microorganisms (fungistatic and bacteriostatic) and compounds that kill living microorganisms, through cell damage (bactericidal and fungicidal preservatives) [9]. Old and commonly used preservatives are derivatives of benzoic acid. Of particular importance in cosmetics are esters of parahydroxybenzoic acid (PHB), or 4-hydroxybenzoic acid, commonly referred to as parabens. Parabens primarily act fungistatically, that is, they stop the growth of fungi (mold), and to a lesser extent they affect bacteria. Apart from the paraben (e.g. methyl paraben), there is also another preservative that inhibits the growth of bacteria, e.g. phenoxyethanol [10]. The group of PHB preservatives also includes compounds with the names parasept, nipagin and aseptin [11]. The concentration of parabens in cosmetics ranges from 0.3 to 0.5% (in the EU to 0.4%). They are poor solubility in water with the lowest being benzyl para-hydroxybenzoate and methyl parahydroxybenzoate the highest of these esters. Parabens, although they are similar in structure to salicylic acid (2-hydroxybenzoic acid) and benzoic acid, have different toxicological and chemical properties.

The presence of parabens in cosmetics is a very controversial topic today. Although they have been thoroughly tested over the recent decades, and their use in production is fully legal, many people have mixed feelings about the impact of these compounds on the body. In 2007, parabens were included in the list of compounds that have a negative impact on the endocrine system. Some specialists also warn that they may cause allergic reactions. However some parabens also occur in nature; an example is methyl paraben which is present in blueberries. Many doctors and pharmacists also claim that the current acceptable dose of parabens in cosmetics is too low to harm anyone [12]. Parabens are a kind of ester and their main purpose is preservation. They fight the yeasts and bacteria that can develop in the cosmetic over time. Consequently – the parabens significantly extend the shelf life date of a given cream or mask. The durability of the cosmetic, and thus the selection of the right preservative is the most important element of cosmetic safety. Without preservatives, all water – based cosmetics would have a very short shelf life and in most cases would have to be stored in the refrigerator. Cosmetics must contain at least a small amount of preservative substance, because water is their main ingredient, and this is an ideal environment for the development of all kinds of microorganisms [13].

Parabens, i.e. esters of p-hydroxybenzoic acid and their analogues, are preservatives that have been used for several decades and are the most commonly used preservatives in cosmetic products. They are widely used not only in the cosmetics industry but also in the pharmaceutical and food industries. Additionally they are used in products intended for children's care and in cosmetics referred to as hypoallergenic. They are active antifungal and antibacterial; however, they are more active against Gram-positive than Gram-negative bacteria [14, 15]. In addition to their antimicrobial properties, they are also used in soaps as anti-perspiration agents and in shampoos as anti-dandruff substances. They are capable of percutaneous penetration. With regard to their penatrative ability, the parabens can be arranged in the following way: butylparaben> propylparaben> ethylparaben> methylparaben. There is a small risk of parabens accumulating in fatty tissues [16]. On the one hand, parabens protect cosmetics against microbial infections, on the other, – they are accused of causing disease. They are one of the most sensitising contact substances, although they are considered to be very weak allergens. Allergic reactions usually have a mild course, – they cause pruritus and erythema, but may also lead to the development of atopic dermatitis. Parabens have been shown to belong to a group of compounds with extremely low oestrogenic activity. Their potency is 1,000–1,000,000 times less than that of natural oestrogen. According to the Scientific Committee on Consumer Safety (SCCS) report [17], parabens used in acceptable concentrations are completely safe and have no toxic, carcinogenic, genotoxic or teratogenic effects. However, increasingly frequently voices are heard that they cause irritations and skin allergies, cancers and can even reduce fertility in men. It should be noted that in the EU Commission Regulation of 18 September 2014 [18], propylparaben and butylparaben and their isomers and salts have been banned in products for children under 3 years of age because of their potential effect on the endocrine system. Furthermore their concentration has been limited to 0.14% of the substance used alone or in a mixture. Similarly, in the EU Commission Regulation of 9 April 2013, due to the lack of studies confirming the safety of

the use of isoparabens (isopropylparaben, isobutylparaben, pentylparaben, benzylparaben, phenylparaben), they have been banned in cosmetics. Parabens are solid bodies that resemble fine, odourless crystals. There are different groups of parabens:



R:		
	CH_3	Methyl para-hydroxybenzoate
	C_2H_5	Ethyl para-hydroxybenzoate
	C_3H_7	Propyl para-hydroxybenzoate
	$CH(CH_3)_2$	Isopropyl para-hydroxybenzoate
	C_4H_9	Butyl para-hydroxybenzoate

Fig. 1. Different groups of parabens

The following parabens are used in cosmetics: methylparaben, ethylparaben, propylparaben, isopropylparaben, butylparaben, isobutylparaben, potassium methylparaben, potassium ethylparaben, potassium propylparaben, potassium butylparaben, sodium methylparaben, sodium ethylparaben, sodium propylparaben, sodium isopropylparaben, sodium butylparaben and sodium isobutylparaben [19].

Parabens are compounds that have no taste, smell or color. They do not change the characteristics of cosmetics or food, a result of which colour, aroma and density remain in their original form. The general characteristics of the parabens are shown in Table 1. Parabens differ from each other by the type of alkyl group, and hence their solubility in water and antimicrobial activity [20]. They are chemically stable lipophilic compounds, depending on the chain length their solubility in water is either weak or very weak (Table 2). Due to the fact that these preservatives are active only in the aqueous phase, it is necessary to add solubilising aids, such as propylene glycol, glycerol or ethanol. They exhibit antimicrobial activity over a wide pH range of 4–8. The antimicrobial activity of parabens can be reduced in the presence of some surfactants by the formation of hydrogen bonds or the incorporation of molecules into micelles. Parabens used on an industrial scale are usually synthetic compounds, however many of them, especially methylparaben and propylparaben, occur naturally in many commercial plants [21].

Table 1. Physicochemical Properties of Parabens*

Property	Methyl	Ethyl	Propyl	Butyl
1	2	3	4	5
Molecular weight	152.16	166.18	180.21	194.23
Melting point (T)	131 125–128	116–18 115–118	96.2–98 95–98	8–69 68–72
Boiling point (°C)	270–280	297–298	–	–

Table 1 (cont.)

1	2	3	4	5
Density	–	–	1.0630	–
Refractive index	1.5250	1.5050	1.5050	–
*max"' in H_20	–	256 ($1.5 \times 1O^{-2}$)	256 (1.5×10^{-2})	256 (1.55×10^{-2})
PKa	8.17	8.22	8.35	8.37
Inorganic impurities**				
As	1 ppm	–	1 ppm	1 ppm
Pb	10 ppm	–	10 ppm	10 ppm
Ash	0.1%	0.1%	0.1%	0.1%
Residue on ignition* (%)	0.05	0.05	0.05	0.05
Loss on drying* (%)	0.5	0.5	0.5	0.5
Acidity* (mEq/750 mg)	0.02	0.02	0.02	0.02
Solubility				
Alcohol	vs	vs	s	s
Water	sl	sl	i	i
Ether	vs	vs	s	s
Acetone	vs	s	s	s
Benzene	sl	–	–	–
Carbon tetrachloride	sl	–	–	–
Glycerin	sl	sl	–	sl

**Maximum recommended; no information available on organic impurities.
vs = very soluble; s = soluble; sl = slightly soluble; i = insoluble.
*[106]

Table 2. Parabenes have limited solubility in H_2O

Property	Methylparaben sol. g/100 mg	Ethylparaben sol. g/100 mg	Propylparaben sol. g/100 mg	Butylparaben sol. g/100 mg
Water 18°C	0.16	0.08	0.023	0.005
Water 25°C	0.25	0.11	0.04	0.015
Water 80°C	3.2	0.86	0.45	0.15
Ethanol	22	25	26	110
Propylene, Glycol	1.7	0.5	0.4	0.3
Peanut Oil	0.5	1	1.4	5
Mineral Oil	0.01	0.025	0.03	0.1

In the cosmetics industry, parabens are used as kinds of preservative in products that are exposed to decay and are easily accessible to bacteria, as well as in products that should last for a long time after opening. These include:

- creams,
- lotions,
- oils,
- tonics,
- glosses,
- lipsticks,
- other wet cosmetics,
- powders and foundations and other cosmetics that are used for a long time,
- antiperspirants and perfumes.

As a result of the addition of parabens, the usefulness of products is extended by up to several months, – the products do not become covered with mould and are protected against other fungi and bacteria that are dangerous to health [22].

3. The mechanism of the action of parabens on microorganisms

The mechanism of the antibacterial action of parabens has not been fully explained. They are suspected to be inhibitors of the synthesis of DNA and RNA nucleic acids or to inhibit the enzymes necessary for the proper functioning of bacterial cells [23]. Parabens can also act by interfering with membrane transport processes. In addition, they can inhibit the influx of amino acids, such as alanine, serine, and phenylalanine, into the vesicles of bacterial cell membranes without altering glucose transport. It is also likely that they have antibacterial effects consisting in the denaturation of bacterial proteins, which increase in the acidic environment. All phenol derivatives work analogously [24, 25]. The mechanism of action of parabens is therefore multidirectional, and the minimum doses that inhibit the growth of selected microorganisms are presented in Tables 3–5.

Table 3. Minimum Inhibitory Concentration of Parabens (%)**

Microorganism		MIC			
		MP*	EP*	PP*	BP*
Molds	*Aspergillus niger* ATCC 10254	0.1	0.04	0.02	0.02
	Penicillium digitatum ATCC 10030	0.05	0.025	0.0063	0.0032
Yeasts	*Candida albicans* ATCC 10331	0.1	0.1	0.0125	0.0125
	Saccharomyces cerevisiae ATCC 9763	0.1	0.05	0.0125	0.0063
Bacteria	*Bacillus subtilis* ATCC 6633	0.2	0.1	0.025	0.0125
	Bacillus cereus var. mycoides ATCC 6462	0.2	0.1	0.0125	0.0063

*MP: Methylparaben, *EP: Ethylparaben, *PP: Propylparaben, *BP: Butylparaben, ** [105]

Table 4. Antimicrobial Effectiveness of Parabens [106]

Microorganisms species	Effective Concentration (% by Weight)			
	Methylparaben	Ethylparaben	Propylparaben	Butylparaben
Fungi				
Rhizopus nigricans	0.05	0.025–0.05	0.0125	0.0063
Trichoderma lignorum	0.025	0.0125	0.0125	0.0063
Chaetonium globosum	0.05	0.025	0.0063	0.0031
Candida albicans	0.1	0.1	0.0125–0.1	0.0125–0.1
Saccharomyces cerevisiae	0.1–0.23	0.05–0.1	0.01–0.0125	0.0063
S. pastorianus	0.1	0.05	0.0125	0.0063
Aspergillus flavus	0.04–0.125	0.03	0.06	0.02
A. niger	0.08–0.27	0.04–0.06	0.02–0.07	0.02
Penicillium digitatum	0.05	0.025	0.0063	0.0031
P. chrysoqenum	0.01	–	–	–
P. glaucum	0.04–0.1	0.03–0.15	0.15	0.02–0.15
P. expansum	–	–	–	0.02
Mucor mucedo	0.04–0.15	0.03–0.04	0.05–0.1	0.02
Torula *sp.*	0.125–0.15	0.025–0.1	0.05–0.1	–
Epidermophyton floccosum	0.025–0.1	–	0.01	0.01
Microsporum audovini	0.01–0.1	–	0.01	0.01
Trichophyton ferrugineum	0.025–0.1	–	0.01	0.01
T. mentagrophytes	>0.006	0.008	0.004	0.002
Hormodendrum compactum	0.025–0.1	–	0.01	0.01
Phialophora verrucosa	0.025	–	0.1	0.1
Geotrichum *sp.*	0.055	–	–	–
Monosporum apiospermum	0.1	–	0.1	0.01
Sporotrichum schenckii	0.05	–	0.01	0.01
Blastomyces dermatitidis	0.01–0.1	–	0.01–0.1	0.01
Cryptococcus neoformans	0.05–0.1	–	0.01	0.01
Haplosporangium parvum	0.025	–	–	–
Histoplasma capsufatum	0.1–0.025	–	0.01	0.01
Trichosporon beigelii	0.1	–	0.01	0.01
Piedraia hortai	0.1	–	0.01	0.01
Other fungi	–	0.1–0.025	–	–

Table 5. Antimicrobial Effectiveness of Parabens [106]

Microorganisms species	Effective Concentration (% by Weight)			
	Methylparaben	Ethylparaben	Propylparaben	Butylparaben
Bacteria				
Bacillus subtifis	0.12–0.25	0.1–0.2	0.025–0.2	0.0125
B. cereus	0.2	0.1	0.125	0.0063
B. coli	0.125–0.15	–	0.05–0.1	0.02
B. coagulans	0.15–0.35	–	0.05–0.07	–
B. megaterium	0.14	0.06	0.03	0.01
Staphylococcus aureus	0.16–0.4	0.065–0.15	0.04–0.15	0.0125–0.02
S. pyogenes	0.063	0.063	0.05	–
Sarcina lutea	0.25–0.4	0.25–0.1	0.25–0.05	0.0125
Klebsiella pneumoniae	0.1	0.05	0.025	0.0125
Escherichia coli	0.125–0.4	0.1–0.125	0.05–0.1	0.4
Salmonella typhosa	0.2	0.1	0.1	0.1
S. schottmulleri	0.2	0.1	0.05	0.1
S. typhimurium	–	–	0.02–0.025	–
Proteus vulgaris	0.2	0.1–0.15	0.05–0.15	0.05
Aerobacter aerogenes	0.125–0.24	0.1	0.05–0.1	0.4
Pseudomonas aeruginosa	0.1–0.4	0.2–0.4	0.2–0.8	0.8
P. fluorescens	0.15–0.4	0.2	0.05–0.2	0.4
Streptococcus hemolyticus	0.01	–	0.1	0.1
S. faecalis	–	0.13	0.04	0.012
Serratia marcescens	0.08	0.049	0.04	0.019
Achromobacter sp.	0.23–0.24	–	0.05–0.07	–
Arthrobacter simplex	0.36–0.38	–	0.07–0.09	–
Clostridium botulinurn	0.1–0.12	0.04	0.04	0.02
Corynebacterium acnes	–	–	1.0	–
Nocardia asteroides	0.025–0.1	–	0.1	0.01

4. Controversy about the use of parabens

If we consider that parabens are very well tested and penetrate the skin to a small extent, there is a growing number of people – experts from the medical community, members of ecological and pro-consumer organizations – who question the safety of these substances [26–28]. It is postulated that the most common parabens present in cosmetics are associated with the following issues:

- They cause skin irritations and allergies – parabens damage the bacterial flora, theymay affect the water management of the epidermis and contribute to the weakening of the lipid layer. Skin devoid of its natural protection, which protects it from the weather, is susceptible to severe allergic reactions. This is why it is sometimes said to be allergic to parabens. In addition, parabens can also cause redness, pruritus and urticaria. The more cosmetics with parabens you use, the greater the likelihood of skin problems. In particular, individuals who have delicate and sensitive skin prone to irritation should pay attention to this issue [29, 30].
- Producers of cosmetics, aware of the influence of parabens on skin condition, are using increasingly small amounts of these preservatives.
- They affect the functioning of the hormones – one theory states that parabens influence sex hormones and consequently reduce fertility in men.
- They can have carcinogenic effects. The paraben that has the strongest effect is butylparaben, it is blamed for triggering breast cancer.
- They should not be used by pregnant women – they may have a negative effect on foetal development [31, 32].

The use of parabens is constantly criticised by consumer protection organisations, the media and manufacturers of natural cosmetics. However, evidence has been put forward that all these fears are unfounded. The European Commission and its scientific advisory committees [33]. as well as the independent American evaluation committee, Cosmetic Ingredient Review (CIR) [34], have repeatedly confirmed that parabens do not pose a threat to health. According to these studies, all parabens absorbed by our bodies undergo rapid decomposition. Parabens are generally well tolerated. Like all substances, they can cause sensitisation in individual cases, but this happens less often than with other preservatives. According to the European Commission and the Polish Union of the Cosmetics Industry [35]: parabens used in cosmetics are safe. Similarly, the US Food and Drug Safety Agency (FDA) [36], has included methylparaben and propylparaben on the GRAS list (Generally Recognized as Safe) – i.e. as substances found safe for use in food [33].

When it comes to carcinogenic activity of PHB esters, the matter is controversial. It is known that parabens are lipophilic components (they have an affinity for fat), so they freely penetrate subcutaneous fat, including breasts, and can accumulate there [37]. There are test results confirming the accumulation of parabens in the mammary gland. To clarity, this is not a discovery, because it is hardly surprising. It is obvious that when we rub the lipophilic compounds into the skin every day, they will eventually penetrate the skin into the subcutaneous layer.

One of the most vocal acaedemics on the issue of the carcinogenic activity of PHB ester is Philippa Darbre [38], a senior lecturer in oncology and a researcher in biomolecular sciences at the University of Reading, in England. She specialises in the impact of oestrogen on breast cancer. In 2004, Darbre's team published a pivotal study that detected parabens in 18 out of 20 breast cancer biopsies. Her study did not prove parabens cause cancer, only that they were easily detected among cancerous cells. The study was criticised on the basis of paraben levels in normal tissue [39, 40].

The effect of parabens on oestrogen receptors exists. It is notpossible to discuss whether it is strong or weak, but it does occur and it is another factor used by a man who works oestrogens. In 2011, the Scientific Committee on Consumer Safety (SCCS) – an advisory body of the European Commission [33] to the safety of cosmetic ingredients – stated that methyl paraben and ethyl paraben are safe at the current maximum concentration of 0.4%, while for butyl paraben and propylparaben the maximum safe concentration should be reduced to 0.19%. With regard to the safety of the other parabens, the committee did not respond without having enough toxicological data. In May 2013, the SCCS re-examined the safety of butylparaben and propylparaben in cosmetics, in which it maintained its current position. The threat posed by parabens results from their enormous popularity. They are used in a wide range of cosmetics and personal hygiene products, which translates into a greater overall exposure to their potentially negative effects. According to FDA (Food and Drug Administration) data [36], the average daily exposure to parabens for a man weighing 60 kg is 76 mg, of which 50 mg comes from cosmetics. American data also indicates that women are more exposed to parabens than men.

Due to the prevelance of parabens and the fact that many sources constitute the average total exposure, the use of one cosmetic is not a serious threat from parabens. However, given that the amount of cosmetics used is often much higher, the potential side effect of parabens should be considered. The SCCS also draws attention to the use of parabens in cosmetics for infant skin care [33]. In the opinion of the SCCS in 2011, the use of parabens in cosmetics for children under 6 months of age is safe, with the exception of "under-nappy" cosmetics [41, 42]. This is associated with a greater risk of penetration of cosmetics ingredients, including parabens, through irritated or damaged skin in this area, as well as immature metabolism of newborns. An important aspect in favour of parabens is their poor penetration of the epidermal barrier – around 4–6%. At the same time, the parabens do not accumulate in the tissues. After crossing the epidermal barrier and entering the vascular bed, they are metabolised to p-hydroxybenzoic acid, which does not show oestrogenic effects.

Of course, scientific data that confirms parabens oestrogenic action cannot be ignored, on the other hand, it seems that parabens have also become the subject of negative PR. Evidence of the oestrogen action of parabens – for example, reduced male fertility. In addition, it should be noted that it is difficult to determine a specific alternative to parabens. Other preservatives, e.g. sorbic acid, essential oils, aldehyde have a number of limitations, such as, weak fungistatic activity, unacceptable odour, too high pH. In summary, parabens – according to the current state of knowledge – are effective and relatively safe preservatives and if used in accordance with the SCCS guidelines [35], do not pose a risk to their users. At the same time, the debate on them is not closed and perhaps further scientific data would lead to a possible review of opinions regarding the safety of parabens.

5. The fate of parabens in the environment

In the last few years, cosmetics, as well as pharmaceuticals and many other products for personal care that do not fall within cosmetic regulation (disinfectants, insect repellents, dietary supplements), have raised significant concerns as one of the most important classes of emerging pollutants. This is as a result of them being continually released into the aquatic environment; their ecological and environmental impact is associated with large amounts being used and with the fact that sometimes they are environmentally persistent, bioactive, and potentially able to bioaccumulate [43–45].

Parabens have been fund in urban streams [46, 47] into which treated or untreated effluent from wasewater treatment plants flows. Consequently, these chemical compounds have been identified in rivers and drinking water sources. Parabens have been detected in soil from agricultural fields, possibly from irrigation or fertilisation practices [48]. Hause dust has also been found to contain parabens. Although commercially used parabens are of synthetic origin, some – parabens are produced by living organisms, especialty by plants and microbes, e.g., a marine bacterial strain belonging to the genus *Microbulibifer.* Plants such as blueberries, carrots, olives, strawberries and others produce parabens (mainly methylparaben) for its presumed antimicrobial activity. Overall, the concentration of parabenes within the environment are low with water concentrations of around 7 ng/L and effluent concentrations of up to 6 µg/L, soils concentration range from 0.5 to 8 ng/g while house dust contains up to 2,400 ng/g [49, 50].

Sewage treatment plants are not always effective in removing chemicals used as cosmetic ingredients, as shown, for example, with synthetic musks , perfluoroalkyls compounds, some organic UV-filters and microplastics. Another issue of concern is that some of these products can accumulate in sewage sludge [51]. Turning wastewater treatment and exist then in the environment because of the common practice of using sludge as a fertilizer on crops [52]. Cosmetics pose the most pressing ecological problems compared to pharmaceuticals because they are used in much larger quantities and throughout the course of life and being intended for external application, are not subjected to metabolic transformation; therefore they are introduced unaltered into the environment in large amounts during washing, showering and bathing [53]. Since relatively little is known about the fate and the toxicity of personal care products released into the environment, increasing attention is being placed on their occurrence, persistence, and potential threat to ecosystems and human health.

In 1996 the first analytical results of the occurrence of parabens in water were published. With parabens being considered as emerging contaminants, it is useful to review the knowledge acquired over the last decade regarding their occurrence, fate and behaviour in aquatic environments. Despite treatments that eliminate parabens relatively efficiently from wastewater, they are always present at low concentration levels in effluents of wastewater treatment plants. Although they are biodegradable, they are ubiquitous in surface water and sediments, due to the consumption of paraben-based products and their continuous introduction into the environment. Methylparaben and propylparaben predominate, reflecting the composition of paraben mixtures in common consumer products. As compounds

containing phenolic hydroxyl groups, parabens can react readily with free chlorine, yielding halogenated by-products. Chlorinated parabens have been detected in wastewater, swimming pools and rivers, but not yet in drinking water [54]. These chlorinated by-products are more stable and persistent than the parent compounds and further studies are needed to improve knowledge regarding their toxicity.

Based on available use data, parabens are expected to be found in a range of household and commercial products available for use in Australia. Chemicals used in cosmetics and cleaning products are typically released in to sewers as a normal part of their use in domestic and industrial applications. Studies on the fate of parabens have indicated that their removal from influent is above 90% [20], with degradation and adsorption to sludge being major mechanisms of removal. Parabens may be released to the environment in treated effluent, while those removed by adsorption to sludge may be applied to land as biosolids. Thus, emissions of parabens to both environmental surface waters and soils are considered as part of this assessment.

6. Transformation of parabens

A biodegradation study conducted with river water as the inoculant found that benzylparaben had a half-life of 10–19 hours depending on temperature and origin of the river water inoculant [55]. In addition, biodegradation calculations for benzylparaben gave an ultimate biodegradation half-life of 14.1 days.

No biodegradation data was identified for the parabens with alkyl chain lengths of 7–12 carbons (long-chain parabens; heptyl-, octyl-, isooctyl- and lauryl-paraben). Calculated biodegradation rates for the long-chain parabens gave ultimate biodegradation half-lives of 9.5–10.4 days for the linear parabens and 20.1 days for the branched isooctylparaben.

Abiotic processes may also represent significant degradation pathways for the chemicals in this group. Yamamoto [56, 57] reported a photolysis half-life of less than one day for benzylparaben in water under natural light, with photolysis half-lives for butylparaben and isobutylparaben ranging from 14.6 to 24.2 days.

Parabens are stable in acidic conditions, but can undergo hydrolysis above pH 7. The methylparaben hydrolysis half-life at pH 8 is calculated to be 1260 days, and increases with longer ester alkyl chains. Therefore, abiotic hydrolysis is not expected to be a significant degradation pathway for parabens. Biotic or abiotic hydrolysis of the ester bond produces *p*HBA as a degradation product common to all parabens [58]. *p*HBA is a chemical that has been assessed at Tier I level under the IMAP framework and found to be of low concern to the environment [59, 60, 61].

A general scheme for the transformation of parabens in an ecological system is shown in Fig. 2.

Parabens readily undergo halogenation on the aromatic ring carbons *ortho* to the hydroxyl group to form several mono- and di-halogenated compounds [62]. These chemical derivatives can be formed in chlorinated waters such as drinking water, and during chlorine treatment in

STPs. They show slower biodegradation than the parent compounds; in a biodegradation study according to ISO 7827 using activated sludge as the inoculant, dichloromethylparaben (3,5-dichloro-4-hydroxybenzoic acid methyl ester, CAS RN 3337-59-5) had a half-life of 8.7 days, compared to 1.8 days for the parent chemical methylparaben [63, 64, 65]. In this study, 99% primary degradation of dichloromethylparaben was achieved after 16 days.

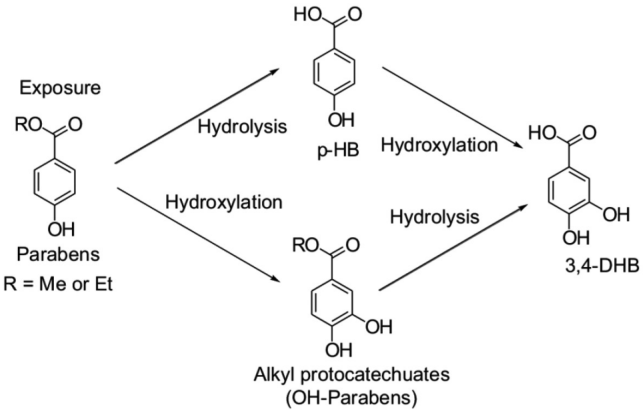


Fig. 2. Metabolic transformation of parabens in biological systems. DHB, 3,4-dihydroxybenzoic acid (source: [107])

7. Bioaccumulation

The short-chain parabens in this group and benzylparaben are not expected to bioaccumulate, while the long-chain parabens in this group have the potential to bioaccumulate [66].

Low octanol-water partition coefficient (K_{OW}) values for the short-chain parabens and benzylparaben do not exceed the domestic categorisation threshold for bioaccumulation hazards in aquatic organisms (log $K_{OW} \leq 4.2$). This indicates that there is a limited bioaccumulation potential for these chemicals .

There is evidence for the rapid metabolism of short-chain parabens in fish; a 10-day feeding study showed that less than 1% of the total ingested propylparaben was found in rainbow trout liver and muscle tissue after doses of 1830 mg kg^{-1} every second day [67]. Half-lives of 8.6 hours in liver and 1.5 hours in muscle tissue were derived. A similar study showed that less than 1% of the total butylparaben ingested at 51 mg kg^{-1} every second day over 12 days remained in rainbow trout liver tissue at the end of the experiment [68].

The long-chain parabens have measured or calculated K_{OW} values which exceed the domestic categorisation threshold for bioaccumulation hazards in aquatic organisms (log $K_{OW} > 4.2$). High octanol-water partition coefficients can indicate a high bioaccumulation potential, as the chemical may preferentially partition to lipid-rich tissues. This potential may be reduced by possible metabolism in biota, as seen for propyl- and butyl-paraben. Bioconcentration modelling for these compounds incorporating estimated rates of biotransformation in fish gave BCF values of 76 – 1,598 L/kg for heptyl-, octyl- and isooctyl-paraben, and 2,148 L/kg for laurylparaben .

A series of studies of parabens and their metabolites in biota found methylparaben and *p*HBA at high concentrations in many marine organisms [69, 70, 71]. A trophic magnification factor of 1.83 was calculated for methylparaben in one food web. It was noted that methylparaben could be formed from *p*HBA through biotransformation by gut microflora. The trophic magnification of methylparaben would, therefore, be partially reliant on the availability of a high concentration of *p*HBA, which can arise from ester hydrolysis of any paraben, or from natural sources. The highest methylparaben concentration was found in the liver of a bottlenose dolphin, at 865 ng/g wet weight.

8. Predicted environmental concentration (PEC)

In the absence of comprehensive reported Australian environmental monitoring data, standard exposure modelling for the release of chemicals to surface waters in STP effluents was used to calculate riverine environmental concentrations, assuming annual introduction volumes of 100 tones [59]. The calculated riverine PECs from this analysis are 7.88 micrograms per litre (µg/L) for methyl- and ethylparaben, 7.27 µg/L for propylparaben, 6.66 µg/L for butyl- and benzylparaben, and 4.85 µg/L for heptyl-, octyl- and isooctylparaben.

These calculated values are reasonably consistent with available domestic monitoring data for short-chain parabens. A study focusing on the concentrations of the short-chain parabens in urban water and storm water drainage systems in the Sydney metropolitan area took seventy-two water samples from a variety of sources across different land use areas [72]. Methylparaben was detected at an average concentration of 5.41 µg/L and a highest observed concentration of 13.78 µg/L. Ethylparaben was detected at an average and highest concentration of 13.86 and 305.55 µg/L respectively – propylparaben at an average and highest concentration of 2.97 and 8.29 µg/L respectively – butylparaben at an average and highest concentration of 4.36 and 8.47 µg/L respectively. The study also sampled STP effluent, finding the highest concentrations of methyl-, ethyl-, propyl- and butyl-paraben to be 12.28, 4.95, 3.15 and 4.82 µg/L, respectively.

The highest observed concentration of each paraben were from diverse water sources, covering both river water and storm water samples from both industrial and residential land use areas. The sample containing ethylparaben at 305.55 µg/L was taken from the Duck River, downstream from an industrial area which includes a waste transfer station [73].

Based on this domestic monitoring data, and for the purposes of this assessment, the PECs for methyl-, ethyl-, propyl- and butyl-paraben are determined to be 13.78, 305.55, 8.29 and 8.47 µg/L, respectively.

It is noted that these measured concentrations for parabens are somewhat higher than results from international monitoring studies [72]. Methyl- and propylparaben are the most commonly detected parabens, and occurat higher concentrations than other parabens due to their combined use in cosmetics [74]. In effluent from a Spanish STP, methyl- and propylparaben were found at maximum concentrations of 50 and 21 ng/L respectively, with lower maximum concentrations of ethyl- and butylparaben [64]. Two studies on parabens

in Japanese rivers found methyl- and propylparaben at maximum concentrations of 525 and 181 ng/L respectively [14], and at 676 and 207 ng/L respectively [75]. These maximum concentrations are all significantly lower than the mean values of parabens measured in Sydney surface waters and Sydney STP effluent [72].

Long-chain parabens are very rarely detected in international monitoring studies, and at much lower concentrations than short-chain parabens. Heptyl- and octylparaben were detected in urban surface water samples in Beijing at maximum concentrations of 2.94 and 4.89 ng/L respectively [76]. In the same study, methylparaben was detected at a maximum concentration of 920 ng/L. Heptyl- and benzylparaben were found in influent waters of a STP in the Albany area in New York at maximum concentrations of 0.31 and 0.27 ng/L respectively [77], indicating low emissions to waste waters. Benzylparaben was found at a maximum concentration of 3.93 ng/L in urban surface waters in Beijing, and two further studies concluded that benzylparaben was present below the limit of detection in STP effluent samples [64, 78, 79].

It would not be appropriate to predict the Australian environmental concentrations of heptyl-, octyl- or benzylparaben based on this international monitoring data, given the disparity between the measured domestic and international concentrations of the short--chain parabens. Therefore, the PECs for heptyl-, octyl- and isooctylparaben are taken to be 4.85 µg/L, and 6.66 µg/L for benzylparaben, based on calculations using the default introduction volume and the SimpleTreat model.

Chlorinated transformation products of parabens have been detected in wastewater treatment plant waters. At an STP in Beijing, 3,5-dichloromethylparaben and 3,5-dichloroethylparaben (3,5-dichloro-4-hydroxy benzoic acid ethyl ester, CAS RN 17302-82-8) were detected in effluent water after secondary treatment at mean concentrations of 13.6 and 19.8 ng/L respectively. These concentrations were higher than the effluent concentrations of their respective non-chlorinated parent parabens [77, 78]. In a second study, the average total chlorinated paraben concentration in river water was found to be 50.1 ng/L, while the average total paraben concentration was 44.3 ng/L [79, 80]. One study investigated chlorinated parabens in river water in Shizuoka City, Japan, as combined concentrations from suspended solid and dissolved phases [81]. Dichloromethylparaben was found in one sample at 6.1 ng/L, while dichloropropylparaben (3,5-dichloro-4-hydroxy benzoic acid propyl ester, CAS RN 101003-80-9) was found at up to 28 ng/L.

9. Effects on Aquatic Life

The chemicals in this group range from slightly to highly toxic in aquatic organisms [82, 83]. The measured median lethal concentration (LC50) and median effective concentration (EC50), as well as the no observed effect concentration (NOEC) and the lowest observed effect concentration (LOEC) values for model organisms across three trophic levels for methylparaben (MeP), ethylparaben (EtP), propylparaben (PrP), butylparaben (BuP), benzylparaben (BzP), heptylparaben (HeP), and octylparaben (OcP) have been reported [75, 84, 85].

Calculated data for long-chain parabens indicates higher levels of toxicity than for short-chain parabens. This trend is consistent with previous studies, which demonstrated that the toxicity of parabens is proportional to their lipophilicity [75]. This indicates that the acute toxicity of parabens is likely to occur through the non-specific disruption of the cell membrane function [86]. Calculated and measured toxicity values for the short-chain parabens were fairly consistent – therefore the calculated ecotoxicity endpoints for the long-chain parabens appears to be reliable. Reliable values for acute ecotoxicity endpoints for laurylparaben cannot be calculated.

Data for the branched isomers in this group have not been presented. However, acute ecotoxicity endpoint values for isopropylparaben and isobutylparaben have been published [55, 56, 75, 84]. The calculated acute ecotoxicity values of octyl- and isooctylparaben are very similar. These values indicate that the acute toxicity of the branched isomers is expected to be similar to or less than that of straight chain isomers:

A study investigated the comparative acute invertebrate toxicities of parabens and their chlorinated transformation products according to OECD TG 202 [87]. The dichlorinated transformation products of methyl-, ethyl- and propylparaben all showed increased acute toxicity compared to their parent parabens.

Chlorination increases the acute toxicity of the parabens with comparative EC50 values of 62 mg/L for methylparaben and 16 mg/L for dichloromethylparaben, 32 mg/L for ethylparaben and 13 mg/L for dichloroethylparaben, and 23 mg/L for propylparaben and 8.3 mg/L for dichloropropylparaben. This trend is consistent with the trend of increasing toxicity with increased lipophilicity of these chemicals, as the chlorinated parabens are more lipophilic than their parent paraben. These increases in acute toxicity may be a cause for concern when considered in the context of the increased persistence of the chlorinated parabens.

A study investigated the comparative chronic toxicity of parabens and their chlorinated transformation products in the invertebrate *C. dubia* [86, 87]. In contrast with the comparative study of acute toxicity, the chronic toxicity of chlorinated parabens was lower than that of their parent compounds.

10. Endocrine Activity

Parabens are considered to have oestrogenic activity, though at much lower potency than naturally produced oestrogens [59]. The estrogenic effect of parabens in fish has been investigated in a number of studies. Oestrogenic activity in fish can be measured by blood vitellogenin levels, a known biomarker for exposure to environmental estrogens [88]. Propyl-, butyl- and benzylparaben have all been shown to increase the average blood vitellogenin concentration in studies conducted with rainbow trout and medaka, but at concentrations well above what is expected to be found in the environment [55, 67–88].

The oestrogenic effect of chlorinated paraben transformation products was investigated in a yeast assay incorporating the medaka oestrogen receptor gene [86]. Chlorinated parabens were found to generally have lower ability to activate the receptor than their parent parabens.

Pharmaceuticals, the ingredients of personal care products and cosmetics and detergents are products commonly used in everyday life, and routinely find their way into sewage system [89]. Because they are usually difficult to biodegrade, there is a serious risk of accumulation and the occurrence of irreversible changes in nature. These products are harmful because they have a long disintegration time and they show the ability to bioaccumulate in living organisms, as a result of which they easily enter the trophic chain. The environmental effects and health effects of these preparations have been extensively researched [90], and the most important include: abnormal hormone levels, masculinisation of feminisations of males, and consequently reduced fertility [91, 92, 93, 94, 95] Studies comparing the similarity of the structure of compounds with the alkylhydroxybenzo group to alkylphenols of known oestrogenic compounds have confirmed that the parabens are oestrogens [96, 97, 98, 99]. The more spatial alkyl group enhances the lipophilic hydrophobic character, and also affects a more efficient association with oestrogen receptors. The longer the chain, the higher the estrogenic activity. Parabens are placed on the European list of priority compounds in category 1. As substances with proven effects on the endocrine system. Oestrogen tests have shown that parabens have lower estrogenic potency than 17β-estradiol. Studies have shown that benzylparaben has the highest oestrogenic potency of all parabens. It has been demonstrated that benzylparaben (YES test, EC50 = 0.351 mg•dm-3) has similar estrogenicity to Bisphenol A (YES test, EC50 = 0.342 mg•dm-3) [100, 101]. As a result of estrogenic activity, benzylparaben is suspected of participating in the development of breast cancer. Toxicity and oestrogenicity studies have shown that benzylparaben is the most harmful of all parabens [100]. Benzyl-barane also has a high acute toxicity against *Vibrio fischeri,* green algae – *Pseudokirchneriella subcapitata*, as well as *Daphnia magna* and against the Japanese median *Oryzias latipes* (Table 4) [84].

Table 6. Toxicity of benzylparaben [100; 75]

	Daphnia magna	***Vibrio fischeri***	***Pseudokirchneriella subcapitata***	***Oryzias latipes***	**YES test**
EC50 mg/dm-3	30 (48 h)	0,11 (15 min.)	1,2 (72 h	0,73 (LC50, 96 h)	0,351

In sewage flowing out of the treatment plant, benzylparaben was detected at a concentration of 0.01–0.26 μg•dm-3 in Spain and Canada, while in Sweden it wasat a concentration of 1 μg•dm-3 [55]. However, many times the concentration of this xenoestrogen was below the detection threshold [56]. Studies confirm that even in such low concentrations xenoestrogens may interfere with the work of internal endocrine organs [55, 56]. The extensive and ever--growing body of scientific evidence confirms the harmfulness of chemical compounds, such as benzylparaben for species living in the natural environment. There is a justified fear that these chemicals contribute to an increase in the number of ailments associated with the immune, nervous and, above all, reproductive systems [102, 103, 104].

11. Conclusion

The number of emerging contaminants released in the environment as a consequence of human activity is increasing day by day and reflects the growing consumption of a wide range of products, including cosmetics and personal care products. Chemical compounds that comprise cosmetics formulations number in the several thousands, and the annual production and consumption of personal care products exceeds thousands of tons. The hazard of the continuous release of these huge amounts of chemicals into waters should not be underestimated. The environmental fate of these products is largely unknown, and, if in some cases they are removed in wastewater treatment plants, in other cases, they can escape conventional treatment processes, persist in the environment at unexpected levels, undergo bioaccumulation, and even react with other pollutants to form new unpredictable contaminants. Banning the products responsible for these problems is an impracticable option, except in particular circumstances (for instance, the use of sunscreen is banned in some marine ecoparks in Mexico). Addressing this issue realistically requires different approaches and strategies. To some extent, our increased awareness of the pollution potential of these products is the result of advanced technologies of analytical chemistry. Therefore, the development of improved extraction and analytical methods would allow a more comprehensive and accurate evaluation of environmental pollutants in complex matrices. Further studies on the acute and chronic toxicity of these contaminants should be conducted to allow a more precise assessment of their actual ecological and health risk. Finally, information displayed on packaging concerning the environmental impact of cosmetics could encourage consumers to employ a more responsible and informed use of these products.

It should be noted that EU cosmetics legislation (Regulation 1223/2009/EC) is the most advanced system of legal requirements for cosmetic products in the world. Each cosmetic product and all ingredients contained in the product are subjected to a detailed toxicological and dermatological assessment before being placing on the market. The assessment takes into account who might use the product (e.g. a child, a pregnant woman, a person with sensitive skin), how often they might use it (several times a day, once a week) and how the product will be used. Substances for which the safety is questionable are subject to additional toxicological evaluation by the Scientific Committee on Safety of Cosmetics – an independent advisory team of the European Commission consisting of toxicologists, allergists, epidemiologists and experts in the field of risk assessment. Based on the recommendations of the committee, in justified cases, the European Commission may decide to ban or restrict the use of a given substance in cosmetic products. Cosmetic products legally placed on the European Union market, including Poland, do not contain toxic substances for which their presence in cosmetics could endanger the health or safety of users.

Generally parabens are the most commonly used preservatives. They are relatively active against a broad spectrum of microorganisms. The methyl ester is most effective against bacteria and moulds while the ethyl, propyl and butyl esters are more active against yeast and moulds. Parabens are more effective against gram negative than gram positive organisms.

Parabens are commonly used as antimicrobial preservatives in household products, cosmetics, pharmaceuticals, and food and beverage processing, and are environmental compounds with oestrogenic activity.

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Paid car park zone management with regard to the principles of providing parking spaces for disabled people

Zarządzanie strefami płatnego parkowania w aspekcie zasad udostępniania miejsc parkingowych dla osób niepełnosprawnych

Abstract

Disability can cover various areas of people's activities, but it is primarily associated with difficulties that relate to independent movement. The possibility of free movement is one of the basic human rights. People with disabilities who cannot get to work and take employment, despite a desire to do so, assimilate with the rest of society to a worse extent, do not have the means to support themselves and do not earn national income. From this point of view, programs and activities aimed at maximising mobility and access to various types of places for people with disabilities, including those in public space, are very important. These types of places include paid parking zones in cities. Their location in city centres provides access to most offices. Due to the fact that they are located in public space, municipalities and city authorities have an impact on their management and on establishing the principles of their functioning. A very important element of this management is determining the rules for providing parking spaces in paid parking zones, particularly with regard to the amount of parking fees for disabled people. The article provides an analysis of the management of the provision of disabled parking spaces in relation to paid parking zones in all voivodeship cities in Poland.

Keywords: paid parking zone, car park, disabled people, transport, management, law, transport accessibility, mobility, spatial management

Streszczenie

Niepełnosprawność może obejmować różne obszary ludzkiej aktywności, jednak kojarzy się przede wszystkim z utrudnieniami, które dotyczą samodzielnego poruszania się. Możliwość swobodnego przemieszczania się jest jednym z podstawowych praw człowieka. Osoby niepełnosprawne, które nie mogą dotrzeć do pracy i jej podjąć, pomimo tego, że chcą, gorzej asymilują się z pozostałą częścią społeczeństwa, nie mają środków na własne utrzymanie i nie wypracowują dochodu narodowego. Dlatego też ważne są programy i działania zmierzające do maksymalizacji mobilności i dostępności do różnego rodzaju miejsc dla osób niepełnosprawnych. Tego typu miejscami są między innymi strefy płatnego parkowania w miastach. Ich położenie w centrach miast zapewnia dostęp do większości instytucji. Bardzo ważnym elementem tego zarządzania jest określenie zasad udostępniania miejsc parkingowych w strefach płatnego parkowania, w tym w szczególności wysokości opłat za parkowanie pojazdów osób niepełnosprawnych. W artykule dokonano takiej analizy w stosunku do stref płatnego parkowania we wszystkich miastach wojewódzkich w Polsce.

Słowa kluczowe: strefa płatnego parkowania, parking, osoby niepełnosprawne, transport, zarządzanie, prawo, dostępność transportowa, mobilność, gospodarka przestrzenna

1. Introduction

Koźmiński, Jemielniak [1] list the following functions that make up the management:

1. planning,
2. organisation,
3. information and knowledge management,
4. the organisation's financial management,
5. operations management,
6. personnel policy,
7. marketing and public relations,
8. negotiations,
9. control.

All of the above functions comprise activities relating to the designation, organisation and functioning of paid parking zones in the city. These activities are often complicated, and their effect is the need to compromise between the expectations of city-centre residents who, to provide space for their cars, are increasingly demanding the inclusion of individual districts in the paid parking zones, and the demands of drivers from peripheral districts, drivers from neighbouring cities and tourists who are interested in direct access to the city centre. In addition, due to the high dynamics of the increase in the number of cars, previously undertaken actions should be corrected from time to time, regarding, for example, the boundaries of paid parking zones, the number of spaces, traffic organisation, parking prices. This causes chaos, confusion and upset for drivers. This results in extreme demands formulated by some decision makers regarding paid parking zones from those which assume their liquidation, to the postulates aimed at covering the entire cities with the paid parking zone. An example of such an idea is the idea of introducing a paid parking zone in the entire city of Krakow.

Very often, paid parking zones generate large revenues for cities from parking fees. The effect of the fees is to be, inter alia: the reduction of vehicular traffic, the reduction of vehicular traffic congestion, less pollution of the natural environment by exhaust gases, change in drivers' habits. However, it should be remembered that the policy of reducing the accessibility of city centres to motor vehicles may have negative effects. One of these effects is the reduction of available access to city centres for groups of people who especially need this access. This includes people with disabilities, who are often forced to use cars for access to medical facilities, offices, workplaces, schools, universities, shops, etc. These institutions are usually located in city centres, so where paid parking zones are being introduced. The goal of managing paid parking zones in this case is to ensure an adequate number of spaces for disabled people, to designate and mark them, and to develop rules for accessing and using paid parking spaces in the zones. This approach is consistent with the concept of the company as an entity that meets the needs of the environment [2]. In the case of a paid parking zone, the enterprise will be an external company or a relevant department in the city hall managing the zone.

2. Definitions of disabled people

In the literature, there are various definitions regarding people with disabilities and the resulting different methods for estimating their number. Antczak, Grabowska, Polańska [3] list the biological, functional and social characteristics of disability models.

The biological model considers disability, which defines disability as "any loss of performance or abnormality in the psychological, physical or anatomical structure or functioning of the body, and the psychosocial consequences of this absence or disability" (WHO definition).

The functional model defines:

1. **disability** as "any limitation or impossibility to lead an active life in a way or to the extent considered to be typical of a person of a similar age and the same sex" (WHO definition).
2. **impediment** as "limitation or impossibility of full implementation of social roles corresponding to age, gender and compatible with social and cultural conditions" (WHO definition).

The social aspect takes into account "the lack or limitation of human activity caused by contemporary social organisation, which does not take into account the needs of people with physical damage and learning difficulties, thereby excluding them from the mainstream of social life".

It follows from the above definitions that disability can cover various areas of human activity. In the colloquial meaning, however, it is primarily associated with difficulties that relate to independent movement. The possibility of free movement is one of the basic human rights. Lack of this possibility hinders or prevents people from functioning in society. It is an obstacle to professional work. People with disabilities who cannot get to work and take employment, despite a desire to do so, assimilate with the rest of society to a worse extent, do not have the means to support themselves and do not earn national income.From this point of view, programs and activities aimed at maximising mobility and access to various types of places for people with disabilities, including those in public space, are very important. These types of places include paid parking zones in cities. Their location in city centres provides access to most offices, schools, colleges, shops, service outlets, cultural facilities etc. Due to the fact that they are located in public space, municipalities and city authorities have an impact on their management and on establishing the principles of their functioning. A very important element of this management is determining the rules for providing parking spaces in paid parking zones, particularly with regard to the amount of parking fees, as well as the total number of parking spaces and designated parking spaces intended only for disabled people.

3. The scale of the problem

When considering adapting paid parking zones to the needs of disabled people, it is important to estimate the number of people in this category with regard to particular management aspects concerning parking payment rules and the number of separate parking spaces for disabled people. Determining the exact number of disabled people in Poland causes some difficulties. In addition to the various definitions of disability mentioned above, the different methodologies for testing the number of people with disabilities are also a source of great difficulty.

According to the National Census performed in 2011, there were around 4,697,000 legally and biologically disabled people in Poland. Legally disabled are people whose disability has been confirmed by Zakład Ubezpieczeń Społecznych (Social Insurance Institution) or disability adjudication teams. This number was smaller than the data from 2002 (around 5,456,700 people) and greater than the results obtained in 1988 (around 3,735,500 people).

EHIS research, the purpose of which is to monitor the health status of the population of the European Union, was conducted in Poland in 2014. The tested sample consisted of over 12,000 households (i.e. around 29,000 people). These studies indicate that there are around 4,905,100 people with legal and biological disabilities. Even more interesting is the data referring to the number of people with disabilities aged 15 and over, i.e. at an age that roughly coincides with the age at which a driving license can be obtained. In the case of Poland, the number is around 5,805,100 people with disabilities out of a total of around 32,719,500 people within that age range in 2012. This constitutes as much as 17.7% of the population [3].

4. Literature review and adopted research method

There are relatively few publications in the literature on the mobility of disabled people, especially the availability of parking space, not only in terms of infrastructure, but also with regard to legal regulations, parking prices and the organisation of paid parking zones.

Safety, mobility and transport of the elderly and disabled were the subject of the Transed conference [4].

General rules for using paid parking zones in major Polish cities were presented by Parkitny [5], while another article [6] described the issue of parking integration with the municipal public transport system. A further paper [7] presents an analysis of parking parameters in terms of infrastructure.

Taylor and Józefowicz [8] draw attention to the method of choosing places of recreation for disabled people. These are places that, among other things, do not require significant financial outlay and are accessible to people with disabilities. Therefore, both criteria should be taken into account in the development of regulations and the construction of paid parking zones discussed below in this article. These authors also studied the mobility of disabled people in urban space [9–11].

The authors van der Waerden, de Bruin and da Silva [12] presented the preferences of drivers in terms of additional services in parking lots, which may also be relevant for disabled people. Car parks, paid parking zone equipment and drivers' preferences are also discussed [13].

Carvalho and Paiva [14] drew attention to the problem of illegal parking in places for disabled people. They developed a device that allows identification of vehicles parking illegally in parking spaces for disabled people by means of cameras smartphones and software and informs appropriate persons.

One of the useful tools for parking search can be the system described in the article by Tsai, Kiong and Sinn [15]. They proposed the system to which functions one can number: recommendation and reservation, outdoor navigation to the car park, parking lot detection, and car park indoor navigation.

In the article authored by Ogórek, Kulig and Przeniczny [16] an analysis of the adaptation of buses, stops and the organisation of urban transport to the needs of the disabled and the elderly was performed. The analysis concerns sixteen cities in Małopolska.

Parkitny in a thesis [17] presented the aspect of using a parking lot located in a paid parking zone depending on the weather; furthermore, the modelling of parking lot selection was described in another article [18].

The research presented in this article was based on the analysis of resolutions and documents of the authorities of all voivodeship cities in Poland which concern paid parking zones as well as statistical data of individual municipal units managing these zones.

5. Analysis of the rules for using the paid parking zones by disabled people

The above definitions of disability from the point of view of a driver – a disabled person who wants to park in one of the provincial cities in Poland – are not as important as his disability certificate, which is the basis for issuing a so-called parking card and the rules for using parking spaces. These rules are different in different cities. They are described by city councils or municipal councils, and depend on the preferences of individual councils. Below are the parking rules for paid parking zones in all provincial cities in Poland.

5.1. Rules for using parking cards in Poland

Entrance to the paid parking zone is marked with sign D-44 (paid parking zone). Fees should be paid for parking the vehicle in designated places on public roads. Parking on the pavement is possible if: it does not impede pedestrians(i.e. if a free space of at least 1.5 m is left); there is no parking prohibition nearby and the weight of the car does not exceed 2.5 tons.

The Act of 20.06.1997 Road Traffic Law [19] defines road signs that do not have to be followed by disabled people who have the right to drive motor vehicles, and drivers who transport disabled people, provided that they take special care. These signs are: no traffic in both directions (B-1); no motor vehicle, except for two-wheel motorcycles

(B-3); no bus (B-3a); no motorbikes (B-4); no entry of mopeds (B-10); no parking (B-35); no parking on odd days (B- 37); no parking on even days (B-38); restricted parking (B-39) [20, 21].

The document that confirms the rights of disabled people to not comply with selected road signs and to use so-called "envelopes" (i.e. parking space intended for disabled people and parking spaces marked with a wheelchair symbol on a blue background) is a parking card. Without the need to adjudicate again (i.e. based on an existing judgment), such a document can be obtained by persons who:

1. have a certificate of severe disability with the following symbols:
a) 04-O – persons with diseases of the organs of eyesight;
b) 05-R – persons with mobility impairment;
c) 10-N – neurological diseases;
2. 2have an indication of qualifying for a parking card.

To obtain a parking card, the following must be submitted in person:

1. 1an application in the administrative district team for declaring disability;
2. a photograph;
3. confirmation of payment of a fee of 21 PLN for a parking card;
4. declaration of having the right to parental responsibility, guardianship or wardship in the case of persons under 18 years of age or incapacitated persons.

An additional advantage of the parking card is the possibility of its use not only in Poland, but also in other European Union countries; however, as a rule, it does not exempt (except for the cases mentioned above) payment of the parking fee.

Parking cards can also be obtained by institutions that deal with rehabilitation and the care and education of people with disabilities who have limited mobility on their own [21, 22].

The condition for using free parking is to display the parking card in the windscreen of the vehicle in such a way that it is legible to the controllers of the paid parking zone. This is emphasised by the regulations of the paid parking zones of the cities analysed below.

5.2. Rules for using exemptions from parking fees and subscriptions in provincial cities in Poland

Below are described the rules of selling subscriptions for disabled persons, which authorise parking in all paid parking zones in particular provincial cities in Poland (Table 1).

Table 1. Rules for using exemptions from parking fees and subscriptions in provincial cities

Operating hours of the zone	Rules for using exemptions from parking fees and subscriptions
Białystok	
People who want to park in the zone from Monday to Friday, on business days from 10.00-18.00 must pay a parking fee.	Disabled people who have a parking card and place it in the windscreen can benefit from a zero parking fee.

Bydgoszcz	
Parking fees apply between 8.00 and 17.00 from Monday to Friday. Fees do not apply on public holidays.	In Bydgoszcz, disabled people who have a parking card can park for free in a so-called "envelope", i.e. a place for a disabled person's vehicle. In other places, it is possible if at the same time, the disabled person has a so-called disabled person identifier. This identifier can be obtained by persons who: 1. submitted an appropriate application to Zarząd Dróg Miejskich i Komunikacji Publicznej w Bydgoszczy (Municipal Roads and Public Transport Board in Bydgoszcz); 2. have a disabled person's parking card which was issued on the basis of a certificate of severe disability with the code 05-R or 10-N or equivalent, or legal guardians of a disabled person with a parking card, who is a co-owner or owner of the vehicle "whose ownership is confirmed by an entry in the registration certificate or being the user of the vehicle under a civil law agreement concluded in writing with the signatures of the parties to the contact certified by a notary public" [23]. The application should be accompanied by photocopies of: vehicle registration card, parking card, disability certificate, civil law agreement and child's birth certificate (in the case of guardians of disabled minors). Vehicles from, among others, institutions that deal with the rehabilitation, care and education of people with disabilities are exempted from fees (a parking card for this institution and a disabled person's ID are required) [23].
Gdańsk	
The rules related to the hours when the parking fee applies in the paid parking zone in Gdańsk vary depending on the district and are among the most complicated in the country. In general, the parking fee is not charged on Saturdays, Sundays and public holidays, which according to the regulations fall from Monday to Friday. In the case of parking in the Old Town (Śródmieście) and Wrzeszcz, parking is payable between 9.00-17.00, from Monday to Friday. People who want to park in the Main Town sector and in May 3 Street, must pay to do so from Monday to Friday from 9.00 to 20.00, and in Aniołki, Oliwa and Przymorze sectors on the same days, but from 9.00 to 15.00. During the summer holidays, i.e. from July 1 to August 31, parking in Jelitkowo between 9.00-17.00, from Monday to Friday is also payable.	As in other cities, people with disabilities do not pay for parking in spaces for disabled people if they have a parking card. In order to not pay for parking in all places in the paid parking zone, an individual must have the ID "N"+. The ID is issued free of charge. It is obligatory in the following districts: Śródmieście, Wrzeszcz, Aniołki, Przymorze, Oliwa, Jelitkowo. To obtain it, an application must submitted including photocopies of: 1. registration evidence; 2. legal title to the vehicle; 3. driving license; 4. medical certificate confirming the absence of contraindications for driving; 5. certificate of a significant degree of locomotive organ disability or neurological diseases, and fulfillment of the conditions that allow the issuing of the parking card described above [24].

Gorzów Wielkopolski	
Paid parking in the paid parking zone takes place from 9.00 to 18.00 from Monday to Friday.	The number of parking spaces in Gorzów Wielkopolski is 941. Disabled people can park free of charge only in designated places in the zone for them, i.e. in so-called "envelopes". To avoid being charged, drivers must have a parking card.
Katowice	
The collection of parking fees in the paid parking zone in Katowice is valid from 9.00-16.30 on business days, from Monday to Friday [25].	The zero rate for parking disabled persons' vehicles applies for drivers with a parking card.
Kielce	
In Kielce, parking in the paid parking zone is charged. Charges apply from Monday to Friday, from 9.00 to 17.00.	People with disabilities can purchase an ID type "I" for 10 PLN per year. It entitles the driver to free and unlimited parking time throughout the zone [26].
Krakow	
The paid parking zone in Krakow is one of the largest in Poland. This is the first city in Poland where from 22.09.2019 fees have also been charged on Saturdays. Currently, paid parking applies on business days from Monday to Saturday from 10.00 to 20.00.	Changing a parking place from one subzone to another makes it necessary to pay another parking fee in the new subzone, even if the time limit for parking in the previous subzone has not yet expired. The fee for a "N" subscription is 2.50 PLN for 1 month [27]. Until 2017, those who had received a certificate of severe or moderate disability were entitled to purchase a subscription. Currently, the purchase of such a subscription is possible for people who have a valid parking card for a disabled person. A parking card is only granted to people who have significantly reduced mobility, and is not granted to those who only have reduced mobility. Such persons must purchase a subscription for 250 PLN [28].
Lublin	
In Lublin, as in other voivodeship cities, the parking fee is required from Monday to Friday from 8.00 to 17.00.	A subscription "N" is provided for the disabled. It is valid throughout the entire area, except for private car parks. The subscription price is 4 PLN/month. It is valid for no more than 18 months. [29]
Łódź	
The zone is payable on business days, from Monday to Friday from 8.00 to 18.00.	People with severe or moderate disabilities and in possession of a parking card can receive a subscription with zero fees. It authorises parking in the entire zone. [30]
Olsztyn	
The regulations of the paid parking zone in Olsztyn state that the fees in this zone apply from Monday to Thursday, on business days between 8.00-16.00, and on Fridays between 8.00-15.00 [31].	According to the regulations of the paid parking zone in Olsztyn, disabled people and drivers transporting disabled people do not have to pay for parking if they have a parking card.

Opole	
Parking in Opole on Saturdays, Sundays and public holidays is free. Parking is paid between 8.00 and 17.00 on business days, Monday to Friday.	Resolution XIII/203/15 of the Opole City Council of 2.07.2015 provides zero parking rates for disabled people who have parking cards and for people who drive vehicles and transport disabled people who have such cards [32].
Poznań	
Parking is charged in the Poznań zone for parking a vehicle from Monday to Friday from 8.00 to 18.00.	In Poznań, the monthly fee for a vehicle transporting a disabled person registered for permanent or temporary residence in the Wielkopolskie Voivodeship is 5 PLN. The minimum period for which an ID can be bought is 3 months, and the maximum is 12 months. The required documents are: vehicle registration card, identity document confirming the place of residence in the Wielkopolskie Voivodeship, parking card, civil law agreement indicating the actual user of the vehicle in the case of, for example, leasing [33].
Rzeszów	
Of all the Polish voivodeship cities, Rzeszów has introduced a paid parking zone most recently. This occurred on 01.01.2016. Paid parking in Rzeszów applies from Monday to Friday, on working days, between 9.00 and 17.00.	The number of places in the zone is 2,239. It is the largest zone in the Podkarpackie Voivodeship. Disabled people who want to park in the zone can buy a monthly subscription. The subscription price is 1 PLN [34], [35].
Szczecin	
Drivers wanting to park in the paid parking zone in Szczecin must pay if they park from Monday to Friday, between 8.00 and 17.00. Free parking is possible on May 2, December 24 and 31 and on public holidays.	Zero parking fee is provided for: 1. persons with disabilities with a significant degree of disability who have a parking card; 2. parents and legal guardians of disabled persons up to the age of 18 who are disabled or who own vehicles or have vehicles based on a loan or leasing agreement – upon presentation of a parking card, ID card, disability certificate, vehicle registration card, loan agreement, leasing if the vehicle is disposed on the basis of such contracts; 3. war invalids who are the owners of vehicles – the right is granted on the basis of a Military Invalid ID card, ID card, vehicle registration card, loan agreement, leasing if the vehicle is disposed of under such agreements. There is also a 12-month flat-rate fee for a disabled person at the amount of 10 PLN [36].
Toruń	
In Toruń, the paid parking zone is divided into 2 subzones: subzone A is located in the Old Town, and subzone B on the streets adjacent to the Old Town. In both subzones, payment is due for parking from Monday to Friday, on weekends, from 8.00 to 18.00.	There are no reduced one-time fees for disabled people in the city, but drivers can buy a subscription for a disabled person for 12 PLN. It is valid for 1 month [37].

Warsaw	
Paid parking in the paid parking zone in Warsaw is valid from Monday to Friday, with the exception of May 2, 24 and 31 December, between 8.00 and 18.00.	Free parking for people with disabilities, as in other cities, is allowed in designated parking spaces ("envelopes"). People who have the "N+" card can park without paying in the entire paid parking zone. This card is issued free of charge. It can be obtained by a disabled person with significant degree of disability or a person whose disability is confirmed by a disability certificate or a persons with a degree of disability that causes significant difficulties in moving independently [38].
Wrocław	
The days when fees apply in the paid parking zone in Wrocław are business days from Monday to Friday from 9.00 to 18.00.	For persons with a certificate of slight disability connected with neurological diseases (code 10-N) or musculoskeletal disorders (code 05-N), the N subscription has been introduced. It is valid in one of the 14 subzones in which the business is conducted or there are workplaces [39]. The price of N subscriptions is 10 PLN for one month, 50 PLN for half a year, 100 PLN for year. Free "O" identifiers have also been introduced. People who can use these are: 1. disabled people, registered in Wrocław, with reduced mobility holding a certificate or ID card of a disabled person with a significant or moderate degree of disability with a reason from code R or N, 2. legal representatives or the spouses of these persons or other persons driving their vehicles and carrying a disabled person [40].
Zielona Góra	
Paid parking in the paid parking zone applies between 9.00 and 18.00 from Monday to Friday, on business days.	The zero parking rate applies to persons with a disabled parking card, people who transport disabled persons holding such a card, and for marked vehicles that are structurally designed to transport disabled persons [41].

Source: own binding based on data provided in the bibliography

6. Summary and conclusions

A parking card is a document enabling parking at designated places in paid parking zones. However, using it is associated with the following inconveniences and problems:

1. a limited number of designated parking spaces in the zone;
2. the need to search for spaces;
3. the lack of information on the occupancy of spaces;
4. the need to submit a complete set of documents, pay a fee for issuing the card and collect it personally.

Parking in other places in most cities is possible subject to purchasing an additional subscription. Subscription prices vary, but are generally not high. The price of subscription ranges from 1 PLN/1 month in Rzeszów, 10 PLN/12 months in Szczecin up to 12 PLN/1 month in Toruń. Free subscriptions are available in Bydgoszcz, Gdańsk, Łódź and Warsaw. There are different rules for sharing subscriptions in individual cities. Sometimes the procedures associated with obtaining subscriptions are complicated. However, not all cities provide for the possibility of leaving the disabled person's car outside the designated parking spaces ("envelopes"); in such cases, a normal parking fee applies.

A problem for people frequently travelling may also be different hours of parking. Paid parking zones are being introduced to increase the rotation of vehicles in car parks, especially in city centres and during the working hours of offices. From 8.00, charges apply in the paid parking zones of Bydgoszcz, Lublin, Łódź, Olsztyn, Opole, Poznań, Szczecin, Toruń and Warsaw. is the latest time that charges applies to is 20.00; this is the case for the paid parking zones in Krakow. In this city, parking fees are also obligatory on Saturdays.

Parking fees apply for the shortest time in Katowice (7.5 hours). In Gdańsk Główne Miasto, parking fees are compulsory for 11 hours/24 hours. In five cities, the fee for the paid parking zone applies for 10 hours/24 hours.

General problems for drivers may be the change of zone boundaries occurring in some cities, the liquidation of previously existing parking spaces or street fragments available for parking and emerging proposals for differentiating parking fees in individual subzones. The above actions may lead to an increase in the congestion of vehicle traffic and chaos associated with searching for free parking spaces, the extended time taken searching for a place and unintentional violation of regulations by drivers.

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A comparative analysis of the results of terrestrial laser scanning and numerical modelling for assessing the stability of a road embankment on the active landslide on the Just mountain at Tęgoborze at Just – Tęgoborze

Analiza porównawcza wyników naziemnego skanowania laserowego i modelowania numerycznego dla oceny stateczności nasypu drogowego na aktywnym osuwisku Just – Tęgoborze

Abstract

This article presents a method for the quick assessment of the safety of the road on an active landslide on the Just mountain at Tęgoborze using the landslide hazard ratio of landslide movements. The hazard indicator for landslide traffic has been defined as the quotient of the largest displacements obtained from measurements using a terrestrial laser scanner to the largest displacement obtained from a numerical model of the worst geotechnical conditions and an unstable landslide. The application of this indicator was presented on the example of national road No. 75 along the section of the road in km from 51 + 900 to 52 + 700 at the location of the Just mountain at Tęgoborze in the south of Poland. The road is located on an active landslide and has a lot of traffic. The measurements were conducted with the RIEGL. VZ400 terrestrial laser scanner from 2012 to 2016. As a result of the measurements performed with a terrestrial laser scanner, a cloud of 3D points was obtained. Differential models of subsequent measurements were constructed and compared to the first base measurements. The results of 3D differential models obtained from terrestrial laser scanner measurements were compared with results obtained from 3D numerical modelling. Numerical calculations were conducted assuming the worst geotechnical conditions. The model of the landslide was fully saturated. A numerical simulation computed using the finite element method (FEM) in the MIDAS GTS program was applied. A result of the safety factor F = 0.8 (i.e. an unstable landslide) was obtained. In order to estimate the hazard, the values of the landslide hazard indicator were determined for each date using the measurements conducted with the laser scanner.

Keywords: landslides, terrestrial laser scanner, numerical modelling, FEM

Streszczenie

W artykule przedstawiono metodę szybkiej oceny bezpieczeństwa drogi na osuwisku za pomocą wskaźnika zagrożenia ruchem osuwiskowym. Zdefiniowano wskaźnik zagrożenia ruchem osuwiskowym jako iloraz największych przemieszczeń wyznaczonego z pomiarów naziemnym skanerem laserowym do największego przemieszczenia wyznaczonego z modelu numerycznego dla najgorszych warunków geotechnicznych i niestatecznego osuwiska. Przedstawiono zastosowanie tego wskaźnika na przykładzie odcinka drogi krajowej nr 75 wzdłuż odcinka drogi w km od 51 + 900 do 52 + 700 w miejscowości Just-Tęgoborze na południu Polski. Droga położona jest na czynnym osuwisku i ma duże natężenie ruchu. Pomiary przeprowadzono naziemnym skanerem laserowym RIEGL. VZ400 w okresie od 2012 do 2016 roku. W wyniku pomiarów naziemnym skanerem laserowym otrzymano chmurę punktów 3D. Wykonano modele różnicowe kolejnych pomiarów w porównaniu do pierwszego bazowego pomiaru. Porównano wyniki modeli różnicowych 3D otrzymanych z pomiarów naziemnym skanerem laserowym z wynikami otrzymanymi z modelowania numerycznego 3D. Obliczenia numeryczne przeprowadzono dla najgorszych warunków geotechnicznych czyli całkowitego nasycenia osuwiska metodą elementów skończonych (MES) w programie MIDAS GTS. Otrzymano wynik współczynnika stateczności F = 0,8 czyli osuwisko niestateczne. W celu oszacowania zagrożenia wyznaczono wartości wskaźnika zagrożenia osuwiskiem dla każdej daty wynikającej z przeprowadzonych pomiarów skanerem laserowym.

Słowa kluczowe: osuwisko, naziemny skaner laserowy, modelowanie numeryczne, MES

1. Introduction

Landslides are a very dangerous phenomenon for road infrastructure. They cause large material losses and disrupt transport [11, 20]. of quick risk assessment for roads located on active landslides are still being sought. This article proposes a method for the quick assessment of road safety on a landslide with the aid of the landslide hazard indicator. The hazard indicator for landslide traffic has been defined as the quotient of the largest displacements obtained from a terrestrial laser scanner to the largest displacement obtained from a numerical model for the worst geotechnical conditions and an unstable landslide.

In Poland, the largest landslide threat to roads occurs in the Carpathian mountains in the south of the country south of the Carpathians (Fig. 1). It results from the geological structure of the Carpathian flysch, which largely consists of sandstones and shales [13, 18]. Sandstones and shales are arranged alternately, which causes the formation of slip planes in layers of clay shales, which easily become soggy. A feature of the geological structure of the Carpathian flysch is also the existence of a weathered zone under the soil layer, which is characterised by a large extent of rock material. Such a layer of weathered zone laid on a bedrock has a great susceptibility to landslide because a slip zone is formed between the weathered zone and the bedrock. Slip planes may be a useful non-invasive method of seismic interferometry [19]. Many scientists have assessed the threat to the infrastructure of landslides including [1, 4, 6, 10, 21].

Over 95% of all landslides in Poland are registered in the Carpathians. Zabuski et al. [23] reported that 625 road sections (statistically, one landslide on every 5 km of public roads) and 86 sections of railway tracks (statistically, one landslide on every 10 km of railway line) were in the Karpaty region threatened by a landslide. Currently, the situation is more serious as it is related to climate change and the development of infrastructure, where it is not possible to avoid landslides. Landslides threaten buildings and infrastructure. The damage caused by landslides results in huge material losses and constitute a real threat to human life (Fig. 2). Figure 3 presents a summary of the number of landslides occurring on individual national roads within the Krakow Branch of the General Directorate of National Roads and Motorways

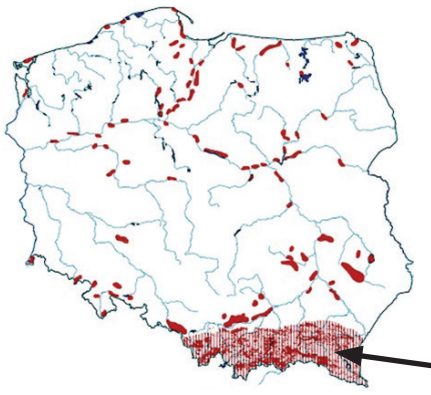

Fig. 1. The landslide threat in Poland [24]

Fig. 2. Landslide on national road No. 87, 28 June 2009 [26]

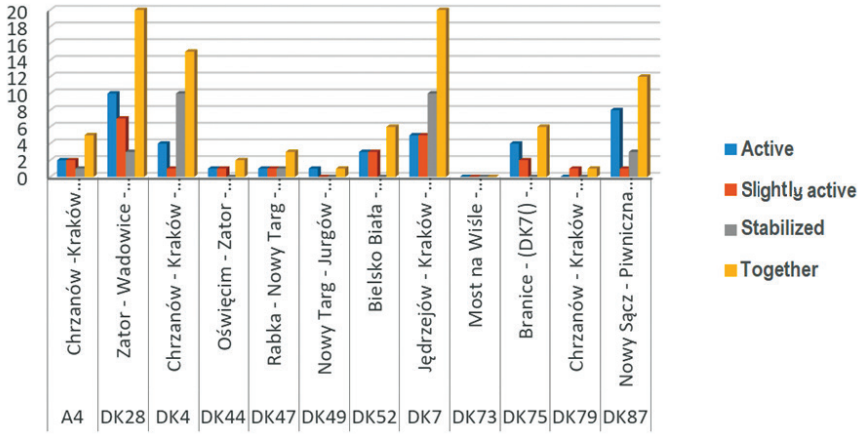

Fig. 3. List of the number of landslides occurring on individual national roads within the Krakow Branch of GDDKiA [16, 24]

(GDDKiA). It can be seen that the most active landslides are on the DK28 Zator–Wadowice national road and on the DK87 Nowy Sącz–Piwniczna route.

The main natural factor for activating landslide movements is water. The saturation of the soil with water results in an increase in its weight as the water displaces the air from the space between the soil particles. Rainfall plays a major role here. Experience shows that long-term rainfall is the most dangerous kind. The additional water contributes to an increase in the water content, the amount of pore water pressure, plasticity or soil compactness and alters rock formations. When the rocks are filled with water, their properties change significantly. Terzaghi [22] has already drawn attention to this problem. Research in this direction on the specific example of landslides was conducted by Ali, et al. [2]. Changing the properties of soils under the influence of water content has a significant effect on their behaviour in relation to pressure. This is of great importance in the formation of landslides. Lowering the cohesion of deeper deposits may lead to larger soil masses. The results of the numerical calculations presented in this article refer to the total losses resulting from landslides, which means the worst geotechnical design variant for the safety factor.

2. Monitoring landslides with a terrestrial laser scanner

For monitoring, surface geodetic methods are used as well as depth monitoring**.** Traditional geodetic methods are not suitable for analysing the vast areas of landslides. Imaging methods are very expensive and labour-intensive. The opportunity for a quick examination of the terrain threatened by a landslide lies in terrestrial laser scanning. This method has been in development all over the world for several years. The laser scanning method applied to road landslides was presented extensively at the Second World Landslide Forum conference in Rome in 2011. In the world literature, many examples of using a terrestrial laser scanner to monitor landslides in close proximity to roads have been shown in publications [5, 7, 9].

Laser scanning is possible in inaccessible places. Kasperski et al. [12] demonstrated the possibilities of using laser scanning to monitor the active Séchilienne landslide in the French Alps. This landslide is a threat to people and to the road RD1091. Similar results of the use of laser scanning were presented by Chinese scientists who determined the risk of a landslide using the example of a landslide in Jingyang, Shaanxi province [15]. The methodology of scanning landslides using a terrestrial laser has been widely developed in many countries, including Italy, the Netherlands, USA and Japan, which has a lot of active landslides as a result of earthquakes. In Poland, measurement technology based on the measurements of terrestrial laser scanners has been in development for several years and has been applied in many areas. It is used in the creation of three-dimensional models of terrain, buildings. Devices are used to detect defects and faults. The first landslide measurements were made at the Polish Geological Institute – the Research Institute [14]. Based on the examples of performed displacement measurements, it may be stated that the use of a terrestrial laser scanner enables the determination of the displacement value with millimetre accuracy. At the same time, the measurement time is shortened, the composition of the qualified measuring team is reduced to one person and the values of the occurring displacements are immediately obtained.

Terrestrial laser scanning is a technology in which the time of the return of a laser beam reflected from the tested surface to the measuring device is measured [3]. Knowing the speed of the electromagnetic wave and the time, the device calculates the distance from which there is a coherent point in space. The emission angle of the laser beam (vertical and horizontal) is also recorded. As a result, after completing the necessary number of measurements (scanners have the ability to process about 200,000 points per second [17], a point cloud is obtained (a set of coordinates of points X, Y, Z) in relation to the position of the scanner. As a result of this, knowing the exact position of the device in space, after recalculation (occurring automatically), the actual coordinates of the measured points are obtained, which produces

Fig. 4. Measurements with a laser scanner on the Just – Tęgoborze landslide [16]

a three-dimensional model of the terrain after further processing. The treatment is necessary to remove irrelevant elements (e.g., plants). It is also important to take measurements from many places (scanner located in different positions) not only does this make the obtained results are more reliable, it also enables the obtaining of data that may be impossible to obtain from another measurement point (part of the area may be obscured by terrain obstacles, rocks, trees, etc.).

In the case of landslide movements, having the results of several measurements performed at certain time intervals by overlapping individual models it is possible to determine the range and size of displacements. As a result of this, the identification of a potential landslide is possible. On the basis of this model, differential analyses and other measurements and calculations are made for the object being scanned. The accuracy of the scan results is approx. 1–5 mm. The RIEGL VZ-400 terrestrial laser scanner was used for the measurements (Fig. 4).

3. Results of measurements with a terrestrial laser scanner

The measurements were performed on a road embankment located on the Just – Tęgoborze landslide. These measurements were conducted cyclically, twice a year; in the spring, after the snow subsided, and then a second measurement, usually in the autumn. The measuring points were located in such a manner as to monitor places of possible moves of road embankment and escarpments on the landslide. National road No. 75 passes through the landslide (Fig. 5).

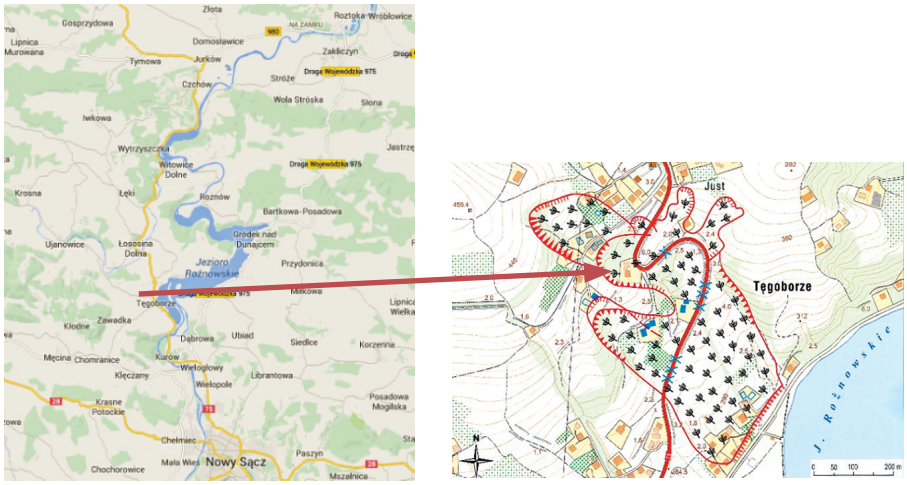

Fig. 5. Location of the Just – Tęgoborze landslide [25]

The terrestrial laser scanner was always located in the same position as determined by GPS coordinates. The processing of data obtained in the scanning process was performed using specialised RiSCAN PRO software. The first measurement was conducted on 10 November 2012. On the basis of these measurements, a three-dimensional landslide model was generated which included the path located on it (Fig. 6).

Fig. 6. Three-dimensional terrain model DK 75 on the Just-Tęgoborze landslide [16]

A further five series of measurements were performed (27.04.2013, 22.10.2013, 04.04.2014; 14.08.2014; 11.06.2016) on the basis of which, displacements occurring in the investigated area of the Just landslide were analysed. Different models were made at different time intervals. Recently, drainage works have been executed in the Just landslide and this has resulted in a change in the morphology of the area. For this reason, the analysis was performed on archival data. Differential models show vertical displacements occurring at given time intervals. The reference point in time was the so-called zero measurement. In this way, variations in displacement changes in the area of interest may be tracked. However, it should be noted that on the monitored area of the landslide, there were constant movements of the colluvium, and therefore in a given place, there may be a negative displacement at a given time, i.e. a ground loss or positive soil movement due to the ground shifting from the top of the slope. Sometimes, at a given moment in time, there may even be a zero displacement, i.e. the ground mass may have moved, therefore, in comparison with the zero measurement in the differential model, it would have zeroed out. The results of the differential numerical models are shown in Figs. 7; 8; 9; 10 and 11. The analysis was conducted in the area of greatest deformation obtained in the numerical model (the area indicated by the rectangle).

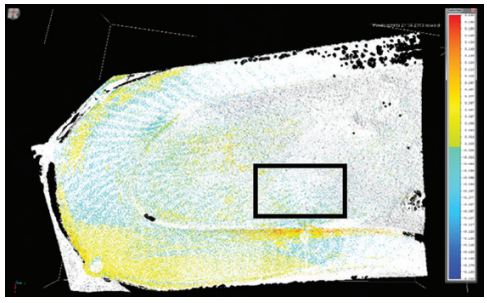

Fig. 7. The differential model between the zero measurement on 10.11.2012 and the control measurement on 27.04.2013

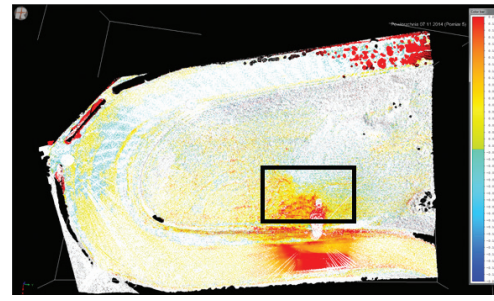

Fig. 8. Differential model between the zero measurement on 10.11.2012 and the control measurement on 04.04.2014

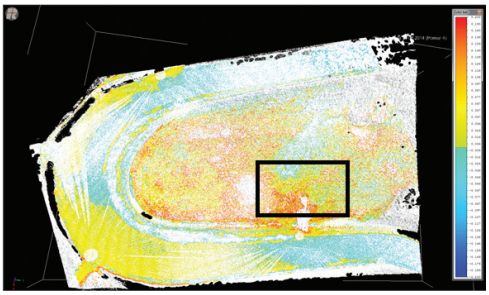

Fig. 9. Differential model between the zero measurement on 10/11/2012 and the control measurement on 14/08/2014

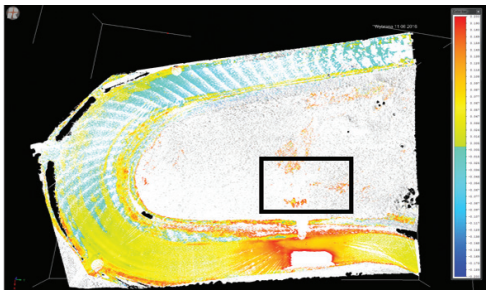

Fig. 10. Differential model between the zero measurement on 10/11/2012 and the control measurement on 11.06.2016

Figure 12 shows the maximum displacements in the test area based on the results obtained in Figs. 7 to 11.

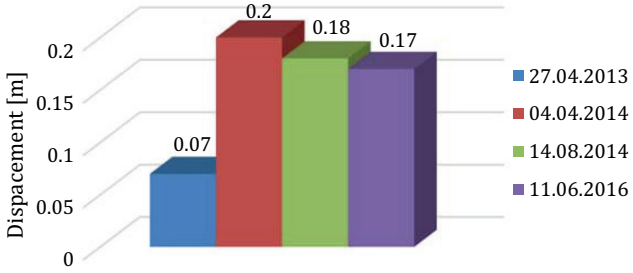

Fig. 11. Maximum displacements read for the tested section

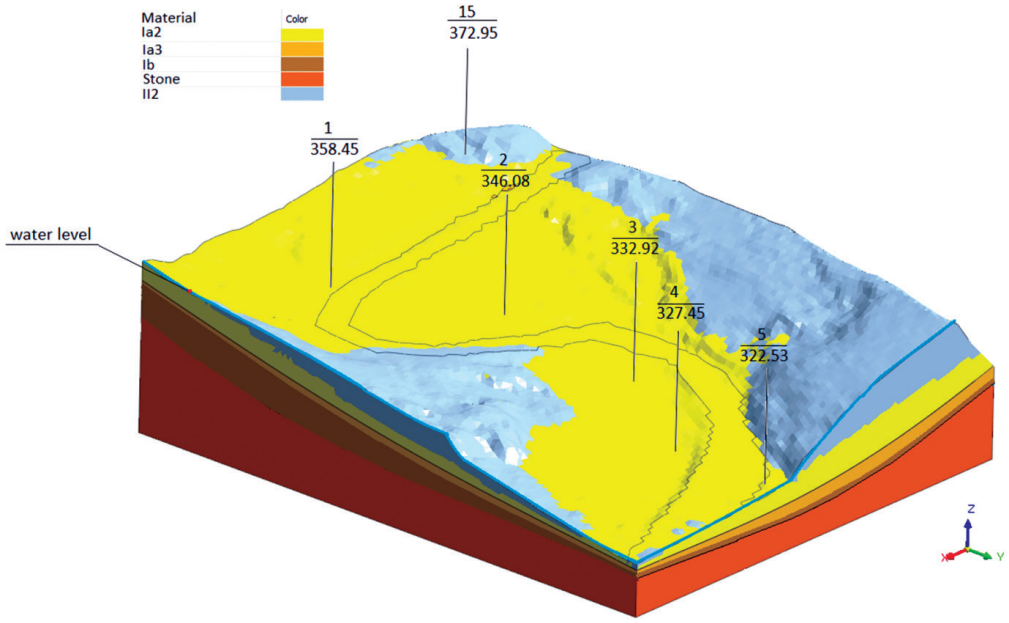

Fig. 12. Geotechnical model of the landslide area in the region of Just – Tęgoborze

4. Results of the numerical stability analysis

The numerical analysis was performed on the 3D spatial model. The model was constructed on the basis of data from six holes [8]. The location of the holes is shown in Fig. 13. The lithological limits have also been confirmed by seismic interferometry studies [19]. The most unfavourable level of the landslide fault were marked. This is a theoretical case of full landslide irrigation. Such a case may take place as a result of, for example, heavy rainfall over a long period of time.

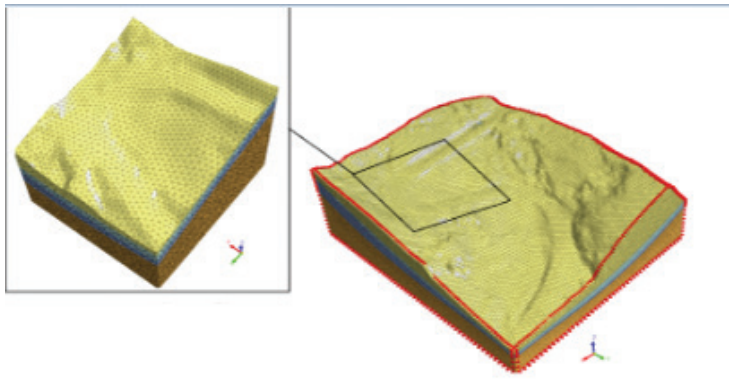

Fig. 13. Model for numerical calculations using MIDAS GTS NX software

The calculations include the values of the physical and mechanical parameters of individual layers (Table 1).

Table 1. Physical and mechanical parameter values of individual layers

Symbol	Density ϱ[g/cm^3]	Poisson ratio ν [-]	Angle of internal friction φ [o]	Cohesion c [kPa]	Deformationmodulus E_0 [MPa]
Asphalt	2.05	0.30	-	-	9,000
Ia2**	1.9	0.30	10*(12)	15*(18)	14
Ia3**	1.9	0.30	10*(15)	15*(25)	17
Ib**	2.18	0.30	15	23	33
Stone	2.5	0.20	–	–	,2000
II2**	2.15	0.30	21	30	27

* introducing the angle of internal friction and cohesion, taking into account flooded area ($I_L > 0.75$)
** Geotechnical layers were adopted on the basis of geotechnical documentation [8] Ia2,Ia3-refers to clay colluviums: saciSi, saclSiOr, Co,clsiOr, saSi, siSa, Ib refers to soft rock, IIa refers toclay delluvium (sasiCl, Cl)

The numerical analysis was performed in the spatial state of stress and strain. The linear elastic-perfectly plastic behaviour of the considered ground was taken into account. The soil model was based on the Coulomb-Mohr hypothesis. A simplified course of geotechnical layers

was established, and determined on the basis of geological – engineering documentation (Fig. 14) [8]. The discretisation of the area was made on the basis of quadrilateral elements. Figure 12 shows the area that was then analysed in the context of vertical displacements for the total level of failure. The area is the same as for the 3D scans analysed above. A numerical analysis was conducted over a larger area to avoid the influence of boundary conditions on the results.

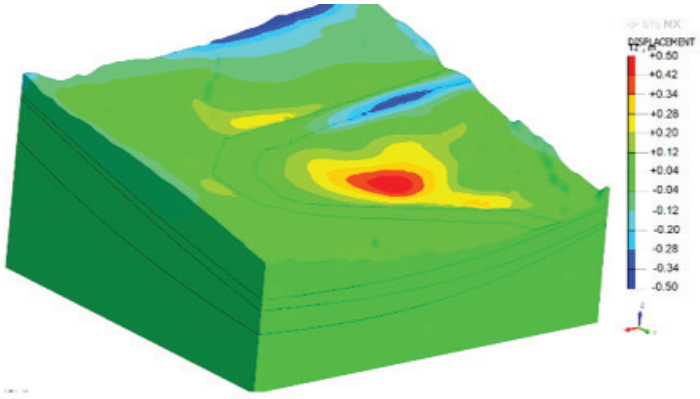

Fig. 14. Results of vertical displacements calculated using the FEM in the MIDAS GTS NX software

As a result of numerical analysis for the conditions of complete failure, a model was obtained that proved to be unstable (safety factor lower than 1) $F = 0.8$. The indicator determined by shear strength reduction method. It is important that reduction of effective stress affecting the reduction of shear strength. In these conditions, vertical displacements illustrate the displacements for boundary conditions (Fig. 15) and may be compared with the vertical displacements obtained by an experimental method from terrestrial laser scanner measurements. From numerical modelling for the conditions of total maximum windfall and slope loss stability, the vertical displacement is 0.5 m. In order to assess the hazard, the landslide hazard indicator R_0 was defined using the following relationship [16]:

$$R_o = \frac{d_{\max}}{D_{\max}} \cdot 100\% \tag{1}$$

where:

$d_{\max}$ – the maximum displacement obtained from the differential model obtained from measurements using a laser scanner,

$D_{\max}$ – the maximum displacement obtained from the numerical model for a given level of ground failures.

The results are summarised in Table 2.

The maximum displacement was considered in order to always assess the most unfavourable situation from the point of view of landslide movement. As seen in Table 2, the threat of landslide movement has different values depending on the displacement measured with the ground laser scanner. Different values of measured displacements at different times result from the movement of the colluvium along the slope and testify to the uneven progress of landslide movements.

Table 2. Hazard indicators for various time periods

	Date	Number of days from zero measurement	Maximum displacement [m]	Hazard indicator
1	2013-04-27	168	0.07	14%
2	2014-04-04	510	0.20	40%
3	2014-08-14	642	0.18	36%
4	2016-06-11	1309	0.17	34%

The following limit values for the landslide hazard indicator have been proposed: $R_0 \geq 50\%$ – increase in the risk of landslide movement, $R_0 \geq 70\%$ – large threat of landslide movement, $R_0 \geq 90\%$ – very large threat of landslide traffic.

5. Summary

The article has presented a methodology for assessing the safety of roads located on natural landslides based on a landslide hazard indicator. The indicator has been defined on the basis of the numerical modelling of landslides and surface monitoring by the RIEGL VZ-400 terrestrial laser scanner. The tests were performed on a section of the road passing through an active landslide. Measurements were conducted from 2012 on national road No. 75 along the section of the road in km from 51 + 900 to 52 + 700 in the town of Tęgoborze – Just. The research was performed on a well-known geologically active landslide. An appropriate level of geological-engineering recognition guarantees the reliability of the obtained results. The presented method of assessing the level of landslide hazard could be used to quickly assess the safety of a road on a landslide.

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FEM DETERMINATION OF THE PLASTIC LIMIT LOAD FOR CYLINDRICAL SHELLS

WYZNACZANIE NOŚNOŚCI PLASTYCZNEJ POWŁOK CYLINDRYCZNYCH NA PODSTAWIE ANALIZY NUMERYCZNEJ MES

Abstract

In this paper a new approach to the consistent identification of the deformation pattern vital for the precise determination of the plastic limit load of a cylindrical shell from MNA when using modified Southwell (MS) and Tangent Stiffness (TS) plots is presented. It is proposed that the formalised assessment of the plastic collapse load can be done by the application of the relation between the load factor increment Δr_R and the arc length s – for an identification of achievement of the complete plastic collapse mechanism from MNA, and then the MS or TS plot for the displacement pattern that corresponds to the identified plastic mechanism.

Keywords: cylindrical shell, plastic collapse, nonlinear analysis

Streszczenie

W artykule przedstawiono metodę pozwalającą na jednoznaczną identyfikację postaci deformacji kluczowej w procesie wyznaczania nośności plastycznej powłoki cylindrycznej z analizy MNA, przy zastosowaniu zmodyfikowanej zależności Southwella (MS) oraz metody sztywności stycznej (TS). Proponuje się, żeby formalna ocena plastycznego obciążenia niszczącego oparta była na wykorzystaniu zależności między przyrostem mnożnika obciążenia Δr_R i długością łuku s – w celu identyfikacji momentu osiągnięcia w analizie kompletnego mechanizmu zniszczenia, a następnie zastosowaniu wykresów zależności MS i TS dla postaci deformacji stowarzyszonej z wskazanym wcześniej mechanizmem.

Słowa kluczowe: powłoka cylindryczna, zniszczenie plastyczne, analiza nieliniowa

1. Introduction

The global numerical MNA/LBA design methodology is widely recommended to be used for the buckling strength assessment of steel shells [1, 2]. Usually, this design format permits to achieve less conservative results in comparison with the stress design approach, acc. to [3] and, at the same time, is much more simple to use in practical applications than the global numerical geometrically and materially nonlinear analysis with imperfections (GMNIA) [4].

The MNA/LBA design procedure uses the materially nonlinear analysis (MNA) and the linear bifurcation analysis (LBA) to access the overall relative slenderness for a shell. A precise assessment of the overall shell slenderness, which is essentially important in problems of elastic-plastic buckling, requires a rigorous evaluation of the elastic critical buckling load and the plastic limit load for a shell. While extraction of the elastic critical buckling load from an eigenvalue analysis is a relatively simple matter, derivation of the plastic limit load from materially nonlinear analysis is much more onerous demand.

According to provisions of the European standard for design of steel shells [3], the plastic resistance of a shell should be obtained through the MNA analysis of a perfect shell, using small displacement theory. As a result of the numerical calculations, relationship between the load factor r_R which is a multiplier on design loads, and the peak deformation w at the point on the shell surface can be obtained. Then, the asymptotic value for plotted r_R-w relation may be taken as the plastic reference resistance ratio r_{Rpl} (which is the largest multiplier achieved from the analysis).

This approach can be easily applied only for cylindrical shells under axisymmetric loading conditions, e.g. for shells subjected to uniform pressure, where the plastic mechanism is governed by membrane yielding [5]. Usually, in such cases, it is also possible to calibrate numerical model by comparing numerical results with analytical solutions. Wide range of such closed-form solutions is presented in [6].

However, for shells under complex loading conditions, it is usually difficult to obtain a suitably long yield plateau on the r_R-w relation to clearly indicate the true plastic strength. For shells where plasticity is dominated by localized bending the load-displacement curve may become flat at very large deformations corresponding to the load that is far in excess of the real plastic strength of a shell. On the other hand, the numerical calculations may be prematurely terminated which produces load-displacement curve that is still rising at the end of the analysis. In such cases development of the plastic mechanism in numerical model requires a large number of increments of nonlinear analysis.

For such cases the plastic strength can be identified using alternative techniques. One of them, recommended in [1], is a modified Southwell plot. Originally this graphical method was dedicated for evaluation of the elastic critical loads of frame systems [7]. Applications of this method for cylindrical shells under simple and complex loading conditions are presented, among others, in [5, 8] and [9]. This plot presents data as the load factor r_R against ratio r_R/w, where w is deformation that seemed to be critical. The modified Southwell plot permits to indicate a precise value of the plastic reference resistance ratio r_{Rpl} even when a complete plastic mechanism has not been achieved during the numerical computations [5]. This estimation is

based on assumption that the plasticity in a given area of the shell is associated with the small change in applied load (r_R) and the high rate of reduction of the secant stiffness (r_R/w).

However, when provisions from the modified Southwell plot are based on data obtained well before an achievement of the complete plastic mechanism in numerical analysis it is desirable to access the accuracy of these provisions using a Convergence Indicator Plot (CIP), proposed in [5]. The CIP presents data as the provisions of the plastic limit load from modified Southwell plot against the parameter ω which is an indicator of the proximity of the load $r_{R,i}$ in a given increment i to the plastic reference resistance ratio $r_{R,MS,i}$ extracted from the MS plot (i.e. $(r_{R,MS,i} - r_{R,i})/ r_{R,i}$). The intercept of $r_{R,MS,i}$-ω curve (or regression lines for all data points) on the ordinate axis can be taken as the plastic collapse load of a shell.

The third graphical technique that enables estimation of the plastic limit load from MNA is Tangent Stiffness Plot (TS). The predictive power of this method for many different cases, i.e. shells, flat plates and plates with imperfections, cylindrical shells, cold-formed U-sections or hot-rolled I-sections, was presented in [10]. The main advantage of TS plot is that it does not require such calculation effort as modified Southwell plot or the convergence indicator factor plot. It uses the measure of reduction in tangent stiffness in a given area of a structural element which corresponds to the development of plastic mechanism in numerical model. It presents data as the tangent stiffness reduction factor τ_κ against load factor r_R, where τ_κ is a quotient of the tangent stiffness K_i (i.e. the actual slope of the load-deformation curve) at a given increment i and the initial stiffness K_{ini}. The load value at which τ_κ achieves value of 0.01 (i.e. K_i drops to 1% of K_{ini}) is taken as the plastic limit load. For further details the reader is referred to [10].

The common denominator for the presented graphical techniques is the dependence of their provisions on the chosen deformation pattern. The chosen displacement pattern, i.e. its location and its direction must correspond to the plastic collapse mechanism for the whole shell. The consequences of different choices of the displacement patterns when using MS plots are illustrated in [5] for the cylindrical shell supported on local brackets. It was shown that selection of displacement which was seemed to be the most intuitive gave 81% overestimation of the correct value of the plastic collapse load. In such cases, determination of the accurate values may require to trial the MS- or CIP and TS plots for different points on the shell surface which may require significant calculation effort.

Sometimes, the final form of the plastic collapse mechanism is unknown at the beginning of the analysis. The shell may start yielding relatively early, which can be an argument for the analyst to terminate the computations. However, achievement of the complete plastic collapse mechanism may require development of local plastic strains in several locations on the shell surface which may involve a large number of additional increments in numerical computations. In such a case, the analysis is terminated prematurely and the displacement pattern selected- and deemed to be critical at given stage of the analysis is not of the crucial importance for the development of the complete plastic collapse mechanism for the whole shell. In such a case, provisions of MS-, CIP- or TS plots will also be incorrect.

This article shows the problem of a consistent identification of the deformation pattern that should be taken for the determination of the plastic limit load of cylindrical shells

from MNA when using MS- and TS plots. Thorough the paper a new graphical technique, using relationship between the load factor increment and arc length, is developed for such identification. The problems encountered when using MS- and TS plots and the potential of the proposed supplementary technique are discussed for a finite element models of a steel cylindrical shell subjected to simple- and complex loading conditions.

2. Finite element model

The numerical models of the shell under consideration were modelled in form of the half-part cylinder using the finite element analysis software Abaqus [11]. The cylinder geometry with radius to thickness ratio r/t = 7.28.8 with thickness t = 5 mm and height $H \approx 2.4r$ was adopted for all calculations (Fig. 1). Elastic-perfectly plastic material model was taken for the analysis with the yield surface described by Huber – Mises - Hencky yield function with: the Young's modulus E = 210 GPa, Poisson's ratio ν = 0.3 and yield stress f_y = 235 MPa. The general-purpose, 4-node quadrilateral shell elements S4R with reduced integration and the hourglass control were applied. Seven integration points were utilized through the wall thickness. The mesh size was adopted individually for each of the considered load case. The cylinder was simply supported at the bottom edge and restrained against out-of-round deformations at the top edge, which reflects the boundary conditions BC2 and BC1, according to [2].

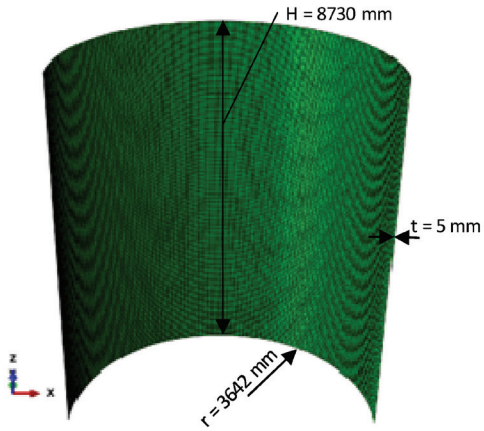

Fig. 1. Geometry of the finite element model

The materially nonlinear analysis (MNA) was performed using the modified Riks method [11] in a regime of small displacement theory, neglecting geometrical nonlinearities. This computational algorithm is mainly utilised to geometrically nonlinear static problems with unstable response of an element. However, it can also be used for problems with nonlinear material characteristics [5, 12]. All calculations were performed with the specified parameters of a Riks step along the static equilibrium path, as follows: the initial and maximum arc length increment of the same value, the total arc length scale factor equal to 1.0, and the minimum

arc length increment computed automatically by the automatic incrementation algorithm. This last set permits to reduce the arc length when a severe nonlinearity appears during the analysis.

3. Shell under simple loading conditions

Identification of the deformation pattern that is vital for the development of plastic mechanism for shells subjected to horizontal ring loading or uniform internal pressure (Fig. 2) is a relatively simple matter. However, these well documented examples with easily identified form of the plastic mechanism are utilised here to develop a new graphical method that will simplify the procedure of identification of the critical deformation pattern for shells with more complex pattern of the plastic collapse mechanism.

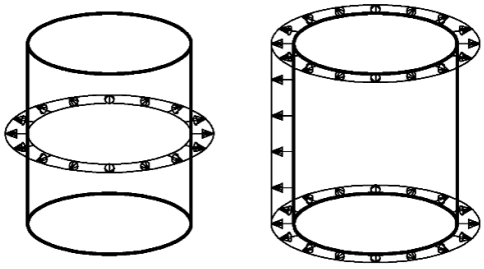

Fig. 2. Investigated shells subjected to (from left): ring loading, uniform internal pressure

3.1. Extraction of plastic limit load from MS plot and TS plot

The adequacy of the modified Southwell plot and tangent stiffness plot for extraction of the plastic strength for a ring-loaded shell and a shell subjected to uniform pressure (Fig. 1) was proved in [5] and [10]. Both problems have analytical solutions, documented in [6]. The plastic limit reference ratio for shell subjected to ring loading (1) and uniform internal pressure (2) may be calculated form expressions:

$$r_{R,l} = 1.949 \frac{f_y \cdot t}{F_{ref}} \sqrt{\frac{t}{r}} \tag{1}$$

$$r_{R,l} = \frac{f_y \cdot t}{r \cdot p_{ref}} \left(1 + \frac{1}{1 + 2\varpi^2} \right) \tag{2}$$

For the ring-loaded shell the uniform line load F_{ref} = 1 kN/m was applied in the plane of symmetry of the shell. In the step definition 2000 arc length increments were specified with an initial, minimum and maximum arc length increments of 0.5, $1.0 \cdot 10^{-10}$ and 0.5, respectively. For the shell subjected to uniform internal pressure of magnitude p_{ref} = 1 kN/m^2, the step parameters were specified, as follows: 1000 arc length increments with an initial, minimum and maximum arc length increments of 1.0, $1.0 \cdot 10^{-5}$ and 1.0, respectively.

The numerically obtained paths of equilibrium for the considered shells are presented in Fig. 3. As it can be seen from relation between the load factor r_R and peak displacement w, the analytically determined values of the plastic reference resistance ratio $r_{R,l}$ of 84.8 (from Eq. 1) and 322.7 (from Eq. 2) are very close to the maximum values of the load factor $r_{R,max}$ obtained from numerical analysis. However in case of the shell under uniform pressure the numerical computations were automatically terminated before achievement of declared maximum number of arc length increments since the required increment was less than the minimum specified.

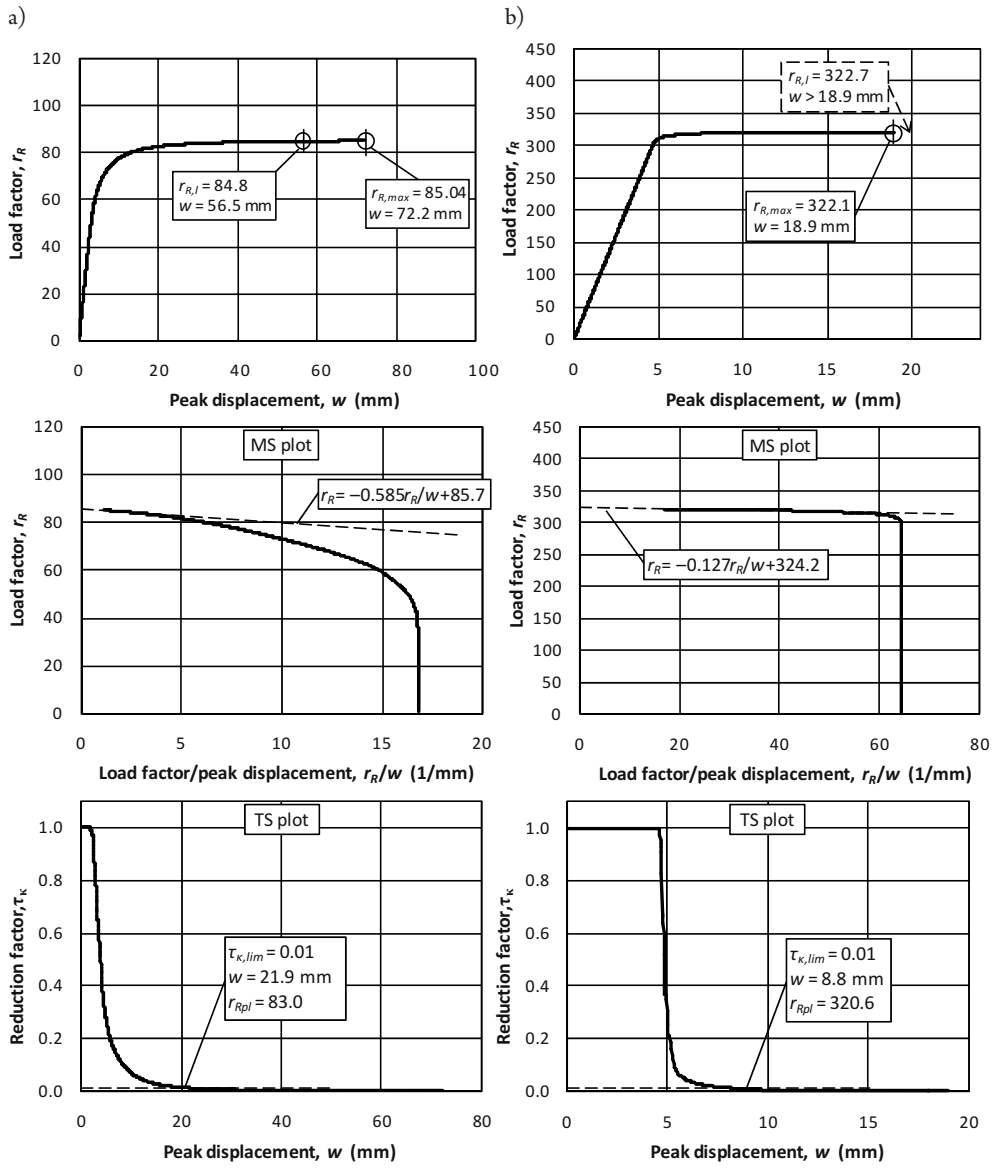

Fig. 3. Paths of equilibrium for a shell subjected to: a) ring loading, b) uniform internal pressure

The curves constructed from the modified Southwell plots (MS plots in Fig. 3) for both considered load cases, initially are vertical, which indicates the elastic range of behaviour of the shells. The first kink of the curves corresponds to the first yield on the shell surface. Departure from the kink to the linear, almost horizontal portion of the curves, corresponds to the development of plastic field in shells. This second portion of the curves is of crucial importance, since the intercepts of regression lines (dashed lines), drawn using three last data points acc. to [5], with the ordinate axes are taken as projections of the plastic limit reference ratio r_{Rpl}. It should be noted however, that usually a series of regression lines is necessary to make since the plastic limit load should be taken as the lowest projection on the vertical axis. The extracted values of r_{Rpl} are 85.7 and 324.4,which gives 1% and 0.5% overestimation of theoretical results.

The tangent stiffness reduction plot (TS plot, in Fig. 3) produces curves that initially are horizontal, i.e. where tangent stiffness reduction factor $\tau_\kappa = 1.0$, which represents the elastic stage of behaviour of the considered shells. The departure from horizontal to almost vertical path corresponds to the beginning of the elastic-plastic range and further development of plasticity in elements. This second portion illustrates a decrement of the tangent stiffness in a point located in the plastic field, relative to the initial elastic stiffness. Extraction of load factor r_R corresponding to $\tau_{\kappa,\mathrm{lim}} = 0.01$ gives $r_{R,pl}$ ratios of 83 and 320.6, which gives 2% and 0.5% underestimation of analytically determined values for shell subjected to ring loading and uniform pressure, respectively.

Comparison of numerical results with closed-form analytical solutions shows the predictive power of MS- and TS plots. The obtained results will be used to show the process of development of a new graphical method that supplies the procedure of identification of the deformation pattern for the precise extraction of the plastic limit load from MS- and TS plots.

3.2. Development of a new graphical technique

It is difficult to indicate a universal rule for the choice of the displacement pattern for Ms- and TS plots. However, the general consideration is that the chosen displacement pattern must be associated with the development of a plastic collapse mechanism of a shell. For the considered shells subjected to ring loading or uniform internal pressure this choice is relatively easy since, as it might be supposed, the critical displacement pattern is a peak displacement which is normal to the shell surface. The progressive plasticity is indicated from MS- or TS plots in form of the rate of reduction of the secant stiffness or the tangent stiffness, respectively, at one-selected point on the shell surface. However, the initiation and the further development of the plastic mechanism in both shells can be also indicated by consideration the course of relation between the load factor increment Δr_R and the arc length s. The load factor increment is one of the unknowns in Riks method, while the arc length is used to measure the progress of the solution [11]. These both parameters correspond to the structural response of the whole element under consideration. The Δr_R-s relations for the ring-loaded shell and the under uniform pressure are presented in Fig. 4. Initially, the curves are horizontal (i.e. Δr_R has its initial value) which corresponds to the stage where both shells remain elastic. The first yield on the shell surfaces is followed by a sudden drop in values of the load factor increment Δr_R. As the shells experience significant plasticity the curves

become almost vertical. The end of the vertical potions is followed by a smoothed bent and transition to the linear almost horizontal portion of the curves, where Δr_R tends to be zero. This graphical technique takes advantage from the feature of the modified Riks algorithm where the development of the plastic strain in a material, at a given arc length, is associated with the reduction of load increments. As it can be seen from Fig. 4, for both considered load cases, the difference in values of the plastic reference resistance ratio extracted from MS- and TS plots (which gave slight over- and underestimation of the analytical values, respectively), is realized within the linear portion of the Δr_R-s relations, where Δr_R is close to zero. It can be also seen, that coordinates from provisions of the TS plots are located in the vicinity of the transition from the smoothed bent to the linear-almost horizontal portion of the curves. At these transition points, the load factor increments $\Delta r_{R,TS}$ achieve 1.2 and 2.9% of their initially set values for the ring-loaded shell and the shell under uniform pressure, respectively. Such decrement in value of load factor increment permits to assume, for further considerations, that the beginning of the bottom linear portion of the Δr_R-s relation indicates the initiation of the plastic collapse mechanism for the shells under consideration.

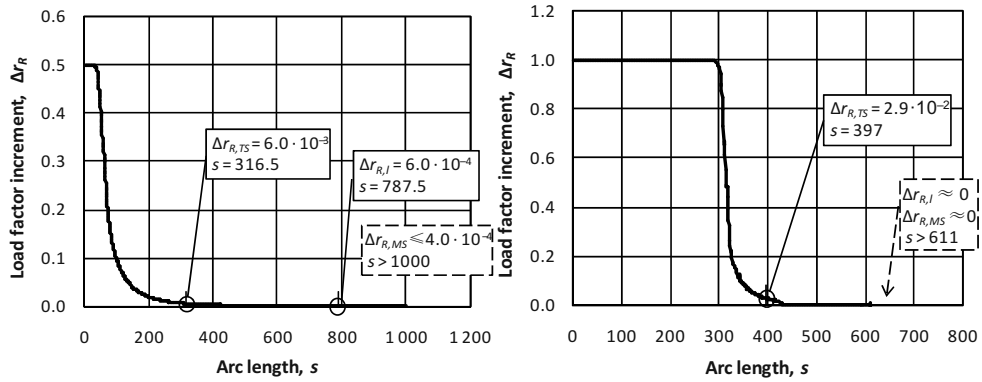

Fig. 4. Relations between load factor increment and arc length for shell subjected to (from left): ring loading, uniform internal pressure

It should be recapitulated that the presented graphical method is based on parameters of the MNA that corresponds to the structural response of the whole shell rather than the limited-arbitrarily selected portion of the shell. This potential feature of this method will be examined for identification of the critical deformation pattern in shell subjected to complex loading conditions, where the pattern of the plastic collapse mechanism is unknown at the beginning of the analysis.

4. Shell under complex loading conditions

To reflect complex loading conditions the shell was loaded by design combination of dead load and wind action (on X axis direction, Fig. 1). For the Riks analysis 2000 arc length increments were specified with their initial, minimum and maximum values of 1.0,

$1.0 \cdot 10^{-10}$ and 1.0, respectively. Computations were automatically terminated at the 1824 arc length increment when the necessary increment size was less than the minimum specified. The shell in a final deformed configuration is presented in Fig. 5. Points 1 and 2, marked in Fig. 5, indicate areas of the shell surface with the several plastic strains that were developed at different stages of the numerical computations. In point 1, peak deformations within the plastic field were associated with attainment of the full thickness yield, first – in vicinity of the bottom edge, and then – near the top edge of the shell, within the first 100 increments. Point 2 indicates the area of the severe plastic straining that developed within the range of further 100 increments (200 increments in total). It should be noted here that attainment of the peak deformation in point 2 was associated with achievement of the final deformed configuration of the shell; in progress of computations only scale of deformations was changing. The paths of static equilibrium for points 1 and 2 and Δr_R-s relations plotted at 100 increment and the last – 1824 increment are presented in Fig. 6.

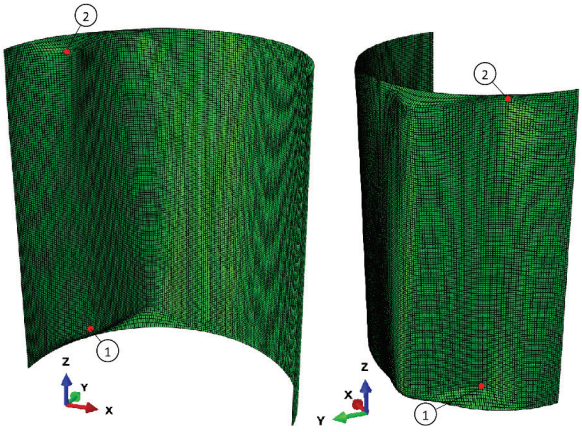

Fig. 5. The finite element model in a final deformed configuration (deformation scale factor is equal to 1.0)

As it can be seen in Fig. 6, the modified Southwell plots (r_R-r_R/w) and tangent stiffness plots (τ_κ-r_R) predict two different values of the plastic limit load for the two selected displacement patterns (in point 1 and 2) which were supposed to be critical at different stages of the analysis. In the considered case the choice of the proper displacement pattern is difficult since the pattern of the plastic collapse mechanism is unknown at the beginning of the analysis. To identify the phenomena involved in development of the plastic collapse visualisation module of Abaqus was used [11]. These phenomena are indicated on Δr_R-s relations by letters A, B, C and D. Coordinates of the letters A, B and C correspond to: the first yield on the shell surface, full thickness yield in a limited area near the bottom and the top edge of the shell, respectively. These phenomena were identified within the first 100 increments of the analysis. The lower slope of the Δr_R-s curve between points B and C provides information that the spread of plasticity is gradual and plasticity is dominated by bending. It can be also seen that at this stage of analysis the load factor increment achieved 17% of its initial value, which can be assessed as a significant reserve. It can be therefore assumed that the selected displacement pattern in point 1 is not associated with the complete plastic mechanism of the shell.

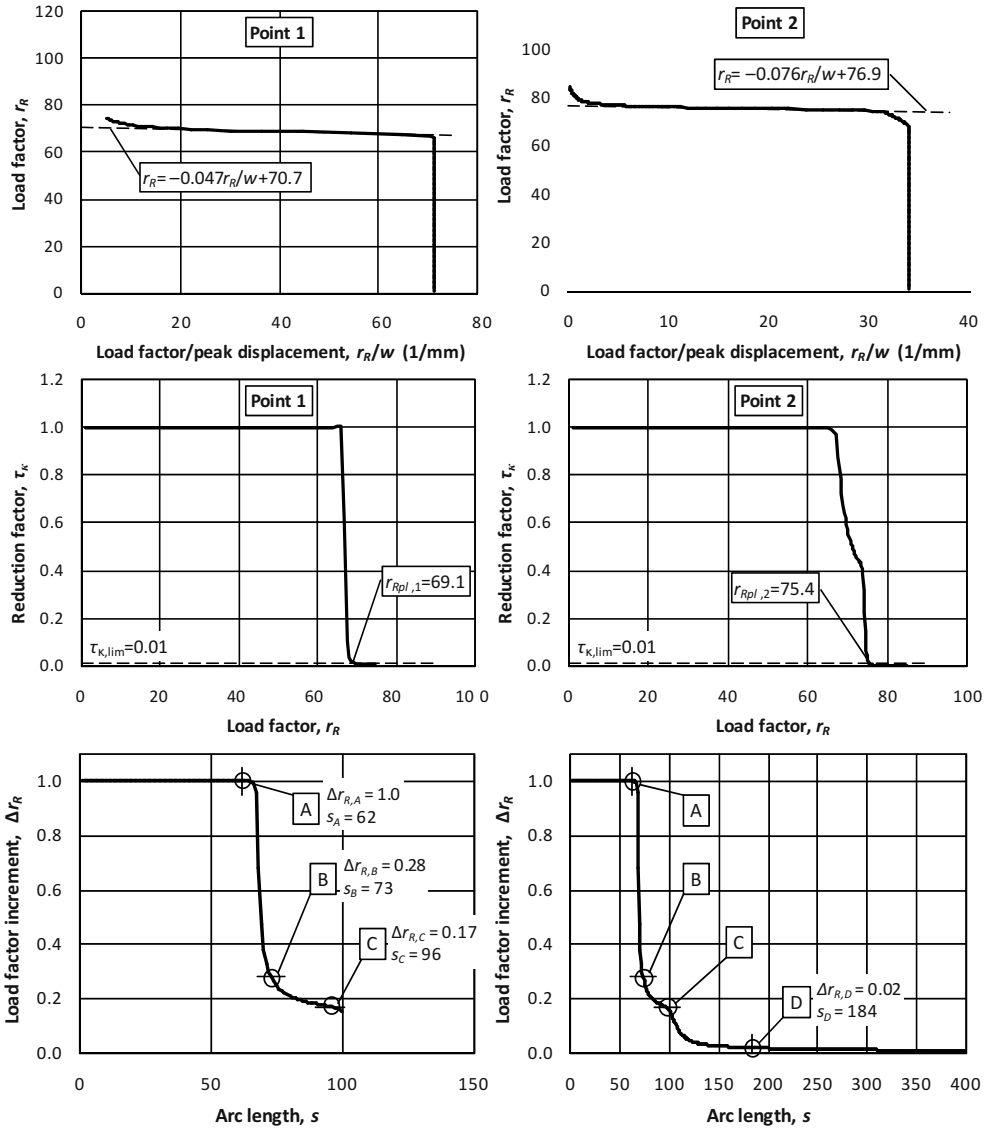

Fig. 6. Paths of equilibrium obtained at: a) 100 increment, b) 1824 increment (for clarity only inital part of Δr_R-s relation was plotted)

Within the further 100 increments of the analysis, the factor Δr_R was reduced to 2% of the initial value which illustrates that the element experiences significant spread of plasticity. Coordinates for point marked with the letter D indicate beginning of the severe plastic straining at point 2 on the shell surface, which was associated with the achievement of the final pattern of deformation of the shell. For higher loads, excessive yielding of the shell, accompanied by unrealistically large deformations, was observed. It suffices to state that coordinates for point D in Δr_R-s curve indicate the development of the complete plastic collapse mechanism of the shell. Therefore the displacement pattern in point 2 (Fig. 5) can be

used for a precise predictions of the plastic limit load from the MS- and TS plots. Note that, similarly as for shells under simple loading conditions, point D is located in vicinity of the transition from the nonlinear bent to the linear portion of the Δr_R-s relation, where Δr_R tends to be zero. It proves that the proposed graphical method can be used for identification of the plastic collapse mechanism and the corresponded deformation pattern for a determination of the plastic limit load from MS- and TS plots.

5. Conclusions

The extraction of the plastic collapse load from the modified Southwell plot (MS) or the tangent stiffness plot (TS) is a challenging task if the collapse mechanism involves high local strains occurring at different locations on the shell surface, at different stages of the analysis. In such cases it may be necessary to trial the MS- and TS plots for different locations which can make these graphical methods impractical.

In this paper a new approach to the consistent identification of the critical deformation pattern for the precise determination of the plastic limit load from MNA when using MS- and TS plots was developed and examined. It is proposed that the formalised assessment of the plastic collapse load can be done by the usage of the relation between the load factor increment Δr_R and the arc length s, and then the modified Southwell plot or the tangent stiffness plot. In this approach the MS- or TS plots should be applied to the displacement pattern that was identified, from Δr_R-s relation, to be associated with the plastic collapse mechanism of a shell.

The Δr_R-s relation permits to track the structural response of the whole element during the progress of the numerical analysis. The curves obtained for examined shells under simple and complex loading conditions reveals a sudden decrement in value of the load factor increment after first yield and further spread of plasticity. The obtained results clearly indicate that the bottom, linear portion of the Δr_R-s curve (i.e. where Δr_R tends to be zero) shows the equilibrium associated with the plastic collapse mechanism. The transition from the smoothed bent to the beginning of the linear portion the Δr_R-s curve can be treated as the achievement of the complete plastic mechanism. Application of the MS- or TS plots to the displacement pattern with a peak plastic strain that corresponds to the plastic collapse permits for a precise extraction of the plastic limit load for a cylindrical shell.

It is worth to mention that the proposed graphical method is a practical alternative for time-consuming visual assessment of the stress/strain state in shell, done during the progress of the analysis to identify the pattern of the plastic collapse mechanism that is unknown at the beginning of the analysis.

The above findings suggest that the transition from the nonlinear to the linear portion of the Δr_R-s curve can be treated as a condition for the termination of numerical calculations which allows for reduction of the computational expense.

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Risk minimization methods for loading dangerous goods into tanker trains

Sposoby minimalizacji ryzyka podczas załadunku materiałów niebezpiecznych do cystern kolejowych

Abstract

The paper focuses attention on the problem of increased risks during the loading and unloading of railway tankers. To evaluate the risk which may occur during loading dangerous goods into tanker trains, the loading processes have been divided into seven stages. Based on HIRA risk analysis, for each stage of improvements, Quick Kaizen tasks were proposed. Special attention was paid to possible improvements in technical means, tools and processes. Thanks to the proposed improvements, it is possible to increase safety, not only during the loading of dangerous goods, but also in cases of loading and transportation of standard cargoes.

Keywords: risk evaluation, tanker train loading, HIRA analysis, dangerous goods

Streszczenie

W artykule zwrócono uwagę na problem zwiększonego poziomu ryzyka powstającego podczas załadunku i rozładunku cystern kolejowych. W celu jego oceny dokonano podziału procesu załadunku na siedem etapów oraz uwzględniono dodatkowo prace konserwacyjne i sytuacje nietypowe, które mogą wystąpić podczas załadunku materiałów niebezpiecznych. Na podstawie przeprowadzonej oceny ryzyka w każdym z poszczególnych etapów utworzono zbiór zaleceń pozwalających na zwiększenie bezpieczeństwa pracowników. Zwrócono szczególną uwagę na możliwe usprawnienia wykorzystywanych środków technicznych, narzędzi oraz sposobu postępowania. Dzięki przedstawionym w artykule zaleceniom możliwe jest zwiększenie poziomu bezpieczeństwa nie tylko podczas załadunku materiałów niebezpiecznych, ale także w przypadku przewozu ładunków standardowych.

Słowa kluczowe: ocena ryzyka, załadunek cystern, analiza HIRA, materiały niebezpieczne

1. Introduction

During loading process of dangerous goods into a tanker train, employees are exposed to vapours and concentrations of the substance being transported. These cargoes are transported in Z type railway wagons (Fig. 1) [9]. Transportation of dangerous goods is regulated by international regulations called RID (Fr. Règlement concernant le transport international ferroviaire des marchandises dangereuses) constituting annex C to the Convention on International Carriage by Rail (COTIF) of 9.05.1980 [11]. COTIF 1999 regulations apply strictly in railway transport in the case where the location of the cargo shipment is located in two countries-signatories of COTIF. These regulations are also used if the place of shipment or reception is located in one signatory country and if rail transport is to be dealt with as one of the elements of the transport process (transport chain) [4, 7].

Fig. 1. Rain wagon, type Zaces [12]

The Minister of Labour and Social Policy Regulation of 23 June 2014 determines the concentrations of harmful factors of chemical and particulate pollutants in the work environment [5]. It determines the highest acceptable concentration of harmful factors for healthy, established as [3]:

- **highest acceptable concentration (NDS)** – weighted value of average concentration, which can impact on the employee during an 8-hour daily and average weekly working time during its activity should not cause negative changes in his state of health and the health of his future generations; working time is defined in the Act of 26 June 1974 – Labour Code;
- **highest acceptable instantaneous concentration (NDSCh)** – average concentration which would not cause negative changes in employee health, if it is present in working

environment for no more than 15 minutes and no more than twice during a work shift, in an interval of not less than 1 hour;

- **highest acceptable ceiling concentration (NDSP)** – the concentration value which due to the risk to the health or life of the employee cannot be exceeded in the work environment at any time.

For the case presented in this paper, during the loading process, employees are exposed to vapours and harmful concentrations of the substances being loaded above the maximum acceptable concentration (NDS) for approximately 110 minutes at a distance of 5 m from the loading funnel. At a distance of 15–50 m, it is possible to smell the odour, which creates extreme discomfort [6, 1]the paper addressed a fuzzy extended fault tree analysis (FFTA).

The stages of the process of loading a tanker train are shown in Figure 2.

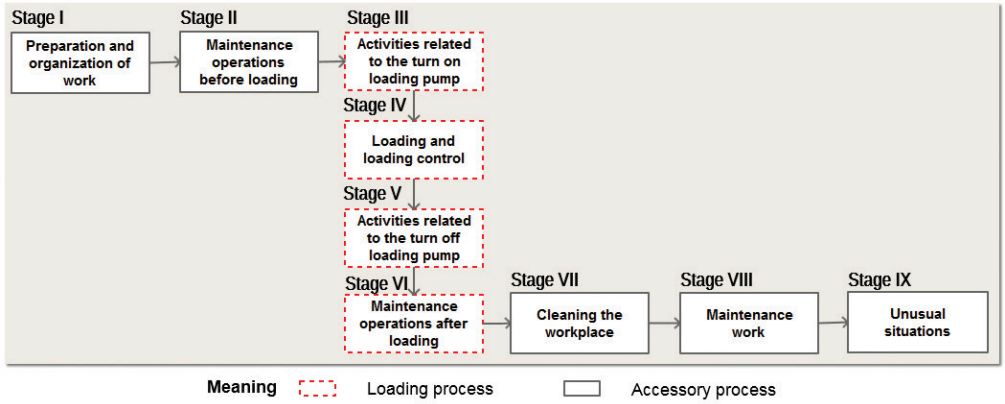

Fig. 2. Stages of the process of loading a tanker train

The process of loading a tanker train can be divided into stages. The risk to human safety in regard of the loading process occurs in steps III–VI.

Under Stage I (Preparation and organisation of work), the following sub activities have been separated out: participation in the briefing shift, moving to workplace, tool preparation, checking exceedances of the concentration on the central gas detection system, checking tanker, handles checking the validity of the revision of the tank and checking the temperature of the tank.

Under Stage II (Maintenance operations before loading), the following sub activities have been separated out: connecting the grounding of the tanker, moving around platforms in the region of loading, checking breathing valve on the tanker, unscrewing the hatches of the tanker, inserting loading funnel to the tanker, and checking the encapsulation.

Under Stage III (Activities related to the turn on loading pump), the following sub activities have been separated out: checking the status of devices for loading, valve manipulation (setting the path), setting the amount of product loading, starting the pump.

Under Stage IV (Loading and loading control), the following sub activity has been separated out: controlling the quantity of goods loaded.

Under Stage V (Activities related to the turn off the loading pump), the following sub activities have been separated out: turning off the pump, manipulation of valves (closing the path), removal loading funnel from the tanker, and closing the hatch of the tanker.

Under Stage VI (Maintenance operations after loading), the following sub activities have been separated out: taking a sample, closing the hatch of the tanker, sealing of all valves, gate valves and top hatch (after taking samples for analysis), raising the loading platform, securing loading funnel, and detaching the grounding connection of the loaded tanker.

Under Stage VII (Cleaning the workplace), the following sub activities have been separated out: cleaning the tray, cleaning the operator's room, cleaning the area of the loading facility.

Under Stage VIII (Maintenance work), the following sub activities have been separated out: maintenance of valves, maintenance of fittings, maintenance of wires.

Under Stage IX (Unusual situations) the following sub activities have been separated out: unsealing standard valves or valves completely emptying the tanker, unloading the tanker.

2. HIRA hazard identification and risk analysis

Securing and proper loading of cargo have a significant impact on human safety. Loading should be done in such way as to minimize the risk of potential danger situations and their results [8].

Risk analysis and determination of the value of safety indicators allows possible risks and their consequences to be visualized [6]. The most common types of risk analyses are HIRA and FMEA, which are performed prior to the planned implementation of improvements [10, 2].

For the stages listed in chapter 1, the identification of risk and its consequences has been conducted. For the identification of risk and its analysis, a HIRA (*Hazard Identification and Risk Analysis*) analysis has been performed. This allowed all potential risks which may occur during the loading or unloading of the tanker to be identified. For analysis, the matrix evaluation in accordance with table 1 has been constructed.

For the calculation of the risk assessment the following formula has been used:

$$R = w_c \cdot p_c + w_p \cdot p_r + w_e \cdot e + w_{sp} \cdot s_p + w_i \cdot i_r \tag{1}$$

where:

R – coefficient of risk,
w_c – weight of potential severity of injury,
w_p – weight of risk perception,
w_e – weight of ergonomics,
w_{sp} – weight of working environment,
w_i – weight of other risk,
p_c – potential severity of injury,
p_r – risk perception,

e – ergonomics,
s_p – working environment,
i_r – other risk.

The weights are established as constant for this method and the values are presented in Table 1. The value of a factor is dependent on the importance (e.g. the potential severity of injury for importance: heavy, deadly $p_c = 3$).

Table 1. Matrix evaluation of risk for HIRA analyze

	The potential severity of injury	The perception of risk (risk awareness by people)	Ergonomics	Working environment	Others eg.: The risk to external staff	Value (p)
Importance	Heavy, deadly	Careless	Not natural	Wrong	Big	3
	Serious	Normal	Slightly unnatural	Problematic	Average	2
	Light	Very important	Normal	No problem	Low	1
	No impact	Safe	Natural	Comfortable	Absence	0
Weight (w)	$w_c = 2$	$w_p = 2$	$w_e = 1$	$w_{sp} = 1$	$w_i = 1$	

If the value of a risk coefficient is in the range 1–6, it is classified as low risk. If the value equals 7, the risk is considered as normal. Whereas, if the value is in the range 8–21, it is classified as average. In the case when this value exceeds 16, the risk is classified as high.

When analyzing all the activities carried during the loading of tankers, the following were identified:

- 248 activities of low risk,
- 44 activities of normal risk,
- 5 activities of average risk,
- 0 activities of high risk.

Based on this analysis, it was found that low risk activities do not require improvements. Table 2 shows groups of activities of normal and average risk level. No high risk activities were identified. For each activity, improvements in the form of Quick Kaizen (QK) have been assigned.

The Kaizen method for processes is characterized by a high quantity of small improvements, which require little effort. Due to this there can be many improvements, and they are easy to implement [1, 2].

In the case analyzed, Kaizen methods were used to adjust the technical elements of the system.

Table 2. Identification of risk taking into account the activities performed by employees

Description of the risk (hazard)	Consequence	Activity	Quant.	QK
uncontrolled movement loading funnel	bruises, sprains	Maintenance operations before loading	2	6
vapours caused by leaks around the cone	poisoning	Maintenance operations before loading	4	5
		Loading and loading control	4	5
		Activities related to the turn off loading pump	4	5
difference in platforms levels	contusion	Maintenance operations before loading	2	7
moving parts	contusion	Maintenance operations after loading	2	6
corroded elements of the thermal insulation of the collector at the height of the loading	contusion, wound	Preparation and organization of work	14	1
		Maintenance operations before loading	4	1
		Activities related to the turn on loading pump	7	1
		Loading and loading control	4	1
		Activities related to the turn off loading pump	2	1
		Maintenance operations after loading	7	1
		Cleaning the workplace	7	1
		Maintenance work	7	1
		Unusual situations	14	1
corroded entrance stairs	sprains, breaks	Maintenance operations before loading	2	2
		Activities related to the turn on loading pump	9	2
		Loading and loading control	4	2
		Activities related to the turn off loading pump	12	2
		Maintenance operations after loading	12	2
		Cleaning the workplace	2	2
		Maintenance work	7	2
		Unusual situations	2	2
height	breaks, contusion	Maintenance operations before loading	2	4
protruding arm of bolts on the intake manifold	bruises, sprains	Maintenance operations before loading	4	3
		Maintenance operations after loading	2	3

3. Possible improvements using Quick Kaizen

Based on the HIRA analysis, seven small improvements (planned as Quick Kaizen) have been proposed. Their description, causes of risk, and corrective actions have been shown above. The part of the tanker used in the loading process is shown in Figure 3.

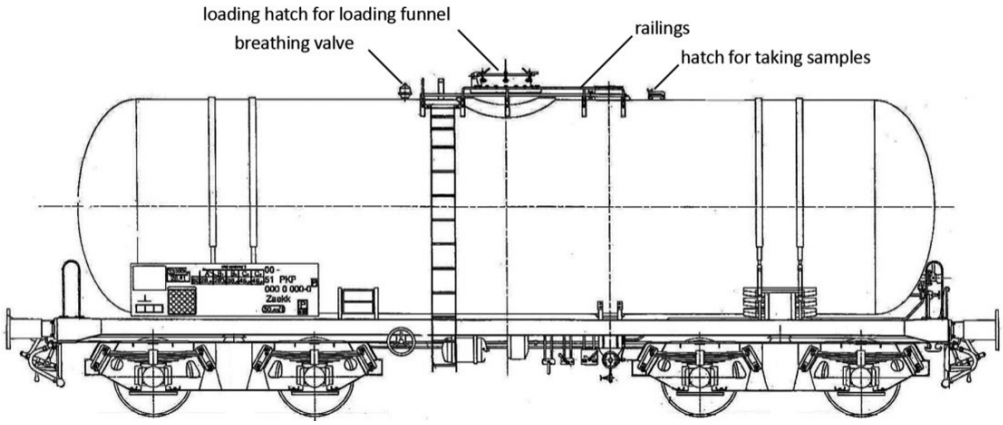

Fig. 3. Selected part of tanker used in the loading process

QK 1 – Vapour collector. Workers are exposed to risk during activities like: checking handle tanker, checking the validity of the revision of the tank and checking the temperature of the tank, grounding the connection of the tanker, cleaning the area of the loading facility, maintenance of fittings, and loading and sealing of the tanker. They are exposed to the risk of insulation falling with the vaporcollector and striking the employee operating the loading station. Possible causes of corrosion include the following: adverse weather conditions, lack of periodic inspections, leak on the pipe suction vapor, incorrectly matched material and incorrectly matched thermal insulation.

As part of the corrective action, it is justified to replace corroded parts of the heat shield of the vapour collector.

QK 2 – Corrosion and anti-corrosion coating. Workers are exposed to the risk of stumbling or falling when entering the loading platform to perform such tasks as: pressing the breathing valve, securing the loading funnel, moving and inserting the funnel into the tanker, checking and controlling the pipe of the hopper and the tank, manipulating valves, maintenance of fittings, and unloading or sealing the tanker. As possible corrosion causes, the following can be listed: adverse weather conditions, lack of periodic inspections, leak on the pipe suction vapour, incorrectly matched material, and incorrectly matched thermal insulation.

As part of the corrective action, replacement of corroded parts of the heat shield of the vapour collector is justified.

QK 3 – Valve of the intake manifold vapour. During the performance of all actions on the loading platform, workers are exposed to being struck by the protruding bolts arm on the

vapour intake manifold, which is extended in the closed position on the loading platform. Possible causes are: a protruding flap in the closed position, a too long arm of the valve, and the vertical position of the valve.

Within the corrective actions, it is possible to rotate the valve in the vapour intake manifold toward the platform by 90 degrees and change the valve arm by 180 degrees.

QK 4 – Picking the tanker. Sometimes, the breathing valve is positioned on the tanker approximately 70 cm from the loading platform railing. Workers inspecting the breathing valve on the tanker must lean out of the loading platform railings, which is associated with the risk of falling. As possible causes, the following may be mentioned: incorrect manner of picking the tanker to control breathing valve, or too small loading platforms.

As a corrective action, it is possible, in the case of a tanker in which breathing valves are located at a considerable distance from the loading platform, to make organizational changes in the manner of picking the tanker train.

QK 5 – Leakage of the vapour of transported substances into the atmosphere. During loading the tanker, part of the vapours comes out via the gap between the hatch and the cone to the atmosphere. The worker who is loading it is exposed to harmful vapours. At the same time, the vapours make an irritating smell despite the absence exceedance of NDS, smelt at a distance of several metres from the loading. Possible causes include: inefficient pneumatic pressure cone, defective gum seal on the cone, low manifold vapour vacuum intake, and clogged vapour intake manifold.

Corrective actions include: replacement of the pneumatic valve pressuring the cone, replacement gum seal on the cone, mount vacuum gauge for measuring the vapour intake in the intake manifold, performing a pairing of vapour intake manifold, executing the adapter cone leveling differences between the hatches of tanks, bringing the vapours to the vapour intake manifold.

QK 6 – Moving funnel. While the employee unfastens the funnel of the railings, he or she is exposed to uncontrolled movement of the loading hopper. In addition, uncontrolled movement of the funnel can be caused by weather conditions such as a strong wind. Causes of this situation can be listed as: the possibility of free movement of the funnel in the fixed position and the lack of locking of funnel in the fixed position.

As a corrective action, it is possible to fix the devices of the loading funnel.

QK 7 – Loading funnel hampers the landing platform on the tanker. Some railway cisterns are equipped with additional railings next to the tanker loading platform, enlarging the platform by about 8 cm. This prevents the movement of the loading funnel over the hatch of the tanker. This forces the workers to lift the funnel above the level of the platform, which creates an additional risk for workers by exposing them to the vapours of the transported substances. Possible causes of this problem include: the inability to complete descent of the platform, the funnel hampers the step of the platform, and a wrongly selected tanker.

As a corrective action is possible to make cutouts in the movable platform.

4. Planned results of implementations

Thanks to the planned implementation of Quick Kaizen, it is possible to make small improvements which will greatly help to reduce the level of risk. For tanker loading, 297 activities have been identified as steps in the loading process. Before the implementation of improvements, 44 activities were classified at a normal risk level, whereas another 5 were classified at the average risk level. After the implementations of improvements and HIRA re-analysis, both normal and average level of risk activities were classified as low risk activities. These changes are shown in Figure 4.

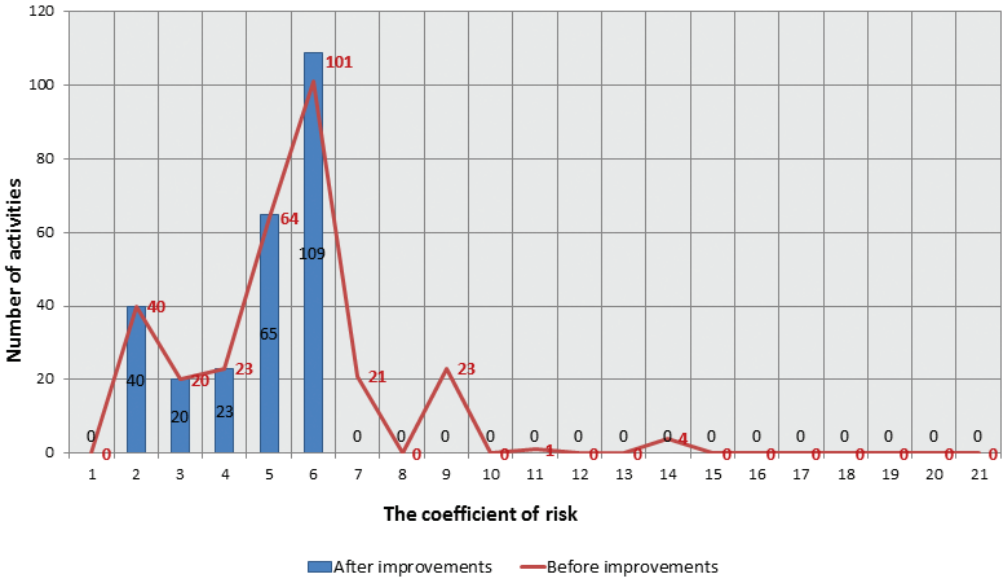

Fig. 4. Changing the values of risk assessment as a result of implementation of Quick Kaizen tasks

5. Conclusions

The problem of increased risks during the loading and unloading of railway tanks is an important issue for the safety of employees. In this case, in order to evaluate the risks which may occur during loading dangerous goods into tankers, the loading processes have been divided into seven stages. Thanks to the HIRA analysis, it was possible to identify and classify activities according to risk criterion. This analysis allowed us to determine which of the activities performed were the most risky and should be improved first. Base on this risk identification and HIRA risk analysis for each stage of improvement, Quick Kaizen tasks were planned. Thanks to this, it was possible in to improve those activities a clear and simple way. Special attention was paid to possible improvements in technical means, tools and processes. HIRA risk analysis can be used not only during loading of dangerous goods, but also in cases of loading and transportation of standard cargoes. In this case, with the planned improvements, it is expected to reduce the level of risk to low level.

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Prediction of thickness of pantograph contact strips using Artificial Neural Networks

Predykcja grubości nakładki ślizgowej odbieraka prądu przy użyciu Sztucznych Sieci Neuronowych

Abstract

The sliding strip of the current collector (pantograph) of a rail vehicle is an element directly cooperating with the catenary and is exposed to abrasion, electric discharge and various types of damage. It is therefore the most frequently replaced element. However, often sliding strips are exchanged before exceeding the limit thickness value, which increases the costs related to technical maintenance. Because the wear process is dependent on many factors, heuristic methods are necessary to predict the thickness of the sliding strip. Knowing the predicted thickness value, it will be possible to adapt the maintenance cycle. In the article, the results of simulations carried out based on the developed structure of the artificial neural network are also presented.

Keywords: rail vehicles, pantograph, current collector, thickness prediction, sliding cover, artificial neural networks, ANN

Streszczenie

Nakładka ślizgowa odbieraka prądu pojazdu szynowego jest elementem bezpośrednio współpracującym z siecią trakcyjną w związku, z czym narażona jest na zużycie ścierne, elektroerozyjne oraz różnego rodzaju uszkodzenia. Jest, zatem elementem najczęściej wymienianym. Często jednak nakładki wymieniane są przed przekroczeniem granicznej wartości grubości, co zwiększa koszty związane z obsługą techniczną. Ponieważ proces zużycia jest zależny od wielu czynników, dlatego do predykcji grubości nakładki ślizgowej niezbędne jest zastosowanie metod heurystycznych. Znając prognozowaną wartość grubości, możliwe będzie odpowiednie dostosowanie cyklu utrzymania. W artykule przedstawiono wyniki symulacji przeprowadzonych na podstawie opracowanej struktury sztucznej sieci neuronowej.

Słowa kluczowe: pojazdy szynowe, pantograf, odbierak prądu, predykcja grubości, nakładka ślizgowa, sztuczne sieci neuronowe, SSN

1. Introduction

The current collector, commonly called the pantograph (Fig. 1), is used to receive current from the overhead lines to feed a traction vehicle. Due to the fact that it is an element directly cooperating with the catenary, it is exposed to operational wear and various types of damage that may arise during usage.

Fig. 1. Current collector (pantograph 160EC [1])

In railroads, it is a common problem to find out the cause of current collector damage. This is a significant problem because the Rail Infrastructure Manager is responsible for the condition of the overhead contact line, while the railway carrier is responsible for the condition of the current collector. In the event of a network failure due to poor technical condition of the current collector, the cost of repairs must be borne by the railway carrier. In the event of damage due to an incorrect condition of the overhead contact line, the costs lie with the infrastructure manager. Currently, in case of such events, a committee is called to determine the cause of damage of the current collector and the overhead contact line. In many cases, this is a subject of dispute due to the lack of methods allowing for a clear assessment of the cause of current collector damage.

The sliding strip, which is part of the direct co-operation of the pantograph with the overhead catenary wire, is exposed to the greatest operational wear. The reason for replacing the contact strips, beyond the mentioned wear, may be damage to the sliding strip surface. Having data on operating parameters such as level of carbon strip wear, vibrations of a current collector or the pantograph – catenary contact force, and information about the cause of replacement of the contact strips and the pantograph, it would be possible to deduce the cause of damage both the contact strips and the entire pantograph.

This article summarizes the most common causes of replacement of carbon strips of the current collector with possible causes of damage. The scale of the problem has been identified based on data from pantograph measurement notes. Over 1500 measurements of 62 locomotives of type EP09 and EU07 were analysed. Properly prepared and digitalized data from the measurement notes were used as input data to teach an artificial neural network that was designed to predict the degree of wear of carbon contact strips.

2. Causes of replacement and damage of contact strips

Numerous scientific papers deal with the problem of interaction between catenary and current collector [2–11]. In order to keep the contact between the contact strip with the catenary, it is necessary to maintain the appropriate force on the current collector. In case of too much force, mechanical damage may occur to both the current collector and the overhead contact line, while in the case of too little an electric arc is produced which causes overburning and thus excessive wear of the carbon strips.

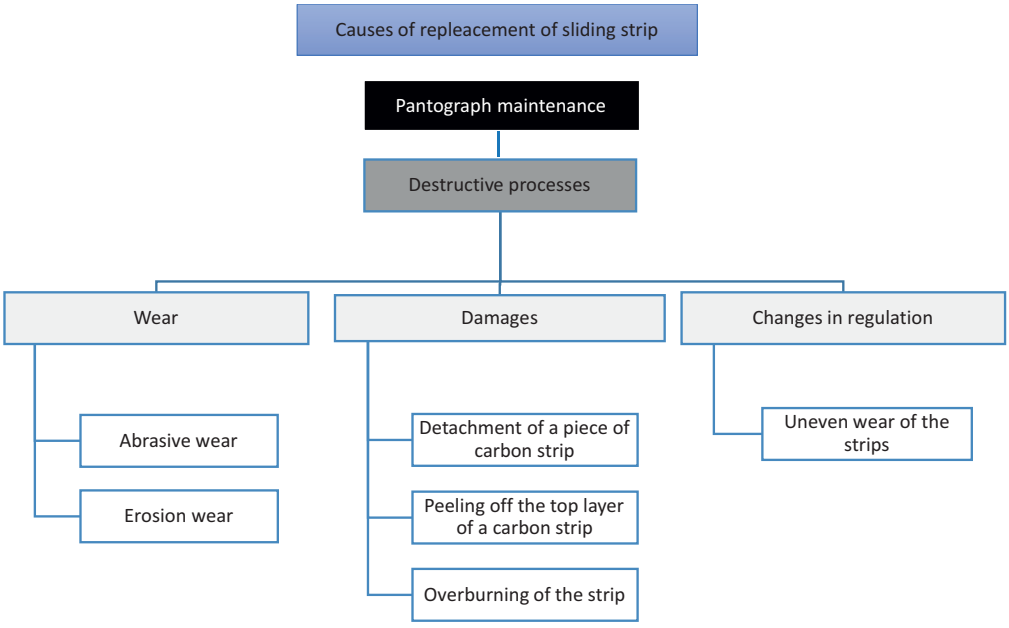

Fig. 2. Reasons for replacing the pantograph contact strips

When using the current collector, the carbon contact strips wears off. If the thickness of the strip is less than the recommended value in the measurement note, the contact strip should be replaced with a new one. In practice, the carbon strips are replaced a little earlier to eliminate over-wear of the strip, which could result in more expensive damage to the current collector and the overhead contact line. However, when the strip is replaced with no obvious signs of damage, we say that the contact strip is replaced because of operational wear. Otherwise, the causes of replacement are various types of damage. The most common damage to carbon strips can include cracks in the strip, detachment of a piece of carbon strip, peeling off the top layer of a carbon strip, uneven wear of the strips, or overburning of the strip. Figure 2 shows as an example the reasons for replacing current collector carbon strips.

Each of the reasons for replacement is caused by a different type of destructive process. During maintenance, the sliding strip wears out by an abrasive or erosion process. When the overlay thickness reaches the recommended minimum thickness, it is necessary to replace the overlay with a new one. The defects generated during the design and manufacturing the

pantograph contact strips may be manifested during the use in the form of detachment of a bigger piece of carbon strip or detachment pf only the top layer of a carbon strip. Such cases are usually caused by a material defect. According to the literature [12, 13], carbon strip detachment may be also caused by excessive wear or hitting in the hinder on an overhead contact line (e.g. improperly mounted section isolator, hanger elements, ice or external elements like tree branches). Another type of contact strip damage is overburning, which can be caused by an electric arc that can be formed in bad weather conditions (rain, snow, overhead contact), and too little pressure between the pantograph and the overhead line [13]. The cause of uneven wear of slides may be incorrect fitting of the carbon strips in the slide plate or incorrect maintenance of the technical condition of the mechanism, which pushes a contact shoe up against the overhead contact wire.

At present, the pantograph measurement note does not include information such as reason of replacing the contact strip and replacing the entire current collector, which is a problem when concluding the potential causes of damage. From the operational point of view, it is important to replace the contact strip before it causes more expensive damage. This may be done using a prediction method. The author decided to use an Artificial Neural Network to forecast a future value of contact strip thickness, because of their ability to map complex non--linear functions.

3. Simulation of wear of carbon contact strips

The methodology for empirical research involved several basic stages:

- collecting data from current collector measurements,
- data analysis and selection,
- developing learning data structures,
- development of artificial neural network architecture,
- testing of artificial neural networks,
- comparison of prediction results,
- selection of the neural network that gives the most accurate prediction of overlay thickness.

In order to predict the consumption of carbon contact strips, properly prepared data from the current collector measurement notes were used as input and output data to teach the artificial neural network.

The input structure of the artificial neural network was developed on the basis of data from the measuring notes of the current collectors as well as information about the replacement of sliding strips and the replacement of the current collector. Data from 62 different locomotives were analysed, which represented 1537 measurements. Measurements were made monthly, and concerned the locomotive number, the pantograph type, the thickness of the carbon contact strips, and the pantograph number.

In the next step, the structure of the Artificial Neural Network was established. In order to conduct the simulation, the ANN structure which gives the best results was chosen. The

network structure was selected from among 20 other structures based on the smallest mean square error. Therefore, in this paper a Feed-Forward network with backward propagation is presented, containing 6 layers of 10 neurons in each layer, and one output layer comprising 8 neurons. The back error propagation algorithm requires the activation function to be continuous and differentiable, which is why a tangentoidal activation function was used. The Levenberg-Marqardt learning algorithm was also used due to the fact that it is currently one of the most commonly used algorithms for teaching one-way networks [14, 15]. This is mainly due to its rapid convergence, not very great computational complexity, and simple implementation. The algorithm uses the solving of the non-linear problem of the least squares presented by Marquardt in work [16]. The structure of the artificial neural network developed within the frame of this work is presented in Figure 3 and in equation (1).

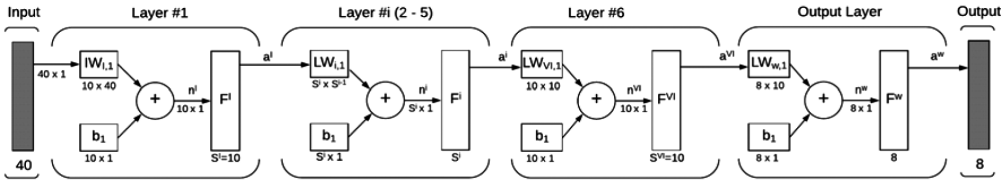

Fig. 3. Structure of Artificial Neural Network used to predict the thickness of carbon contact strip

$$a^w = F^w(LW_{(W,\mathrm{VI}}F^{\mathrm{VI}}(LW_{\mathrm{VI,V}}F^{\mathrm{V}}(LW_{\mathrm{V,IV}}F^{\mathrm{IV}}(LW_{\mathrm{IV,III}}F^{\mathrm{III}}(LW_{\mathrm{III,II}})F^{\mathrm{II}}(LW_{\mathrm{II,I}}F^{\mathrm{I}}(IW_{\mathrm{I,I}}p+b_1)$$
$$+b_2)+b_3)+b_4)+b_5)+b_6)+b_w)$$

where:

- a_w – output value,
- S^i – the number of neurons in the i-th layer,
- F^i – the activation function in the i-th layer,
- IW – initial weights (represent the weights of the first layer neurons, where each weight is connected to the element of the input vector, as shown in Figure 3),
- LW – layer weights (combined with each of the elements of the previous layer's vector).

In the process of preparing the data teaching the artificial neural network, data from the current collector measuring cards were used. In order to accurately map the wear processes, we can treat contact strip consumption as a function dependent on various parameters. Table 1 presents such features, which were considered to be one measurement. This measurement was made on a monthly basis and, in addition to the operational data, included information about the potential replacement of the contact strip and the pantograph.

Each training case used to train the ANN consisted of five such measurements as input data, while measurements from the sixth month were the output values (Fig. 4).

On the basis of data from pantograph measuring cards (operational data) and information about replacement of contact strip and the pantograph, a total of 919 training cases were prepared. 733 of these training cases were used in the learning (training) phase of the artificial neural network. The size of the input training matrix was therefore 40 × 733, while the output

matrix was 8 × 733. For simulation, however, the remaining 186 training cases were used, containing only the input data from the next five months (matrix size 40 × 186), and the result of the simulation were target values has matrix size 8 × 186.

Table 1. The features for the ANN structure used in one measurement

MEASUREMENT	
FEATURE	**SYMBOL**
Current collector type	(Tp)
Thickness of the first carbon contact strip	(THcs1)
Thickness of the second carbon contact strip	(THcs2)
Replacement of the entire collector	(Rp)
Replacement of the current collector contact strip	(Rcs)
Replacement of the cover due to wear (abrasive wear, erosion wear)	(R0)
Replacement of the overlay caused by damage (detachment of a piece of carbon strip, peeling off the top layer of a carbon strip, overburning of the strip)	(R1)
Replacement of the cover due to changes in regulation (uneven wear of the sliders)	(R2)

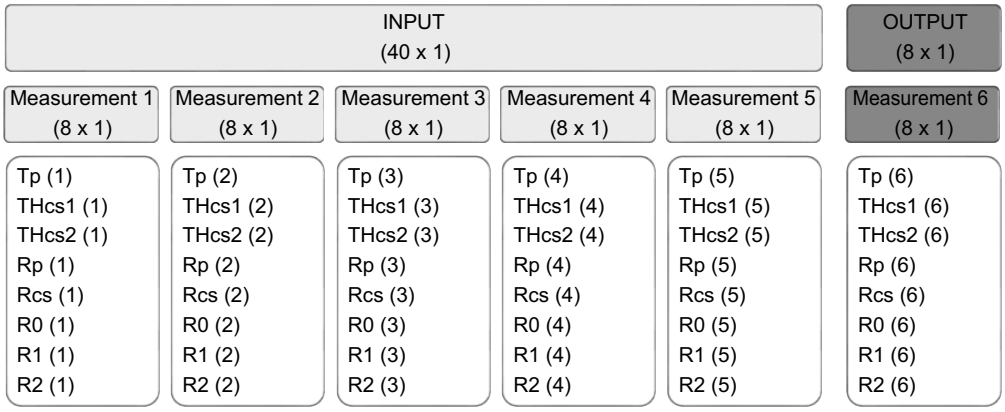

Fig. 4. Artificial Neural Network training case

4. Results and conclusions

The simulation results show that the output values largely correspond to the target values. The straight line coefficient for the training, validation and testing process was approximately 1, and for training the value of shift factor β was 0.012, for validation β = 0.041, while for testing β = 0.032. This shows that the approximated function has been relatively well adjusted at this stage.

Figure 5 shows the results of the simulation of the wear of carbon contact strips. As is clear from the histogram of the difference between simulation results and actual data (Figure 5a), there is an approximate number of underestimated (180) and overvalued (192) results of the simulation.

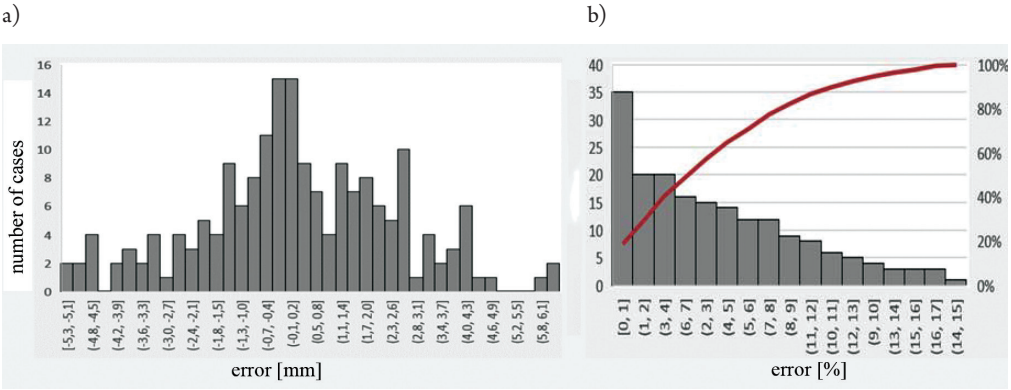

Fig. 5. a) Histogram of the difference in the thickness of the current collector sliding strip between the results of the simulation and the actual data; b) Pareto-Lorenz diagram of the percentage error in the thickness of the current collector sliding strip

The Pareto-Lorenz plot (Fig. 5b) shows that for 90% of the simulated cases, the difference between the actual value and the thickness value obtained during simulation does not exceed 12%. A little below 20% of the results are within the error range of 0 to 1%. Based on these results, it can be concluded that the created neuron network enables prediction of the consumption of the current collector carbon strip in a satisfactory manner.

The Feed-Forward Neural Network with backward propagation proposed in this paper allows the thickness of the pantograph sliding strip to be predicted only on the basis on data from the measurement notes. In summary, the work has shown that artificial neural networks are suitable for prediction of wear of sliding strips. In further work, it is planned to examine neural networks with different architectures and inputs in order to develop a system that supports the operational decision on replacing the sliding strips on the basis of predicted thickness value.

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