Acta Sci. Pol., Administratio Locorum 23(1) 2024, 71–89.
https://czasopisma.uwm.edu.pl/index.php/aspal plISSN 1644-0749 eISSN 2450-0771 DOI: 10.31648/aspal.9420

ORIGINAL PAPER
Received: 25.09.2023 Accepted: 09.11.2023

# AUGMENTED REALITY AS A TECHNOLOGY THAT SUPPORTS THE SPATIAL DEVELOPMENT PROCESS

Rafał Kaźmierczak[1]✉, Agnieszka Szczepańska[2]✉

[1] ORCID: 0000-0001-5780-8949
[2] ORCID: 0000-0001-5184-0710
[1,2] University of Warmia and Mazury in Olsztyn
15 Prawocheńskiego Street, 10-724 Olsztyn, **Poland**

## ABSTRACT

**Motives:** The solutions for designing spatial development methods in planning documents are presented as 2D graphics with supplementary descriptions. Due to the lack of specialist knowledge and insufficient spatial imagination, some readers may be unable to understand the graphic and descriptive content of such documents. The above can lead to the construction of objects that disrupt spatial order without violating the law. This problem can be solved by applying augmented reality (AR) in spatial planning. This paper presents the capabilities of a method for visualizing different spatial development variants on the example of buildings. A model of a building plot and the surrounding area, covered by a local spatial development plan, was developed.
**Aim:** The aim of this study was to determine the applicability of the AR technology for identifying low-precision areas in the plan and its potential impact on the method of land development, with a resulting deterioration in spatial order.
**Results:** The use of the AR technology enables analyses and assessments of planned development in the context of spatial order and its integration with the existing elements. Visualizations presented with the AR technology show that different interpretations of the local zoning plan generate spatial chaos. The utility of 3D visualization for an average reader was also presented. The AR technology can be used at the stage of preparing planning documents (community participation, adopting the plan), adopting by-laws (councilors), and enforcing these regulations (investors' decisions).

**Keywords:** spatial planning, spatial imagination, augmented reality, visualization

## INTRODUCTION

The clarity of future solutions for spatial development methods is one of the main issues in the spatial planning process. Clear and comprehensible presentations of the planned functions, design solutions and limitations are of great importance. This mainly concerns spatial elements such as buildings, transport systems, and greenery. Standard design solutions in planning documentation are presented as 2D graphics with supplementary descriptions. The main aim of 2D drawings is to visualize future functions with the use of colored contours and sectoral symbols. The descriptive part contains detailed guidelines on the method

✉rafal.kazmierczak@uwm.edu.pl, ✉aszczep@uwm.edu.pl

of spatial development with predefined functions. This method of presentation may be difficult to understand for the average reader.

Planning documents are intended for officials, planners, architects, investors, and local communities. This applies at the stage of drafting, adopting, and enforcing by-laws. According to the Act on planning and spatial development, the local community may participate in the process of drafting planning documents. These documents are shared with the public, the adopted solutions are discussed, and stakeholders can make comments and motions. Therefore, by actively participating in the process of preparing planning documents at the local level, residents can have a real influence on changes in their environment. However, the participants are often unable to comprehend the developed documents, both graphics and descriptions, due to a lack of specialist knowledge about urban development and architecture, and poor spatial imagination. Local lawmakers who are responsible for spatial planning and development often experience similar limitations. In order to vote for or against the proposed bills, one has to understand the solutions adopted in planning documents. Similar obstacles are faced by non-professionals who read planning documents, for example those seeking real estate for purchase and planning an investment. Therefore, planning documents should be clear, understandable, and easy to interpret. This problem can be solved by using augmented reality (AR) to present the planned function and method of land development. The authors assume that the visualization of spatial development in 3D AR can lead to a better understanding of the spatial relations between the elements of spatial development and their surroundings.

This article describes the use of the AR technology for presenting the provisions of a draft local land development plan which is the most important document in the Polish planning system and which constitutes a by-law. The aim of this study was to determine the applicability of the AR technology for identifying low-precision areas in the plan and its potential impact on the method of land development, with a resulting deterioration in spatial order. In addition to disturbances in spatial order, imprecise local planning provisions bring about significant legal consequences. The ambiguity of such provisions makes them difficult to interpret, both by investors and by public authorities dealing with architectural and construction matters. This can considerably impact investment decisions because a zoning plan imposes limits on real estate use and – together with other regulations – affects its execution. Therefore, a local land development plan should contain unambiguous provisions which do not raise doubts as to their interpretation. Otherwise, disputes may be brought before an administrative court. Moreover, the utility of 3D visualization of a plan has been demonstrated, and this technology can be used in the planning stage, both during public consultations and when the document is approved and passed, as well as before a potential investment is planned.

This study analyzes a model of an undeveloped building plot covered by the local land development plan whose provisions are imprecise. It can be safely assumed that the use of 3D visualization at the stage of public consultations and later, if the plan is passed, would require changes in its provisions.

## LITERATURE REVIEW

### Augmented reality

Humans gather information about the world through their senses. However, due to the development of information technologies, the sense of sight became dominant. As a result of technical progress, we are surrounded by images which impose a certain vision of the world (Kuczamer-Kłopotowska, 2014; Milgram et al., 1995). We pay great attention to the appearance and the esthetics of the presented materials and information. This is noticeable in practically every area of life, including more realistic special effects generated digitally in films, realistic fairy tales combining fairy tale characters with the real world, interactive museums, and others. Therefore, AR is a rapidly developing field of technology.

✉rafal.kazmierczak@uwm.edu.pl, ✉aszczep@uwm.edu.pl

Augmented reality has been an area of interest for many professionals since the 1950s. Research began about 10 years later, and it was initiated by a pioneer of computer graphics, Ivan Sutherlan, and a group of students from the Harvard University and the University of Utah (Pardel, 2009; Caudell & Mizell, 1992). In simple terms, AR is a technology that combines the real world with the virtual world. It is created by overlaying digital objects on a real-world image. Image processing devices such as cameras, glasses, smartphones, tablets, and cameras are used for this purpose. Ronald Azuma (1997; 2017) has had a great impact on technology development. He defines AR as a system that merges two types of worlds, the real and the virtual.

Another feature of the AR system is that every object in three-dimensional space is located in the real world. This means that the objects present in the real world have a precise location. A third parameter, namely the interactivity of objects, can be introduced when an object's location is known and when the digital and real worlds can be combined (Kołodziejczyk, 2013). Nowadays, the main goal and the greatest challenge for the development of AR technologies are to obliterate the difference between virtual and real objects. This can be achieved by improving the accuracy with which shapes, colors, and mutual relations between virtual objects and the real world are presented. The operating principle of the AR technology is presented in Figure 1.

Due to the development of computer technology, the possibility of creating AR has increased significantly. The exponential growth of information technology (Moore, 1965) has significantly contributed to the above. Recent years have witnessed considerable progress in mobile devices such as smartphones and tablets which are conducive to the propagation of AR. Due to a significant increase in their computing power and popularity, the number of AR-based applications is growing rapidly (Buchwald, 2018). This is because the application of AR on mobile devices increases the user's experience of the virtual world. Technological progress has also affected the way information is presented by linking the use of geographic information to areas commonly associated with a strong visual perception of space (Marques et al., 2019). Therefore, AR is applied in many areas, including education, sales, marketing, sports, tourism, commerce, medicine, entertainment, automotive industry, and cultural heritage. Augmented reality is also used in architecture, construction and land development planning, which will be discussed in greater detail in chapter "The use of AR in spatial and architectural planning".

The ability to see and feel depth is a very complex process. To be able to distinguish between distances,

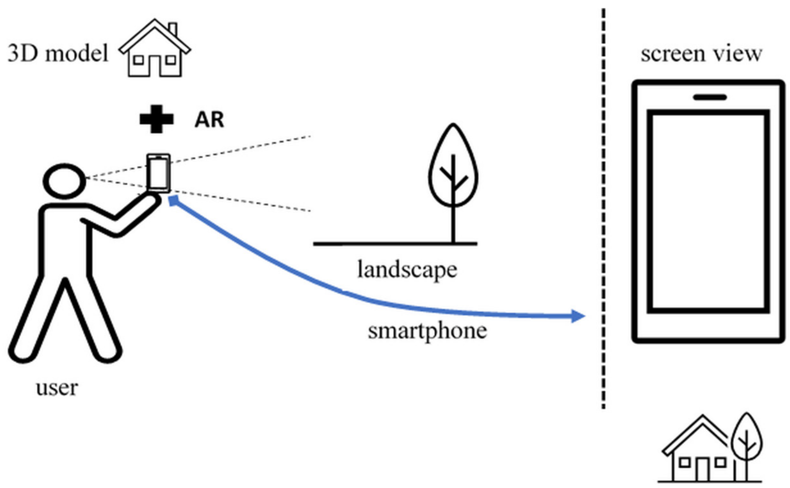


**Fig. 1**. Operating principle of augmented reality

✉rafal.kazmierczak@uwm.edu.pl, ✉aszczep@uwm.edu.pl

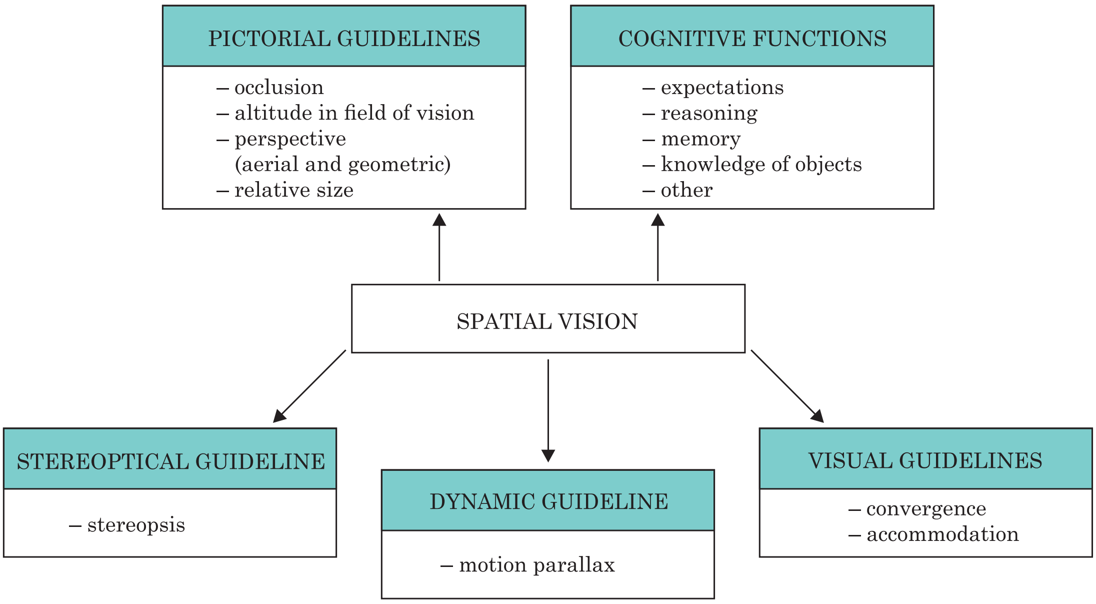


**Fig. 2.** Stereoscopic vision
*Source*: own elaboration based on Howard and Rogers (2012) and Juszka and Papir (2016).

several conditions must be met. Our brain uses several guidelines to correctly interpret the object it sees. These are listed in Figure 2. They include pictorial, visual, dynamic, stereoscopic and some cognitive functions.

The image may not be correctly identified when one of the clues is misinterpreted by the brain. Such an effect may be used intentionally, for example by magicians. However, in the case of land development planning, correct interpretation of records and images is desirable. As indicated above, the spatial vision of an object can be problematic. Most land development plans involve maps (2D), and each recipient visualizes the presented content individually. Therefore, this approach leaves wide room for interpretation. The availability of free three-dimensional AR applications and the potential of tablets and smartphones support the design and implementation of spatial skill development strategies (Carbonell & Bernejo, 2016) to standardize the users' visualization abilities.

## The use of AR in spatial and architectural planning

Until now, the process of land use planning, architectural and structural design was limited to the creation of 2D graphics, descriptive information, or mockups of the proposed solutions (this solution is rarely used because it is laborious and time-consuming). The applied 2D model may lead to discrepancies due to varied interpretations of planning documents, spatial development projects and architectural and structural projects because many people have poor spatial imagination. Individuals differ in their ability to imagine and visualize 2D content. Naturally, the view in the X and Y plane alone does not reflect all spatial relations. The information about the vertical component (height), presented in a descriptive way or with the use of sectoral symbols, is also difficult to understand or imagine. The spatial interpretation of planning solutions is therefore significantly hampered.

Augmented reality creates new digital forms in space, and attempts are made to create an environment that is identical to the real world, which

✉rafal.kazmierczak@uwm.edu.pl, ✉aszczep@uwm.edu.pl

is why the AR technology is increasingly often used in planning and architecture. Digital three-dimensional (3D) environments provide new ways of landscape visualization and topographic interpretation. The advent of AR offers a new way of developing 2D image reading skills. For example, AR can be applied to present terrain features (hills, dunes, depths, valleys, mountains, shapes and slopes), which provides a new way of interacting with the landscape (Carbonell & Bermejo, 2017).

Augmented reality has enabled architects to transfer their designs from 2D format and present them to the public in three dimensions (Siwak, 2016; Tomkins & Lange, 2020). This brings many benefits. A 3D model enables the public to view a designed building in real-world terrain, and it demonstrates whether the building is well-integrated into the surrounding space (Asanowicz, 2012). In addition, AR facilitates digital reconstructions of destroyed buildings, for example in museums (Han et al., 2013). The most important decisions are made at the planning or pre-planning stage. The changes introduced at this stage are less costly and time-consuming compared with later stages of architectural design, not to mention the construction process itself (Peckienė & Ustinovičius, 2017).

Augmented reality can also be used in spatial planning. Spatial design has changed dynamically in the last decade, mainly due to the involvement of local communities in the planning process during public consultations (Konopacki, 2014; Zamojski, 2020). Effective integration of new projects into the existing elements of development is important both for the designers and the community living in the area. However, 2D drawings of the planned investments do not always show how the designed building or public facility will fit in with the existing buildings and the landscape. The popularity and increasing computing power of mobile devices make enable all participants to use AR to visualize the proposed solutions. Augmented reality is used in public debate as a tool for making changes and corrections in graphic models of future investments. The language of communication must be accessible to both specialists and laymen (Khan & Dong, 2011; Marques et al., 2017). Gamification, fuzzy control and AR can solve many of the problems encountered by local and central authorities in managing the spatial planning process. In addition, according to specialists, AR and other ICT systems, such as the Internet, significantly improve communication between urban planners and the future users of space (Milovanovic et al., 2017). Effective communication with citizens is a factor that contributes to the success of public participation in solving spatial planning problems (Olszewski et al., 2017). Social geoparticipation in spatial planning promotes civic engagement through the use of tools adapted to the cultural, historical, economic and social reality of a given city, as well as precise 3D modelling techniques and VR/AR tools (Küspert & Zink, 2017). These tools not only improve the spatial planning process, but also contribute to the evolution of an open geoinformation society which will create "smart cities" in the future (Allen et al., 2011).

In addition to enhancing communication, AR can also improve decision-making in the process of approving an investment project. A visualization of a building or another project can be easily accepted or rejected by remote voting using a mobile device (Allen et al., 2011). Thanks to AR, participants can see how the object will look like from every possible angle. Augmented reality also enables the participants to experience the sensory attributes of a given location, including light, wind and smell (Goudarznia et al., 2017).

Research on the use of AR for enhancing public participation in the spatial planning process was conducted in the Finnish cities of Raseborg and Helsinki. According to the residents of Raseborg, AR was a very helpful tool during land-use planning and public consultations. Another study was conducted on planning officials who saw AR as a very useful tool for analyzing the form of newly designed buildings, their integration into the existing development, influence on the surrounding landscape, and potentially adverse impact on the local community (Konopacki, 2014).

Applications enabling users to create their own vision of the surrounding space play an important role

✉rafal.kazmierczak@uwm.edu.pl, ✉aszczep@uwm.edu.pl

in the process of social participation. "Wysadzulice" was a Polish application that had been developed with the use of AR (it is no longer active). The application enabled users to design urban squares or streets by adding various types of objects, including trees, flowerbeds or benches, to the existing reality. The users could visualize their needs concerning land planning in the surrounding area. As a result, community members could influence the shape of the local space. The program also greatly facilitated communication between the residents and the local authorities. At the same time, the application enabled the authorities and planners to collect information about local needs concerning spatial development. The program was an attractive tool for effective public participation (Maksymiuk et al., 2017). 3D visualization techniques have emerged as a new global trend in spatial and urban-architectural planning (Broll et al., 2004; Dickmann et al., 2021; Phan & Choo, 2010).

## Polish spatial planning system at the local level

Poland has a three-tier spatial planning system which covers the national, regional (spatial development plans developed by voivodeships) and municipal (study of conditions and directions of spatial development, local spatial development plan) levels. Local zoning plans play the most important role in the Polish spatial planning system. This basic tool spatial policy tool is implemented by the commune (the smallest unit of territorial division). This document has legal force and it is universally binding on municipal authorities, public institutions, businesses and citizens. The local plan determines land use, the location of public investments, and the development methods and conditions of land development necessary to achieve spatial order, and it constitutes the basis for all planning activities. The process of drafting local plans involves an element of public participation, which means that every interested citizen can actively participate in the creation of the plan during public consultations. Local spatial development plans are optional; they are adopted at the discretion of the municipal council, and they may cover the entire municipality or selected areas (Nowak, 2019). According to the Spatial Planning and Development Act of 27 March 2003, the local spatial development plans specify:

- land-use types and boundaries separating different land-use types or different types of development;
- the principles of developing building layouts and land development indices, the maximum and minimum development intensity as the ratio of the developed part of a plot to its total area, the minimum biologically active area relative to built-up area, the maximum building height, the minimum number of parking places, building contours and dimensions.

The position of buildings relative to roads, public areas and the borders of adjacent plots, facade and roof color are determined as needed.

Pursuant to the decision implementing the Act on Spatial Planning and Development (Regulation, 2021), a plan concerning the requirements to create public space should lay down the rules for temporary service facilities, technical equipment and greenery, including determining orders, prohibitions, abandonments and restrictions on land development. The decisions on building layout and land development parameters and indices should specify the building contours, built-up area relative to plot area, including the percentage of the biologically active area, as well as the dimensions and height of the planned buildings and roof geometry.

The draft local plan is prepared as a 2D drawing (Fig. 3). The textual description is an integral part of a plan, and it contains detailed regulations on the method of land development.

A local revitalization plan is a special form of a local spatial development plan (Szlachetko, 2017). The descriptive part includes regulations on the principles of spatial composition and harmonizing the planned buildings with the existing ones.

The visualization of the revitalization plan provisions consists of an urban planning concept for the area covered by the plan (2D model) and a spatial structure model of the area covered by the plan, which takes into account terrain features

rafal.kazmierczak@uwm.edu.pl, aszczep@uwm.edu.pl


**Fig. 3**. An excerpt from the local spatial development plan of Olsztyn city
*Source*: https://msipmo.olsztyn.eu/imap/.

prepared in a 3D realistic form, enabling a change of the point of observation in space, considering the existing and planned spatial development elements (3D model). The third element of visualization are the views of selected characteristic elevations or developed views of public spaces, taking into account the nearest surroundings.

The provisions of a local plan (including the revitalization plan) can regulate many issues in detail. Local plans have a direct impact on future spatial development, and their provisions must be comprehensible for the recipients, including local communities interested in changes in the immediate surroundings, investors who make financial decisions, and local lawmakers. The method of presentation, including 2D drawings and a textual description, is not clear for most recipients. In general, 3D visualization techniques are not required by law, except in revitalization plans. However, these plans and the relevant preparatory procedures have been introduced only recently. Despite the fact that visualization is not obligatory, it is used increasingly often at the stage of a draft plan preparation as an element which enhances the study's clarity for an average reader.

Local spatial development plans are prepared by licensed spatial or urban planners or individuals who have a degree in architecture, urban planning or spatial development. Therefore, they have well-developed spatial perception and imagination, and they can mentally convert drawings and textual descriptions into a 3D format. Most (or all) members of municipal councils are not experienced in this area and have no knowledge of these issues (Korbel, 2018), which is why the visualization of drawings and the text of a local plan can be difficult. The above can lead to erroneous decisions regarding plan approval. The same applies to the citizens who participate in public consultations, for whom the draft plan presented for public viewing may not be fully clear. This is a very important consideration because by actively participating in the process of creating the document, local communities can influence the appearance of the surrounding space (Korbel, 2018). Therefore, visualization techniques should be included in the process of preparing planning documents, which is enabled by the development of tools for the acquisition and processing of spatial information (Sieminski, 2011). It can make the

✉rafal.kazmierczak@uwm.edu.pl, ✉aszczep@uwm.edu.pl

provisions of the plan more understandable for the recipients and enhance their clarity. A realistic 3D presentation is more appealing to amateurs (Kolecka, 2008). The precision of local planning provisions is a separate issue. A lack of precise provisions leads to the free choice of spatial development methods concerning design solutions, building dimensions and color. It has a considerable impact on spatial order, despite theoretical compliance with the plan provisions.

These concerns justify the use of 3D visualization techniques in spatial planning, especially in the visualization of planned urban and architectural solutions proposed by municipal officers responsible for spatial planning (Korbel, 2018). Additionally, AR facilitates communication between the local community and individuals in charge of spatial development (Grassi & Klein 2016). Therefore, the legal regulations applicable to planning documents should include provisions governing the use of modern techniques for visualizing the proposed spatial solutions. The first attempts to develop a preliminary concept of a universal modelling language (UML) of a database scheme for integrating the 3D cadaster with 3D spatial planning have been made in Poland (Bydłosz et al., 2018).

## METHODOLOGY

The literature review clearly confirmed the utility of AR in the spatial planning process. The main aim of the study was to visualize spatial development with the use of AR, and it was achieved through the following intermediate objectives:
– to interpret the provisions of a local spatial development plan;
– to analyze the spatial development concept;
– to assess the applicability of novel technologies for visualizing spatial development;
– to support communication with the investor.

These tasks were carried out based on technological solutions that are available to all users of mobile devices, namely smartphones.

Considering the specific nature of the AR technology, the design and presentation of future spatial development methods were analyzed indoors and outdoors. To visualize the existing spatial development with the AR technology, the study relied on design guidelines that comply with the local spatial development plan and specify the parameters of future feasible development. Design solutions arising from the plan were adapted to a single building plot and a residential building, and its elevation was considered. The stages of the study are presented in Figure 4.

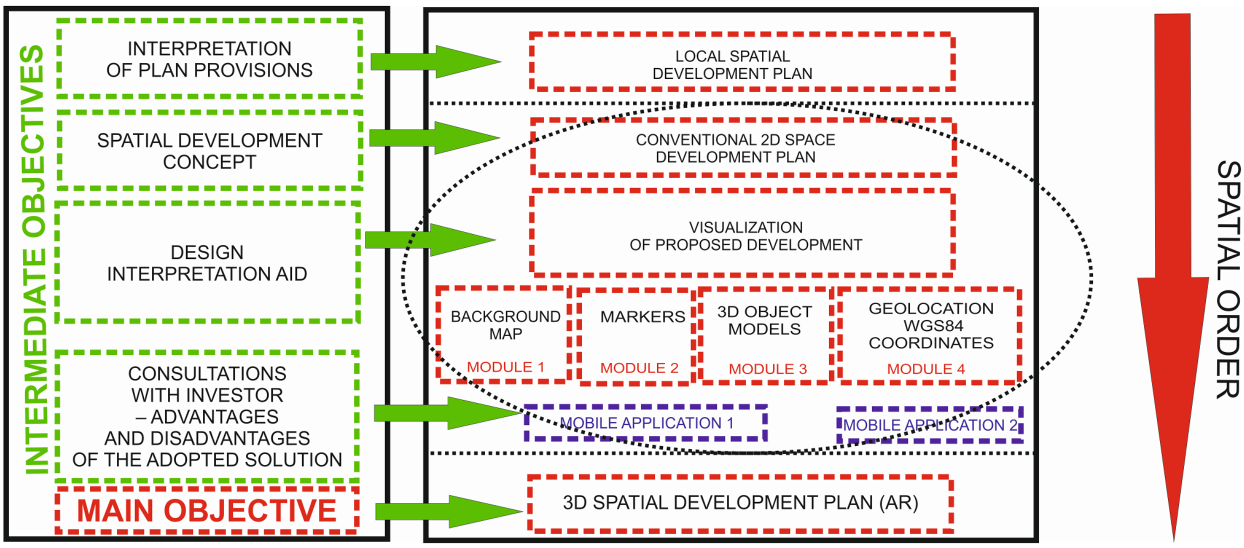


**Fig. 4**. Conceptual framework



rafal.kazmierczak@uwm.edu.pl, aszczep@uwm.edu.pl

**Table 1**. Modules applied in the process

| Number | Name | Characteristics |
|---|---|---|
| Module 1 | Background map | A background map can be prepared based on data acquired during independent field measurements and a vector map developed in the GIS or CAD environment or with the use of the existing geodesic resources (databases or geoportals) |
| Module 2 | Markers | A marker is usually an image in JPG or PNG format with the following characteristics:<br>Rich in detail;<br>Good contrast;<br>No repetitive patterns;<br>Format (8- or 24-bit PNG and JPG formats; JPGs must be RGB or greyscale).<br>The Vuforia library (https://library.vuforia.com/) was used in the study |
| Module 3 | 3D Object Models | Models can be prepared with a tool for designing three-dimensional spatial objects. Architectural designs are usually developed with the use of dedicated software (e.g. CAD). The models can also be applied to changes in land relief. An intuitive SketchUp tool was used in the study |
| Module 4 | Coordinate-based geolocation | The coordinates assigned to 3D objects should be expressed in the WGS84 system (a system of coordinates commonly used in GPS-based navigation devices). Other systems can be used (PZ-90, GTRF, CGCS2000) if 3D objects are modeled with different navigation devices (e.g. GLONASS, Galileo or Beidou). The script was prepared in the UNITY3D environment |

The main objective of the study relating to spatial planning and development, namely the maintenance of spatial order and the achievement of investment goals, is presented on the right side of Figure 4. This procedure starts with an analysis of plan provisions and ends with a 2D spatial development design, which is often not completely clear to the average reader. Hence, an AR-supported 3D spatial development design can considerably enhance the clarity of the proposed solutions and support the identification of alternative methods of spatial development. Therefore, an iterative approach to spatial development planning should be used. The comments made by readers after the visualization stage are taken into consideration in consecutive drafts of the spatial development design. This stage is represented by dotted arrows in the diagram.

An analysis of the technological aspect of the proposed solution associated with the visualization of spatial development produced four technical models. Two applications were prepared for the identified models. In Figure 4, the first application is represented by modules 1 to 3, and the second application is represented by module 4. The modules and the tools used in their creation are shown in Table 1.

## RESULTS

Imprecise fragments of a local plan can generate various ideas and expectations regarding the future development of space. In many cases, buildings erected in compliance with by-laws raise negative emotions or even lead to legal disputes. These problems were analyzed on the example of Bartąg, a village in the suburbs of Olsztyn, in the municipality of Stawiguda in north-eastern Poland. The area is covered by a local spatial development plan that had been adopted as a by-law. A general map of the area and the corresponding excerpt from the local plan are presented in Figure 5.

The local plan for the study area was prepared in 2008. Single-family housing is indicated as the dominant type of development. In the plan, the study area (Fig. 5 and 6) is marked as zone 2MN designated for the construction of single-family houses with gardens. The plan contains the following provisions:

1. regarding land development:
   - all new buildings must have a double-sloped or multi-hip roof, inclined at an angle of 33–45°, covered with ceramic roof tiles or with roof-tile-like material – red or brown;
   - the height of a single-family home or a terraced house cannot exceed one story, counting from the lowest corner of the building to the eaves, plus a habitable attic;

✉rafal.kazmierczak@uwm.edu.pl, ✉aszczep@uwm.edu.pl

2. regarding environmental protection:
   – only the absolutely necessary changes in terrain are allowed;
3. specific provisions:
   – only one residential building may be erected per one building plot;
   – two or more plots can be joined, and one building can be constructed on joined plots;
   – the principal mass of the building is situated in such a way that the roof ridge is parallel to the road axis;
4. 60% of the plot must remain biologically active (non-developed).

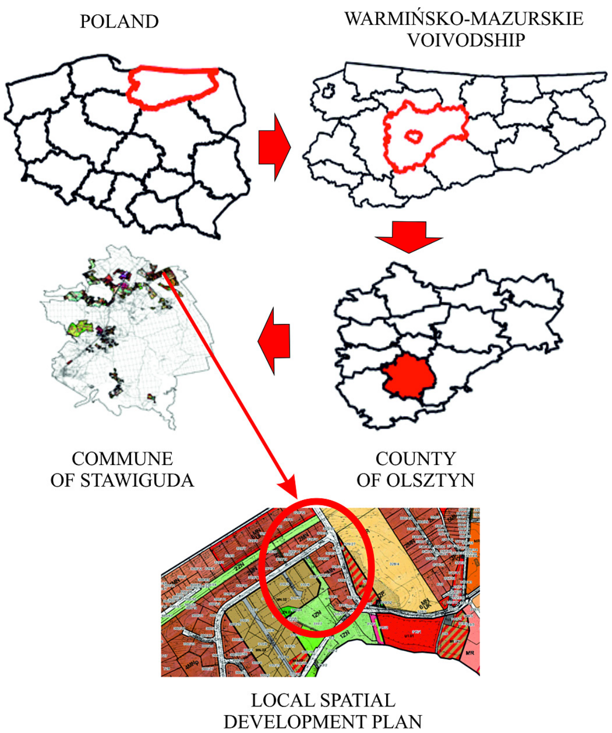


**Fig. 5**. Location of the study area – Bartąg

Numerous construction investment projects were initiated in the study area only in the past two years. Only several isolated buildings, not neighboring on one another, had been constructed in the area earlier due to the lack of the road infrastructure.

The intensity of construction investments revealed the imprecision of local plan provisions, especially where individual investments bordered on developers' investments. These investors have different priorities regarding the forms of spatial development. Developers aim at maximizing profits by increasing development density and building terraced or semi-detached houses. In turn, private investors have a preference for detached buildings with a larger recreational area. The landscape in the study area before and after recent investments is shown in Figure 6.

The development status of the study area in 2016 is presented in Figure 6A. In Figure 6B (photograph taken by a drone), the same area is shown in 2020 after four new detached houses had been built. Current development is presented in Figures 6a-c (Fig. 6a and 6c – detached houses; Fig. 6b – semi-detached houses). The buildings in Figure 6a were constructed first (which is why one of them can be seen in both Fig. 6A and Fig. 6B). In the group of newly constructed buildings, the objects in Figure 6b were designed in compliance with the same local plan as the buildings in Figures 6a and 6c. Figure 6d presents changes in terrain associated with one of the investment projects. A comparison of the study area before (Fig. 6A) and after investment completion (Fig. 6B) reveals considerable changes in terrain features.

Figure 6b shows that the objects presented in Figure 6b do not fit in with the surroundings, whereas the buildings in Figures 6a and Figure 6c are similar in terms of the architectural features. According to the plan, the height of residential buildings may not exceed one story above ground. At first glance, the buildings in Figure 6b resemble two-story buildings with a habitable attic, whereas the remaining buildings have one story and a habitable attic. This is because the first above-ground story in "b"-type buildings is theoretically an underground story, i.e. a cellar, which can be attributed to the imprecision of plan fragments. Building height was not linked with the height of the roof ridge, as shown in the building in Figure 6b.

Augmented reality can be useful for avoiding the situations shown in Figure 6 at the stage of plan creation, public consultations, issuing building permits,


rafal.kazmierczak@uwm.edu.pl, aszczep@uwm.edu.pl

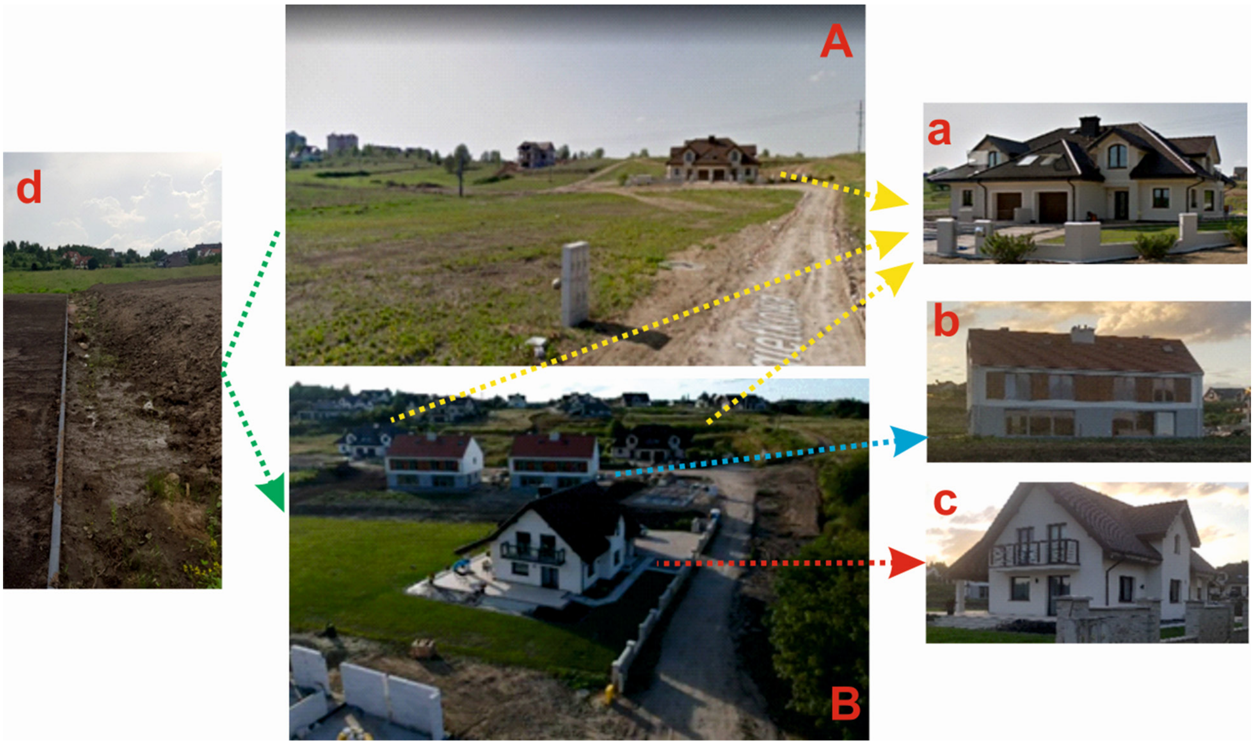


**Fig. 6.** The study area before 2016 (A) and after the most recent investments in 2020 (B) (a, b, c – present form of development, d – terrain features associated with one of the investment projects)

or before purchasing land plots for construction. Augmented reality enables visualization of the possible methods of spatial development in an urban planner's or architect's office, or in the field. It enables multiple interpretations of the provisions of the plan, as discussed below.

In the first variant, AR was used to visualize plot development based on a background map (indoors). A general orientation map was the starting point for visualizing plot development in AR (MODULE 1 in Fig. 4). In the analyzed case, the general orientation map was a map of the building plot and its immediate surroundings (Fig. 7).

Subsequently, 3D models were developed for the existing buildings neighboring the plot covered by the design. Markers showing visualizations of the existing residential buildings were prepared (Fig. 8).

In the next step, the prepared markers were used as the basis for generating projections of the analyzed methods of spatial development (MODULE 2 in Fig. 4). The examples of newly designed buildings are shown in Figure 9, and the proposed changes in terrain features are shown in Figure 10.

3D models were prepared in the SketchUp program in accordance with the planning guidelines (MODULE 3 in Fig. 4). This program is intended for creating 3D objects, and it is used by planners and architects. Moreover, the files created in AutoCAD can be imported to the program. Models of new buildings were created based on the planning guidelines laid down in the local spatial development plan.

The process was completed by developing a MOBILE APPLICATION 1 (MODULE 1, 2 and 3, Fig. 4) which employs AR. The application can be used to visualize plot development and to determine whether the newly designed buildings meet the conditions laid down in the local spatial development plan. Additionally, the application can be used as a tool for public consultations. Augmented reality can be used to visualize both the existing and newly

✉rafal.kazmierczak@uwm.edu.pl, ✉aszczep@uwm.edu.pl


**Fig. 7**. Background map for plot development

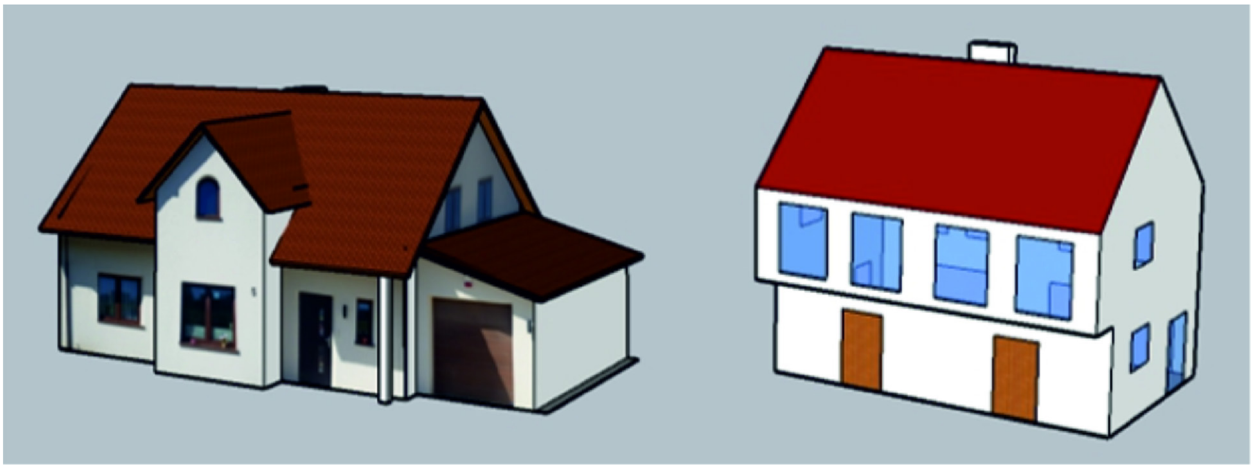

**Fig. 8**. Examples of 3D models of the existing buildings


✉rafal.kazmierczak@uwm.edu.pl, ✉aszczep@uwm.edu.pl

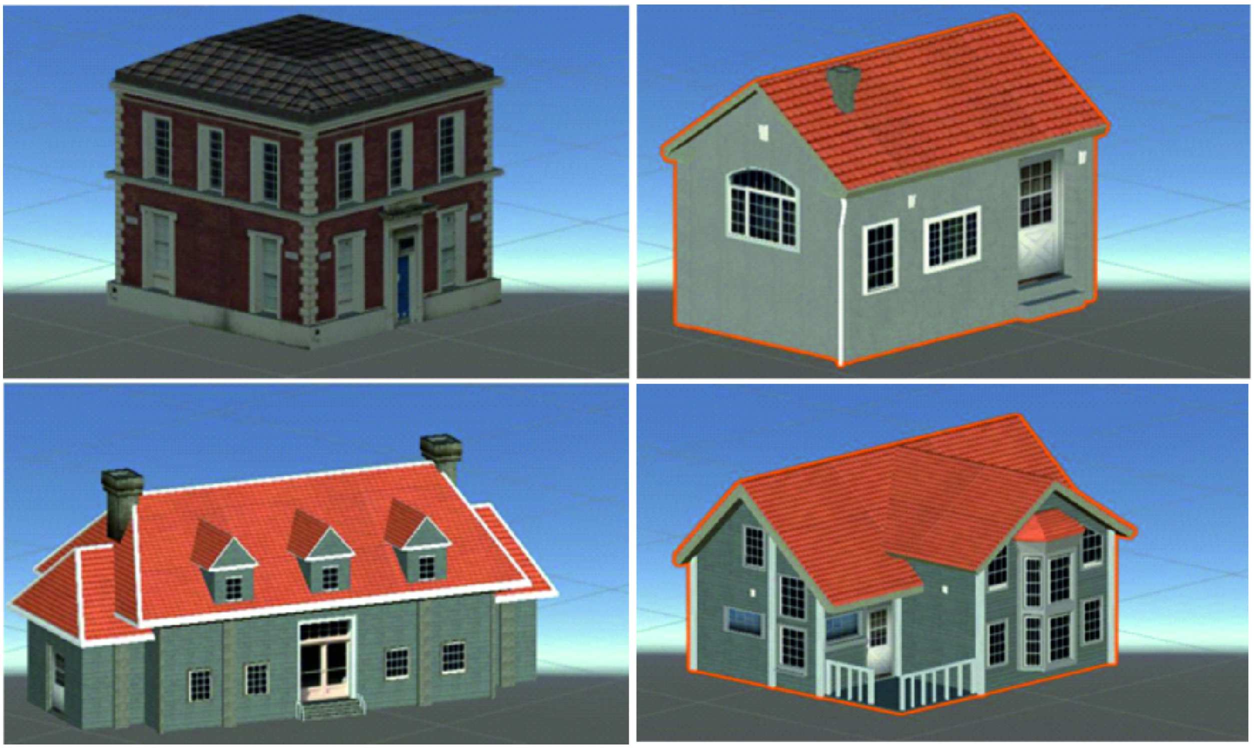

**Fig. 9**. Examples of 3D models of newly designed buildings
*Source*: own elaboration – adaptation of models from https://assetstore.unity.com/.

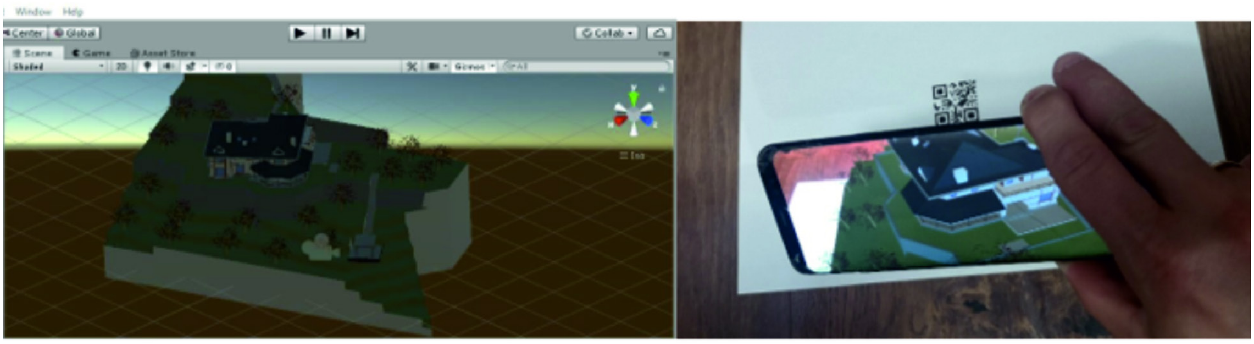

**Fig. 10**. Example of changes in terrain features
*Source*: own elaboration – adaptation of models from https://3dwarehouse.sketchup.com.

designed spatial development, and it can be helpful in assessing the integration of the new objects with real-world conditions. The user can generate many models of newly designed building to select the best design solutions.

The application can generate different models of new buildings. Augmented reality can be used to assess their impact on the existing spatial order (Fig. 11 and 12) and to explain the provisions of the local spatial development plan to potential investors/officials/residents.

The second variant shows the effect of using AR in the field. In the analyzed case, the Unity3D MOBILE APPLICATION 2 (MODULE 4 in Fig. 4)

✉rafal.kazmierczak@uwm.edu.pl, ✉aszczep@uwm.edu.pl

was used to present possible forms of plot development based on Global Navigation Satellite System (GNSS) coordinates (Fig. 13).

In the presented approach, users can assess the spatial relations in reality and make corrections to spatial development designs. Augmented reality is also a valuable tool for persons who find it difficult to interpret ordinary 2D maps and designs.

## DISCUSSION AND CONCLUSIONS

Augmented reality tools deliver practical benefits, and they can be widely applied in spatial, architectural and construction-related planning. The use of the AR technology enables analyses and assessments of the planned development in the context of spatial order and integration with the existing elements (Soria

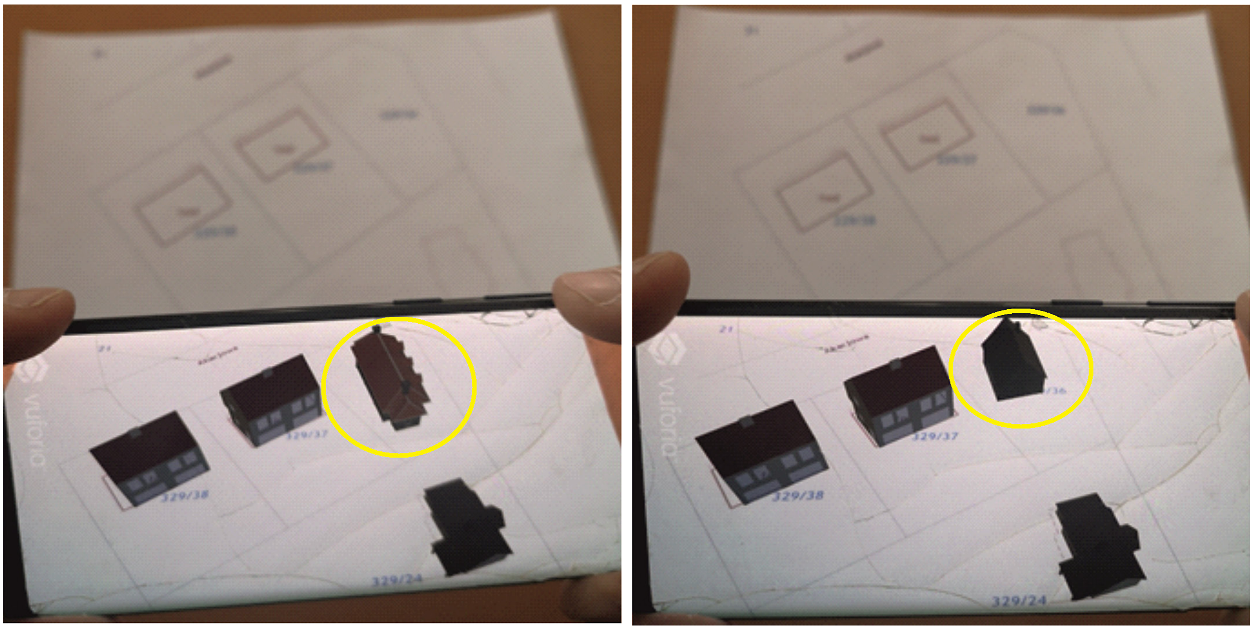


**Fig. 11**. Alternative methods of plot development: semi-detached house (left), detached house (right)

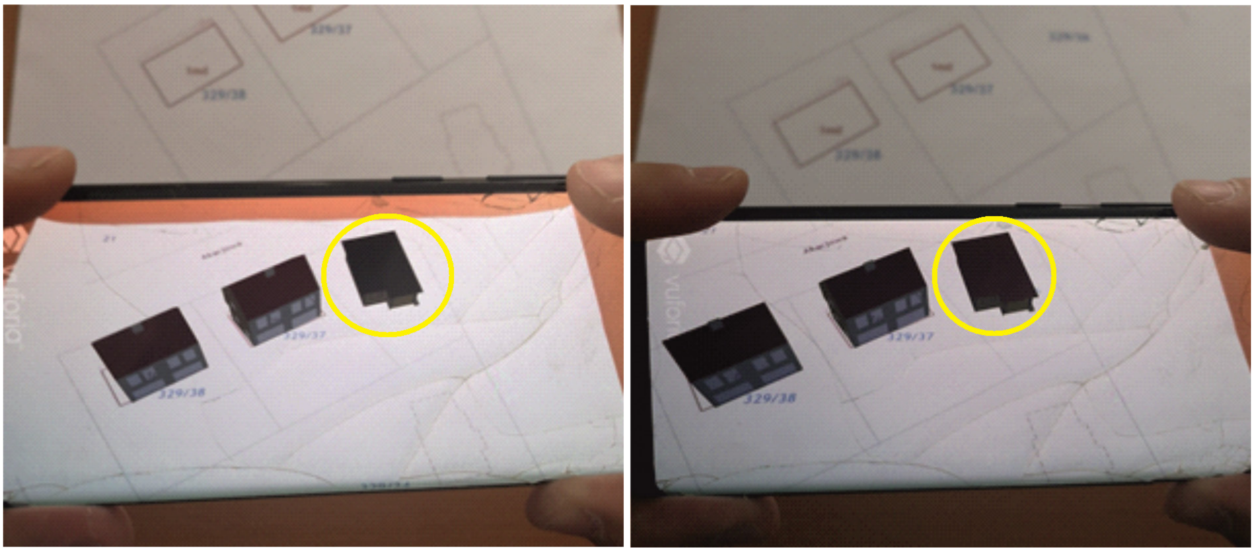


**Fig. 12**. Visualization of buildings with different roof color

✉rafal.kazmierczak@uwm.edu.pl, ✉aszczep@uwm.edu.pl

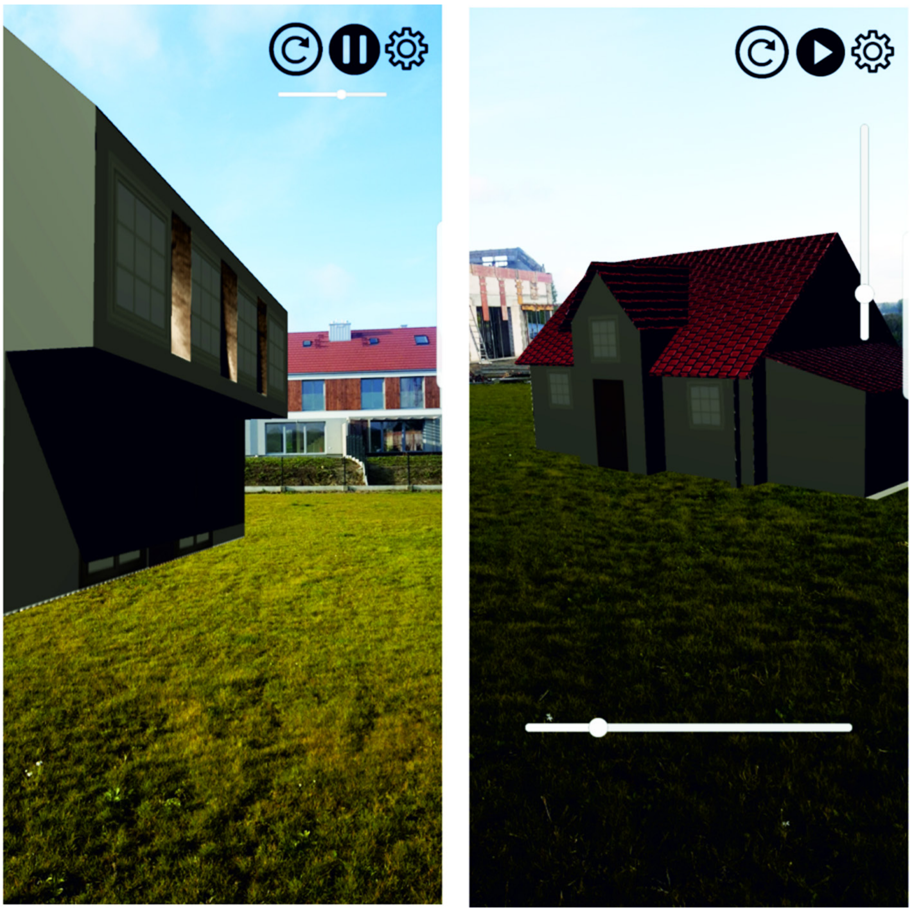

**Fig. 13**. Visualization of buildings that comply with the provisions of the local plan (screen capture from a smartphone)

& Roth, 2018). The visualizations presented with the AR technology show that different interpretations of local plan provisions can result in spatial chaos. Detailed parameters for determining the method of spatial development are not available, and the imprecision of local plan provisions contributes to the degradation of spatial order.

In the first version, the visualization of the development design was performed based on background maps and markers (these solutions are applied by, among others, Vuforia and Wikitude Augmented Reality). In this approach, real-world objects were visualized with the use of virtual reality based on a marker analysis conducted with a mobile device (smartphone) and the generated computer graphics (3D objects).

The provisions of the spatial development plan provisions can also be visualized based on a scanned flat plane (this solution has been implemented by Google – ARCore).[1] In this case, the device scans the background map and uses it as the basis for generating a 3D model which, when the application is run again, can be displayed in a different location (centimeter differences in the map scale). In this solution, the model's location must be corrected each time against the background map. This solution primarily involves an understanding of the natural environment. This process involves scanning the surroundings and recognizing characteristic points and planes. An algorithm in the mobile devices interprets groups

[1] https://www.wikitude.com/; https://developer.vuforia.com/; https://developers.google.com/ar.

✉rafal.kazmierczak@uwm.edu.pl, ✉aszczep@uwm.edu.pl

of points which create common planes (horizontal or vertical). ARCore determines the boundaries of these areas and localizes a predefined digital object on these boundaries.[2] An advantage of this solution is that there is no need to generate a separate marker. Unlike in the approach that involves markers, the displayed object is generated in a different location each time. For a 3D object to be placed correctly relative to the obligatory building line, an interactive element must be added, namely the option of changing the object's position and editing its shape (width, length and height). This requires a more extensive knowledge of informatics.

Since an interactive element can also be used in the marker approach, this solution was applied in this study. In the solution based on the prepared markers, 3D objects generated in the process will be always displayed in the same location. Therefore, the marker-based technology is the recommended solution whenever a map is used as the background element.

Augmented reality can also be used to visualize the designed spatial development directly in the investment area based on GNSS coordinates. In comparison with the previous solution, this approach facilitates the presentation of 3D models on a scale of 1:1, which can be as large as up to several dozen meters. The accuracy of coordinate determination is a significant limitation in this case. The altitude coordinate is smallest in the installed GNSS receivers, for example in smartphones. The difference between the actual and the measured height can reach up to several meters. The option of adjusting the height of a 3D object determined in the field was implemented to eliminate this technological limitation. The instability of the determined co-ordinates is a certain problem. GNSS receivers in smartphones determine position at 1-second intervals. This position is determined in real-time, and the consecutive observation intervals can differ by several meters. Therefore, the displayed object was stabilized by averaging the positions from several measurement intervals (the determined positions should not be refreshed every 1-second interval) (Kaźmierczak, 2020). A local system of coordinates was defined for each 3D object.

The presented methods seem to be optimal for visualizing spatial relations. The marker-based approach for presenting 3D objects seems to be particularly useful. A map with a land development plan can be used as such a marker. This solution preserves the carto metricity of a visualization, particularly its scale. However, it is more laborious because it requires a background map. The frame of the reference parameters for the map, the marker and the 3D object is easier to define in the programming environment. The beginning of the frame of reference, the directions of the coordinate axes, and the units of measurement are defined when an object is created. The location where a 3D object is displayed on the marker is also defined.

The AR application enabled the visualization of a newly developed building and a comparison with the existing buildings. Augmented reality can be used to assess the impact of newly designed buildings and their foundations on spatial order. Therefore, applications that rely on AR can be used as tools in the process of developing local plans by designers as well as decision-makers who approve the adopted solutions. Augmented reality is also a tool which can be widely used in consultations – the generated development models can help users to select the most suitable form of buildings (Fegert et al., 2020; Saßmannshausen et al., 2021). Augmented reality is also a useful tool for investors. The AR technology can play an important role in the investment process at the stage of adapting the architectural design to the surroundings. This technology can also be used to track moving objects, and it involves a sound component.

These functions corroborate the hypothesis put forward at the beginning of this paper, namely that visualization of spatial development of a building plot in 3D AR helps to understand the spatial relations between a building and its surroundings (Goudarznia et al., 2017). The study also demonstrated that the AR technology can be used to identify imprecise fragments of the local plan and its impact on the method of space development.

[2] https://developers.google.com/ar.



✉rafal.kazmierczak@uwm.edu.pl, ✉aszczep@uwm.edu.pl

The use of AR facilitates an understanding of spatial development planning which takes into account the principles of spatial order. Technological progress and the popularity of mobile devices have increased the availability of 3D visualizations involving the AR technology.

**Author contributions:** R.K. and A.S. approved the final version of the article. R.K. and A.S. developed the concept and designed the study, R.K. and A.S. collected the data, R.K. and A.S. analyzed and interpreted the data, R.K. and A.S. drafted the article, R.K. and A.S. revised the article critically for important intellectual content.

**Funding:** This research received no external funding.

## REFERENCES

Allen, M., Regenbrecht, H., & Abbott, M. (2011, November). *Smart-phone augmented reality for public participation in urban planning.* Paper on the 23rd Australian computer-human interaction conference, Canberra, Australia (pp. 11–20). https://doi.org/10.1145/2071536.2071538

Asanowicz, A. (2012). Systemy rzeczywistości wirtualnej w architekturze [Virtual Reality in architecture]. *Architecturae et Artibus*, *4*(4), 5–12.

Azuma, R. T. (1997). A survey of augmented reality. *Presence: Teleoperators & Virtual Environments*, *6*(4), 355–385. https://doi.org/10.1162/pres.1997.6.4.355

Azuma, R. T. (2017, June). *Making augmented reality a reality. Paper on Conference* Propagation Through and Characterization of Atmospheric and Oceanic Phenomena San Francisco, California, United States. https://opg.optica.org/abstract.cfm?URI=AIO-2017-JTu1F.1

Broll, W., Lindt, I., Ohlenburg, J., Wittkämper, M., Yuan, C., Novotny, T., Schieck, A. F., Mottram, C., & Strothmann, A. (2004). Arthur: A collaborative augmented environment for architectural design and urban planning. *JVRB-Journal of Virtual Reality and Broadcasting*, *1*(1), 1–10.

Buchwald, P. (2018). *Urządzenia mobilne w systemach rzeczywistości wirtualnej* [*Mobile devices in virtual reality*]. Wydawnictwo Helion.

Bydłosz, J., Bieda, A., & Parzych, P. (2018). The implementation of spatial planning objects in a 3D cadastral model. *ISPRS International Journal of Geo-Information*, *7*(4), 153. https://doi.org/10.3390/ijgi7040153

Carbonell C.C., & Bermejo . L. A. (2016). Augmented reality as a digital teaching environment to develop spatial thinking. *Cartography and Geographic Information Science*, *44*(3), 259–270. https://doi.org/10.1080/15230406.2016.1145556

Carbonell C. C., & Bermejo, L. A. (2017). Landscape interpretation with augmented reality and maps to improve spatial orientation skill. *Journal of Geography in Higher Education*, *41*(1), 119–133. https://doi.org/10.1080/03098265.2016.1260530

Caudell, T. P., & Mizell, D. W. (1992, January). *Augmented reality: An application of heads-up display technology to manual manufacturing processes.* Paper on Hawaii International Conference on System Sciences, Kuai, Hawaii (Vol. 2). ACM SIGCHI Bulletin. https://doi.org/10.1109/HICSS.1992.183317

Dickmann, F., Keil, J., Dickmann, P. L., & Edler, D. (2021). The impact of augmented reality techniques on cartographic visualization. *KN – Journal of Cartography and Geographic Information*, *71*, 285–295. https://doi.org/10.1007/s42489-021-00091-2

Fegert, J., Pfeiffer, J., Peukert, C., & Weinhardt, C. (2020, March). *Enriching E-Participation through Augmented Reality: First Results of a Qualitative Study.* Paper on 15. Internationalen Tagung Wirtschaftsinformatik, Potsdam, Germany (pp. 560–567). https://doi.org/10.5445/IR/1000117706

Goudarznia, T., Pietsch, M., & Krug, R. (2017). Testing the effectiveness of augmented reality in the public participation process: a case study in the city of Bernburg. *Journal of Digital Landscape Architecture*, *2*, 244–251. https://doi.org/10.14627/537629025

Grassi, S., & Klein, T. M. (2016, September). 3D *augmented reality for improving social acceptance and public participation in wind farms planning. Journal of Physics: Conference Series*, *749*(1), 012020. IOP Publishing. Paper on Conference WindEurope Summit 2016, Hamburg, Germany. https://doi.org/10.1088/1742-6596/749/1/012020

Han, J. G., Park, K. W., Ban, K. J., & Kim, E. K. (2013). Cultural heritage sites visualization system based on outdoor augmented reality. *Aasri Procedia*, *4*, 64–71. https://doi.org/10.1016/j.aasri.2013.10.011

✉rafal.kazmierczak@uwm.edu.pl, ✉aszczep@uwm.edu.pl

Howard, I. P., & Rogers, B. J. (2012). *Perceiving in depth*, Vol. 2: *Stereoscopic vision*. Oxford University Press.

Juszka, D., & Papir, Z. (2016). Badanie korelacji pomiędzy technicznymi parametrami obrazu wideo stereoskopowego (3D) a subiektywną oceną treści wideo [A study on corelations between technical parameters of stereoscopic 3D video image and subjective assessment of video content]. *Przegląd Telekomunikacyjny – Wiadomości Telekomunikacyjne* [*Telecommunications Review – Telecommunications News*], *6*, 229–232. https://doi.org/10.15199/59.2016.6.13

Kaźmierczak, R. (2020). Geoinformation support system for real estate market. *Acta Scientiarum Polonorum. Administratio Locorum*, *19*(2), 85–95. https://doi.org/10.31648/aspal.4782

Khan, M. A., & Dong, A. (2011). Geo-Located Augmented Reality as a Platform for Citizen Engagement. *International Reports on Socio-Informatics*, *8*(2), 32–36.

Kolecka, N. (2008). Integracja GIS i wirtualnej rzeczywistości do wizualizacji i eksploracji danych geograficznych [Integration of gis and virtual reality for geographic data visualization and exploration]. *Archiwum Fotogrametrii, Kartografii i Teledetekcji* [*Archives of Photogrammetry, Cartography and Remote Sensing*], *18*, 241–250.

Kołodziejczyk, E. (2013). Kody QR i rzeczywistość rozszerzona (AR) – przykłady nowych rozwiązań technologicznych w bibliotekach szkół wyższych [QR codes and augmented reality (AR) – examples of new technological solutions in higher education libraries]. *Biuletyn EBIB* [*Bulletin EBIB*], *8*(144), 1–11.

Konopacki, J. (2014). Rozszerzona rzeczywistość-jako narzędzie wspomagające procesy analityczno-decyzyjne w architekturze i planowaniu przestrzennym [Augmented reality as a tool supporting assessment and decision-making processes in architecture and spatial planning]. *Przestrzeń i Forma* [*Space and Form*], *21*, 89–108.

Korbel, W. (2018). Instytucja Miejscowego Planu Zagospodarowania Przestrzennego – ocena i oczekiwania zmian według gminnych władz samorządowych w Polsce [Institution of land development plan – valuation and expectations of changes in the eyes of the communal authorities of Poland]. *Prace i Studia Geograficzne* [*Studies in Geography*], *63*(4), 23–39.

Kuczamer-Kłopotowska, S. (2014). Sensoryczne oddziaływanie na klienta jako forma wspierania procesu komunikacji marketingowej [Sensual marketing]. *Zarządzanie i Finanse* [*Journal of Management and Finance*], *12*(2), 115–132.

Küspert, S., & Zink, R. (2017). Concept of a digital communication platform to increase the citizens' interest in spatial planning. *JoDLA: Journal of Digital Landscape Architecture*, 136–143. https://doi.org/10.14627/537629014

Maksymiuk, G., Suchocka, M., Błaszczyk, M., & Juźwiak, A. (2017). Nowe technologie i ich możliwości zastosowania w badaniach preferencji społecznych względem kształtowania krajobrazu [Modern technologies and their application in studies on social preferences towards landscape development]. *Prace Komisji Krajobrazu Kulturowego* [*Dissertations of the Cultural Landscape Commission*], *36*, 99–112.

Marques, B., Santos, B. S., Araújo, T., Martins, N. C., Alves, J. B., & Dias, P. (2019, July). *Situated visualization in the decision process through augmented reality*. Paper on 23rd International Conference Information Visualisation, Paris, France (pp. 13–18). IEEE. https://doi.org/10.1109/IV.2019.00012

Marques, L. F., Tenedório, J. A., Burns, M., Romão, T., Birra, F., Marques, J., & Pires, A. (2017). Cultural Heritage 3D Modelling and visualisation within an Augmented Reality Environment, based on Geographic Information Technologies and mobile platforms. *ACE: Arquitectura, Ciudad y Entorno*, *11*(33), 117–136. https://doi.org/10.5821/ace.11.33.4686

Milgram, P., Takemura, H., Utsumi, A., & Kishino, F. (1995). Augmented reality: a class of displays on the reality-virtuality continuum. *Telemanipulator and Telepresence Technologies*. Proc. SPIE 2351, 282–292. https://doi.org/10.1117/12.197321

Milovanovic, J., Moreau, G., Siret, D., & Miguet, F. (2017, July). *Virtual and augmented reality in architectural design and education*. Paper on 17th international conference, CAAD futures, Istanbul, Turkey.

Moore, G. E. (1965). Cramming more components onto integrated circuits. *IEEE Solid-State Circuits Society Newsletter*, *11*(3). https://doi.org/10.1109/N-SSC.2006.4785860

Nowak, M. J. (2019). *Planowanie i zagospodarowanie przestrzenne: komentarz do ustawy i przepisów powiązanych* [*Spatial planning and development: commentary on the Act and related regulations*]. C.H. Beck.

Olszewski, R., Gnat, M., Trojanowska, H., Turek, A., & Wielądek, A. (2017, July). *Towards social fuzzy geoparticipation stimulated by gamification and*

rafal.kazmierczak@uwm.edu.pl, aszczep@uwm.edu.pl

*augmented reality*. Paper on 13th International Conference on Natural Computation, Fuzzy Systems and Knowledge Discovery (ICNC-FSKD), Guilin, China (pp. 1363–1370). IEEE. https://doi.org/10.1109/FSKD.2017.8392965

Pardel, P. (2009). Przegląd ważniejszych zagadnień rozszerzonej rzeczywistości [A survey of augmented reality important issues]. *Studia Informatica*, *30*(1), 35–64.

Peckienė, A., & Ustinovičius, L. (2017). Possibilities for building spatial planning using BIM methodology. *Procedia Engineering*, *172*, 851–858. https://doi.org/10.1016/j.proeng.2017.02.085

Phan, V. T., & Choo, S. Y. (2010). A Combination of Augmented Reality and Google Earth's facilities for urban planning in idea stage. *International Journal of Computer Applications*, *4*(3), 26–34. https://doi.org 10.5120/809-1149

Regulation of the Minister of Development and Technology dated December 17, 2021 on the required scope of the draft local development plan (2021). Dz.U. item 2021.

Sabath, K. (1996). Nowe spojrzenie na ewolucje oczu [A new look at eye evolution]. *Wiedza i Życie* [*Knowledge and Life*], *1*, 46–50.

Saßmannshausen, S. M., Radtke, J., Bohn, N., Hussein, H., Randall, D., & Pipek, V. (2021, June). *Citizen-centered design in urban planning: How augmented reality can be used in citizen participation processes.* Paper on Designing Interactive Systems Conference 2021, Virtual Event, USA (pp. 250–265). https://doi.org/10.1145/3461778.3462130

Sieminski, W. (2011). Wizualizacja trójwymiarowa w prognozowaniu zmian zagospodarowania przestrzennego i jako metoda wzmacniania dyskusji publicznej w procesie planowania przestrzennego [Application of 3D visualisation to forecast changes in land use and as a method of stimulating public discusssion in the process of spatial planning]. *Człowiek i Środowisko* [*Man and Environment*], *1*(35), 37–52.

Siwak, W. (2016). Matrix i pół-Matrix czyli rzeczywistość wirtualna i rzeczywistość rozszerzona jako wyzwania dla tożsamości, kultury, sztuki [Matrix and semi-Matrix, or virtual reality and augmented reality as a challenge for identity, culture, art and education]. *Rocznik Naukowy Kujawsko-Pomorskiej Szkoły Wyższej w Bydgoszczy. Transdyscyplinarne Studia o Kulturze (i) Edukacji* [*The Annals of Kujawy and Pomorze University in Bydgoszcz. Transdisciplinary Studies on Culture (and) Education*], *11*, 355–388.

Soria, C., & Roth, M. (2018). Unreal reality: An empirical investigation of augmented reality effects on spatial cognition in landscape architecture. *Journal of Digital Landscape Architecture*, *3*, 150–162. https://doi.org/10.14627/537642016

Szlachetko, J. (2017). Miejscowy plan rewitalizacji a miejscowy plan zagospodarowania przestrzennego. Różnice w zakresie przedmiotowym upoważnienia ustawowego [Local Revitalization Plan and Local Spatial Development Plan. Comparison]. *Metropolitan. Przegląd Naukowy* [*Metropolitan. Scientific Review*], *1*(7), 40–59.

Tomkins, A., & Lange, E. (2020). Bridging the analog--digital divide: enhancing urban models with augmented reality. *Journal of Digital Landscape Architecture*, *5*, 366–373. https://doi.org/10.14627/537690037

Tota, P. (2015). Miasto oswojone. Znaczenie kompozycji urbanistycznej dla orientacji w przestrzeni miasta [Tamed city. The importance of urban composition for the orientation in the city space]. *Środowisko Mieszkaniowe* [*Housing Environment*], *14*, 180–189.

Ware, C. (2019). *Information visualization: perception for design*. Morgan Kaufmann.

Yarbus, A. L. (1967). Eye movements during perception of complex objects. In A. L. Yarbus (Ed.), *Eye Movements and Vision* (pp. 171–211). Springer, Boston, MA. https://doi.org/10.1007/978-1-4899-5379-7_8 (1967).

Zamojski, T. (2020). *Computer Aided Urban Landscape Design Process.* In: W. Zamojski, J. Mazurkiewicz, J. Sugier, T. Walkowiak, & J. Kacprzyk. (Eds.). Theory and Applications of Dependable Computer Systems DepCoS-RELCOMEX 2020. Advances in Intelligent Systems and Computing, Vol. 1173. Springer, Cham. https://doi.org/10.1007/978-3-030-48256-5_67

Zhang, G., Tian, L., Liu, Y., Liu, J., Liu, X. A., Liu, Y., & Chen, Y. Q. (2016, August). *Robust Real-Time Human Perception with Depth Camera*. ECAI'16: Proceedings of the Twenty-second European Conference on Artificial Intelligence, Amsterdam, Netherlands (pp. 304–310). https://doi.org/10.3233/978-1-61499-672-9-304

✉rafal.kazmierczak@uwm.edu.pl, ✉aszczep@uwm.edu.pl