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ANALYSIS OF THE PROSPECTS FOR THE DEVELOPMENT OF 3D CADASTRAL VISUALISATION

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ABSTRACT

Motives: In the past twenty years, considerable progress has been made in 3D real estate cadastres and 3D visualisation technologies. These developments require advanced solutions for the visualisation of 3D cadastral objects.
Aim: The main aim of this study was to propose an optimal 3D cadastre visualisation strategy that accounts for user needs, the types of visualised data, and visualisation platforms.
Results: The optimal 3D cadastre visualisation strategy was determined by performing a SWOT/TOWS analysis. Both internal and external factors that can influence the development of 3D cadastre visualisation policies were considered in the analysis. The results of the study were used to propose an aggressive strategy (based on the identified strengths and opportunities) for the development of 3D cadastre visualisation.

Keywords: 3D cadastre, 3D visualisation, SWOT/TOWS analysis, visualisation platforms, visualisation analysis

INTRODUCTION

The main purpose of the conducted research is to determine the direction in which work on visualization of 3D cadastral information should be carried out. To date, issues related to the visualization of 3D cadastral data have not been sufficiently developed or are at an early stage of development. Hence, it was decided to conduct a study on determining the strategy of 3D cadastre visualization. It was decided that a SWOT/TOWS analysis would be a suitable method to accomplish this goal. The background of the main research is the consideration of user needs, types of visualized data and visualization platforms. The performed work is intended, in part, to fill the research gap in the absence of a clear strategy for visualizing 3D cadastral information.

DEVELOPMENTS IN 3D CADASTRAL ISSUES – OVERVIEW

The subject of three-dimensional cadastre, usually referred to as 3D cadastre, came into being in a wider sense with the organisation of the first 3D cadastre workshop in Delft (the Netherlands) in 2001.

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Since the beginning of the second decade of the 21st century, it has started to become more and more popular, which is mainly determined by two factors. In 2010, the joint commission 3 and 7 Working Group on 3D Cadastres of the International Federation of Surveyors (FIG) was established and a questionnaire on the future development of the 3D cadastre was developed and then made public. The questionnaire was completed for numerous countries. Its aggregated results are described in (Oosterom et al., 2011). In 2011, also in Delft, a second workshop on the 3D cadastre was held. This resulted in a wider appearance of the term '3D cadastre' in the consciousness of those involved in the property management in its broadest sense, such as surveyors, urban planners, architects and lawyers. This is also due to the increasing popularity of various types of software and mobile applications that consider the third dimension, or that enable the creation of own 3D visualisations.

In 2014 and 2018, two similar questionnaires were conducted on the work concerning the 3D cadastre (Oosterom et al., 2014; Shnaidman et al., 2019). These were completed by respondents from numerous countries. They considered developments in both theory and practise in the broader domain of 3D cadastre. Literature on this field has been collected and presented on the website of the Joint Commissions 3 and 7 Working Group on 3D Cadastre (Literature, 2022). A more comprehensive description of modern cadastre concepts can be found in (Bydłosz & Bieda, 2020) and (Bydłosz, 2022).

It is also worth noting that the implementation of 3D cadastre in various aspects can meet numerous barriers – among other things mental, legal, technical and organisational (Ho, et al., 2013).

VISUALISATION OF 3D CADASTRAL DATA – STATE OF THE ART

Despite the intensive work carried out on the development of the 3D cadastre for more than two decades, relatively little time has been spent on the visualisation of cadastral information, especially in 3D. To systematise the current activities concerning the visualisation of the multidimensional cadastre, the article discusses its three aspects:

1. User needs.
2. Type of data to be visualised.
3. Visualisation platforms.

Potential users of the 3D cadastre need to be part of the R&D activities of visualising its data. Pouliot and Wang (2014) show that such users are willing to explore and gain knowledge about the advantages of using 3D visualisation.

Looking in more detail at the results of conducted and published global studies, it can be concluded that, generally, the potential users of 3D visualisation of cadastral information are those who also use 2D cadastral systems, e.g. notaries, lawyers, surveyors, or government and public administration agencies responsible for the land administration system. However, the third dimension contributes to the expansion of this group to include architects, engineers, real estate brokers and developers. Some of the aforementioned consumer groups use 3D models in their work, so access to an integrated 3D cadastre is seen as valuable.

A survey carried out in the province of Quebec (Canada) described in (Pouliot & Wang, 2014) showed that users' expectations of the 2D and 3D cadastre data associated with both cadastres do not tend to differ. The multidimensional visualisation of cadastral data, on the other hand, can help distinguish between private and common parts in residential buildings or in performing 3D geometric analyses such as buffering. It also supports other management systems, including co-visualisation of land taxation, spatial planning or land use regulations. Cadastral data visualised in the third dimension support the calculation of the area or volume of real estate, and become the basis in the analysis of spatial relationships such as overlapping or identification of spatial conflicts in terms of RRR (rights, restrictions and responsibilities).

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User needs

The need for a full representation of data in three dimensions has accompanied researchers since the first 3D cadastre workshop in 2001. However, since then, most countries in the world only have 2D cadastre data and only some limited 3D survey data.

A study by Pouliot and Wang (2014) investigated the need to provide and evaluate how 3D cadastre descriptive data are placed (outside, inside). The survey consisted of a direct interview with possible users of the 3D cadastre. According to potential data users, the placement of information outside the visualised object is of little use. Instead, many specialists advocate the creation of a multidimensional cadastral system that additionally monitors urban development over time, depicts statistics of land use changes and archives them. So far, the biggest challenge for researchers is to develop a 3D visualisation system that would allow the integration of multiple data sources.

Another aspect to consider is the requirements for visualising 3D cadastre data (Cemellini et al., 2018). One of these is the availability of labels with official measurements of cadastral data relating to the geometry of property boundaries. In most cases, this information is certified by surveyors or notaries (Dimopoulou et al., 2018). It has been recognised that direct access to them is crucial for any cadastral visualisation system. Physical objects play a critical role in cadastral data visualisations, as they act as landmarks that are usually easily recognisable by users (Thompson et al., 2018). Thus, the representation of the relationship of 3D legal entities with their corresponding physical objects is crucial because of the facilitation associated with measuring, establishing and comparing their geometry.

Types of visualised data

The variety of semantic and geometric objects in 3D cadastral systems is not surprising. Consequently, many data groups can be distinguished. A distinction can be made between the different types of objects that can be considered for cadastral visualisation. Isikdag et al. (2015) distinguished between physical and virtual objects. While Pouliot (2011) and Wang (2015) found that at least two types of spatial objects are needed as boundaries of legal and physical objects. Vandysheva et al. (2012) proposed the visualisation of underground objects in a 3D cadastre. In summary, the researchers emphasise that not only legal, but also physical representations are important. First, they focus on the need to distinguish between private and public land, but equally important is the combination of spatial relationships and 3D geometric information.

In the state of Victoria, Australia, it has been demonstrated that Building Information Modelling (BIM) environment can enable various physical and legal boundaries to be represented in several ways (Atazadeh et al., 2017). However, it should be recognised that traditional BIM does not provide a guarantee for the correct definition of 3D objects. The visualisation of invisible objects, such as legal boundaries, can be considered in a way similar to underground object boundaries, for which the problem of visualisation is a major difficulty in the operation of current cadastral systems.

The ability to visualise descriptive data as object attributes is an important aspect in cadastral applications. For example, Atazadeh et al. (2016) used the possibilities of managing legal information that is related to private property in a 3D BIM digital data environment.

The relationships between multidimensional legal entities, and in particular the overlapping between them, are crucial in terms of visualisation. These include topological relationships, neighbourhood, orientation relationships and the distance between them. For example, in the case of parts of a multi-unit building such as a ceiling or a wall, all 3D objects must be in contact with each other to form a unified whole. In the case of a classic 2D cadastral map, a topology can be constructed quite easily. In the case of a 3D cadastral visualisation, due to perspective projection and occlusion, it is much more difficult to realise. Equally important seems to be the representation of the relationship between 3D legal units and 2D land parcels, on which almost all cadastral systems are based (Thompson et al., 2016b).

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It is also important to represent 3D legal boundaries, which can be bounded when 3D objects have a correctly defined volume or partially bounded when these boundaries cannot define a finite volume (Pachelski & Góźdź, 2014). The latter type of legal entity should be presented in such a way that users can recognise their bounded and unbounded parts without problems.

An important element in the visualisation of 3D cadastre objects is the spatial representation of the data used. Currently, spatial object geometries are not well supported by current software such as GIS, CAD and DBSM or ISO standards (Shojaei et al., 2017). Ying et al. (2015) followed the definition of a 3D parcel as defined in (Thompson & Oosterom, 2011) state that a 3D cadastral object, can be represented by a polyhedron satisfying the following characteristics: internal connection, correct structure and correct orientation.

The introduction of the ISO 19100 series of international standards for geographic information can also be helpful for the visualisation of 3D cadastral objects. Of particular relevance here seems to be the international standard ISO 19152 'Land Administration Domain Model' (LADM), which provides a reference model for modelling systems containing cadastral information, both 2D and 3D (ISO, 2012). Each cadastral system contains components such as unique identifiers assigned to all parcels of land, attributes describing the geometry of the property (length, area, volume or RRR associated with a parcel of land) or geodetic grid data. The Land Administration Domain Model defines how spatial units should be and how they relate to each other through rights, restrictions and responsibilities (RRR). A simplified diagram of the database storage is delivered by Thompson et al. (2016a). Different types of multidimensional entities are presented there. The class 'LA_BoundryFaceString' is here connected by a composition relation (it is part of and cannot exist without) to the class 'LA_SpatialUnit'.

The equivalent of a 2D pixel in 3D visualisation is the voxel. A voxel, as a volumetric pixel, is a unit of volume with which a numerical value is associated. Representing cadastral data in this way has many advantages, such as, for example, the ability to calculate volumes and record them. An additional advantage is the visualisation of 3D objects through 3D cubes. The disadvantages of this type of representation, a is the complexity of storing the data and its inefficient handling by the spatial database management system (Goncalves et al., 2016).

Another issue of 3D data visualisation is the possibility of using point clouds (Góźdź et al., 2014). Their use in 3D cadastre greatly facilitates the visualisation of the data used. For both 2D and 3D objects, the reference information is stored as vector models. Point clouds can also be used to determine whether a parcel is above, below, or on the Earth's surface. Another application is the creation of 3D parcels to be generated as physical objects with rights, restrictions and responsibilities (RRR).

Visualisation platforms

With the development of 3D cadastre, there has been an increased need for prototypes of web-based system technologies to support the visualisation of multidimensional cadastre objects. There are systems, such as ESRI CityEngine, that greatly facilitate 3D visualisation, but the sophistication required to operate such software may make it unsuitable for many user groups. Open source solutions focussing on the creation of a web-based 3D cadastral visualisation system may provide an answer to this problem. A system based on Google Earth for ePlan/LandXML type data has therefore been developed for use when properties overlap. This is used to illustrate both physical and legal objects. Based on KML from Google Earth and X3D from ArcGIS online two prototype online 3D maps were created for the jurisdictions of Indonesia (Aditya et al., 2011).

User interactions with the objects of a 3D digital environment are at the heart of the success of any 3D system. In a 3D cadastre prototype in the Russian Federation, consumers can drag a 3D model of floors along with a 2D floor plan of a building to overcome occlusion issues. Some prototypes also allow user navigation, attribute queries, or object search (Vandysheva et al., 2012).

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In the Republic of North Macedonia, Dimovski et al. (2011) proposed a highly developed solution for visualising 3D objects. It is based on Oracle and GeoServer databases and Java and NASA World Wind software. This system has the capability to image buildings in 3D, but this visualisation is limited to the ground level part of the buildings only.

The implementation of digital systems using AutoCAD Map 3D, PostgreSQL/PostGIS and a Google Earth plug-in is also an answer to the problems of 3D visualisation. In the 3D cadastral prototype developed for the People's Republic of China by Guo et al. (2011) ArcGIS Server, Skyline (TerraExplorer), SkechUp and Oracle were combined. Unlike Google Earth and NASA World Wind, Skyline also supports underground objects. All the systems discussed are still in the prototype phase and require validation by potential users before formal use.

In summary, visualisation platforms should include features that are enabled by the tools used, such as zooming in/out, changing colour, changing transparency levels, attribute queries, navigation and spatial analysis, among others. However, despite so many possibilities, there are also challenges associated with them. Perhaps the most important of these is that the interface does not always function in full software compatibility, which limits access and implementation options. There may also be problems with the legal and institutional implementation of these solutions.

SWOT ANALYSIS OF 3D CADASTRAL DATA VISUALISATION STRATEGIES.

In order to systematise, collate and in a way summarise the overview of the work on 3D cadastre visualisation, a SWOT/TOWS analysis (Grzelka, 2022) was conducted. SWOT/TOWS analyses were already used in land administration related issues (Bieda & Brzozowska, 2017; Glinka, 2022), as well as in marine cadastre (Dawidowicz & Źróbek, 2014; Bieda et al., 2019).

The analysis was performed in the following 4 steps:

1. identification of the factors to be analysed;
2. identifying the links between the factors to be analysed;
3. analysing individual strategies;
4. selection of the best strategy for visualisation of 3D cadastre data.

To perform the SWOT/TOWS analysis, external and internal factors were identified. The 'Strengths' and 'Weaknesses' were analysed as internal factors and 'Opportunities' and 'Threats' as external factors. Twenty factors were used in the analysis (five for each element). The factors analysed are presented in Table 1.

To determine the links between the factors, the supporting questions developed for determining spatial development directions using SWOT/TOWS analysis (Bieda & Brzozowska, 2017) were used. The questions are presented in Table 2.

The identification of connections between the factors was determined by answering the supporting questions listed in Table 2. Each factor was considered equally important, hence individual factors were not assigned weights. Three grades were adopted to determine the strength of the connections between the individual factors:

2 – strong relationship
1 – weak relationship
0 – no relationship.

Based on the identified factors, SWOT and TOWS analyses were performed. SWOT relationships are presented in Table 3 and TOWS relationships in Table 4.

The summary results of the SWOT/TOWS analysis are presented in Table 5.

The final results of the strategic analysis are presented in Table 6.

Based on the results of the analyses described above, one of four strategies can be chosen:

1. aggressive, in which strengths and associated opportunities dominate;
2. conservative, which is dominated by strengths and their associated risks;
3. competitive, in which weaknesses and associated opportunities dominate;
4. defensive, which is dominated by weaknesses and their associated threats.

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Table 1. SWOT/TOWS analysis factors

Internal factors	External factors
Strengths (S)	Opportunities (O)
Presenting the 3D cadastre data in a multi-dimensional way gives you an idea of space.	Growing number of developments under or above the surface.
Educating the public about spatial real estate.	Opportunity to engage new users.
Possibility to use the spatial parcel simultaneously for various purposes (underground, e.g. metro line, above-ground, e.g. a single-family house).	Development of the spatial property market.
Development of urban spatial infrastructure.	Opportunity for better development of densely built-up areas especially in cities.
Representation of 3D cadastre objects with voxels.	Global commitment to the introduction of global standards for the visualisation of 3D cadastre data.
Weaknesses (W)	Threats
Limited access to 3D data.	A change in the law that may result in unfavourable changes for the visualisation of the 3D cadastre.
Complicity of visualised 3D cadastre data.	Transition from 2D to 3D data modelling with an outdated, incomplete and non-standardised database.
Occlusion in 3D cadastre data visualisations.	Impossibility of creating a standardised international 3D cadastre data visualisation system due to various legal systems in different countries.
Volumetric registration of the parcel without 3D presentation on the cadastral map.	A slowdown in the development of 3D cadastre visualisation due to the inability to use it in the majority of the country's area, as the spatial potential is mainly employed in highly urbanised areas.
Recording of 2D geometric elements containing 3D information.	High cost of the 3D cadastre building.

Source: own preparation based on Grzelka (2022).

Table 2. Auxiliary questions in the factor connection analysis

Questions in the SWOT analysis	Questions in the TOWS analysis
Will strength make it possible to benefit from a given opportunity?	Does the opportunity enhance the given strength?
Will the strength enable a given threat to be neutralised?	Does the opportunity neutralise the given weakness?
Does the weakness reduce the opportunity? Does the weakness intensify the risk associated with a given threat?	Does the threat reduce the given strength? Does the threat magnify the given weakness?

Source: own preparation based on Bieda & Brzozowska (2017).

It is worth realising that the increasing number of building developments both above and below ground provides opportunities for the further advance of 3D cadastre visualisation and thus the possibility of using a spatial parcel of land simultaneously for different purposes, e.g. the construction of an underground line and family houses. The prospect of engaging new users, which enhances the education of the public in terms of knowledge of real estate or spatial objects in general, also contributes significantly to such a development.

It is also worth noting, the introduction of international standards in the field of geographic information, especially the ISO 19152 standard (ISO, 2012).

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Table 3. SWOT connections

	O1	O2	O3	O4	O5	T1	T2	T3	T4	T5
S1	2	1	2	2	1	0	0	0	1	0
S2	2	2	2	1	0	0	0	0	0	0
S3	2	1	2	2	0	0	0	0	0	2
S4	2	1	2	2	0	0	0	0	1	1
S5	0	0	1	2	1	0	1	0	0	1
W1	2	1	2	2	0	1	2	0	2	0
W2	1	1	1	1	0	1	1	1	2	2
W3	0	1	0	1	0	1	0	0	0	0
W4	0	0	1	1	0	1	1	0	1	0
W5	1	1	1	1	0	1	1	0	1	1

Source: own preparation based on Grzelka (2022).

Table 4. TOWS connections

	S1	S2	S3	S4	S5	W1	W2	W3	W4	W5
O1	2	1	2	2	2	2	1	0	1	1
O2	1	2	1	2	0	2	1	0	1	1
O3	1	2	2	2	0	1	1	0	1	1
O4	2	1	2	2	2	1	1	0	1	1
O5	1	1	0	1	1	1	2	2	2	2
T1	1	1	0	1	1	2	2	2	2	2
T2	1	0	1	1	1	1	1	0	1	1
T3	1	1	1	0	1	1	0	0	1	0
T4	1	2	0	0	1	1	1	0	1	1
T5	0	2	2	0	1	2	0	0	1	1

Source: own preparation based on Grzelka (2022).

This also supports the progress of the visualisation of 3D cadastre objects, especially in terms of improving and clarifying its stages, defining the accuracy with which it should be done and the development of software. This is strongly linked to the development of urban spatial infrastructures and their presentation, which makes it possible to increase the knowledge of land parcels or spatial properties.

Table 6. Strategic analysis results and strategy selection

	Opportunities	Threats
Strenghts	Aggressive strategy	Conservative strategy
	Number of interactions	Number of interactions
	136	56
	Weighted number of interactions	Weighted number of interactions
	136.00	56.00
Weaknesses	Competitive strategy	Defensive strategy
	Number of interactions	Number of interactions
	92	88
	Weighted number of interactions	Weighted number of interactions
	92.00	88.00

Source: own preparation based on Grzelka (2022).

Despite both strengths and opportunities, weaknesses and threats have also been identified that may slow down or limit the development of 3D cadastre visualisation. The weaknesses are mainly related to internal factors, and concern the occlusion and complexity of the visualised data. Current work on 3D cadastre has highlighted two main visualisation problems. The first is the volumetric recording of parcels of land while lacking 3D presentation on cadastral maps, while the second is the recording of 2D geometric elements containing 3D information that does not have its spatial representation.

The threat faced by researchers working on 3D cadastre data visualisation is the fact that cadastral

Table 5. Aggregated results of the SWOT/TOWS analysis

Combinations	SWOT analysis results		TOWS analysis results		SWOT/TOWS summary	
	Sum of interactions	Sum of products	Sum of interactions	Sum of products	Sum of interactions	Sum of products
Strengths/Opportunities	66	66,00	70	70,00	136	136,00
Strengths/Threats	14	14,00	42	42,00	56	56,00
Weaknesses/Opportunities	38	38,00	54	54,00	92	92,00
Weaknesses /Threats	40	40,00	48	48,00	88	88,00

Source: own preparation based on Grzelka (2022).

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databases are very often outdated, transitioning from 2D to 3D difficult. Possible changes in the significant legal acts concerning land administration issues may also cause problems in the operation of the 3D cadastre. Additionally, for the vast majority of areas of the countries there is currently no need for a 3D cadastre, on a larger scale, as areas with intensive development are mainly found in city centres and the 3D cadastre itself is getting transferred into 3D land administration (Oosterom et al., 2020).

In conclusion, the development of the visualisation of the 3D cadastre should move towards a greater commitment to the introduction of international standards, allowing the best use of the strengths of the visualisation, as presented in the SWOT/TOWS analysis. It is also necessary to reduce the weaknesses by creating solutions to problems on the technical side of visualisation creation. Additionally, researchers should find solutions to protect the visualisation of 3D cadastre objects from impacts resulting from changes in the law or the lack of up-to-dateness of databases. An aspect that may prove to be crucial here is the number of costs of building a 3D cadastre.

Because of the SWOT/TOWS analyses, based on the results presented in Table 6 and the considerations carried out, it was considered that the development of 3D cadastre data visualisation should be based on the use of strengths and related opportunities. This is equivalent to proposing an aggressive strategy.

DISCUSSION – IMPACT OF VISUAL VARIABLES

Despite the popularisation of the issue of multidimensional cadastre, relatively few experts have focused on the visualisation and symbolisation aspects from a semiotic perspective. Independently, experts have investigated which visual variables are most suitable for depicting 3D cadastral data order to facilitate user perception and interpretation.

In the paper (Bertin, 1983) five basic types of symbols that make up a cartographic representation are identified. These are point, line, area, surface (differing from area in that it exists in 3D space and has no theoretical thickness) and volume. The variables affecting the visualisation of these elements are size, shape, value, colour, texture and orientation. Additionally, Bertin defined their nature through five tasks of visual interpretation:

a. selective – answers the question of whether modifying a visual variable allows users to select one element from a group of objects;
b. associative – when users can easily distinguish the link between two groups of symbols just by using this variable;
c. quantitative – refers to allowing users to quantify the change in that variable;
d. orderly – answers the case of whether, by making a change to a particular variable, a difference in order can be observed;
e. duration – determines how many changes of a particular visual variable can be used effectively.

Bertin (1983) also recorded definitions of the visual variables listed above. A change in the fineness or roughness of an object defined its texture, while a value was described as a different degree of colour intensity between white and black. The explanation of the other variables was literal, e.g., the definition of colour was the use of a hue from the base it specified. The orientation was defined by a similar relationship, as it was defined by changing the orientation of the line. Size, on the other hand, was defined by changing the height or width of the object in question.

Although transparency was excluded in the first list of visual variables created by Bertin, it was later introduced by other experts who investigated its perceptual properties. A test described by (Elmqvist et al., 2007) showed that the use of dynamic transparency to manage occlusion, can significantly improve the user perception. Recently, specialists have done a lot of research in cognitive science to figure out how the perception of transparency is related to physical stimuli, namely, brightness, colour, contrast and shading of 3D visualisations. The experiment described by (Hillstrom et al., 2013) demonstrates that transparency does not cause difficulties with subjects' object recognition.

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Pouliot et al. (2014) tested the usefulness of visual variables such as hue, saturation, position, texture and transparency in their study of 3D cadastre object imaging. Summarising the results, with or without transparency, hue was found to be one of the more preferred solutions compared to the use of texture. Two years later, the tests were repeated, but the focus was solely on testing transparency (Wang et al., 2017). Three different levels of transparency were used during the experiment, thus proving to be an efficient solution that makes it easier for users to delineate property units using their physical equivalents. Applying high transparency to simple legal boundaries compared with physical boundaries results in increased user confidence in the decision-making process. In contrast, setting higher transparency on physical boundaries is much more effective in presenting property concepts to consumers.

A survey performed by Seipel et al. (2020) provided information on rendering attributes. The project itself was based on visual representations of RRR (rights, restrictions and responsibilities) objects in the context of 3D architectural models. An interactive visualisation prototype was proposed, which included both 3D models of buildings and terrain. It was also complemented by newly designed legal representations of objects. Some of those taking part in the experiment found the choice of colours pleasing, while others noted difficulties in distinguishing between them. Respondents suggested several solutions to this problem, such as the development of a common colouring standard, or suggested that it should be up to users to choose colours according to their private preferences. Additionally, the ability to adjust the level of transparency of 3D objects was considered a highly desirable feature.

There is no choice of colours in the visualisation of three-dimensional property rights that simultaneously satisfies preferences, standards and perceptual requirements. Nevertheless, irrespective of the choice of colour palette, software or end user, the colour scheme should reduce the risk, as much as possible, of the user making a mistake, such as overlooking or confusing an object.

Additionally, an essential aspect of the use of colours is the variability of their perception due to lighting or shading. Therefore, it is impossible to directly assign one unique colour to specific objects. It is worth noting that different colour shades are a desirable feature in the spatial visualisation of 3D cadastre data. Problems arise when using transparent rendering, which causes the initially different base colours of objects to take on very similar tones. This is illustrated in Figure 1, which shows four types of simple objects with decreasing levels of transparency. As can be seen, type 1 (2D property unit) and type 2 (3D property unit) objects are similar in colour. Furthermore, in the transparent rendering, the regions occupied by object type 2 contain colours similar to those of object type 4 (easement in use). The type 3 object is simply an easement. In the figure, visualisations a to c show the rendering of 4 types

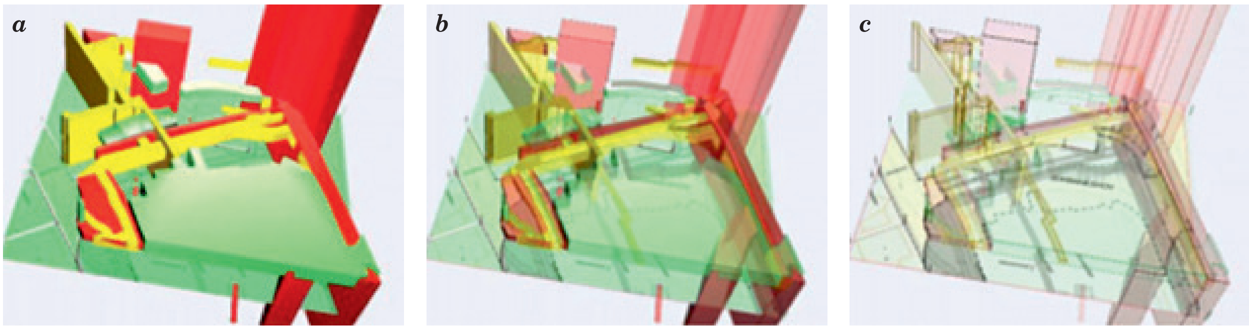

Fig. 1. Three types of legal objects with decreasing levels of transparency: a) no transparency, b) 50% transparency, c) 90% transparency

Source: Grzelka (2022) based on (Seipel et al., 2020).

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of 3D objects with 4 colours (light green, dark green, yellow, red). The first is depicted without using transparency, the second with 50% transparency and the third with 90% transparency.

Size as a visual variable, right after transparency and colour, has the characteristics with the best perception. Its change is very easy to perceive and is therefore considered a very effective visual variable with a significant impact on the user. The orientation, on the other hand, turns out to have the least impact on consumers. It only works well in situations involving relationships between objects as line intersections. The biggest problem with its use in perspective display is the change in the orientation of individual symbols. Because of this, people using these visualisations may be confused whether the difference in the orientation is due to the symbol or whether it is due to the perspective projection.

Additionally, Wang et al. (2017) conducted a survey-based study on the variables used in 3D visualisation of flats on user perception. They then compared the results of this experiment with the suitability of the same variables for 2D visualisation, which were obtained from the subject literature.

Their first conclusion was that there is almost imperceptible difference in the usefulness (hue, saturation) of colour and texture for 2D and 3D visualisation. In the case of the latter variable, which can be similar to the surface of physical objects in the real world, it can give participants the feeling that they are looking at real buildings visualised in 3D. Wang et al. (2017) found that this could be useful in distinguishing physical objects from legal ones. The next finding was the ineffectiveness of orientation as a variable. The perspective view in 3D visualisation made the perception of orientation ambiguous.

A similar conclusion related to brightness, which was minimally effective and not preferred in 3D visualisation. Lorenz et al. (2008) concluded that illumination, shading, texture and transparency influence the perception of brightness in visualised 3D objects. In Figure 2, surface A, may appear darker than surface B. In reality, they have the same brightness value. This may be due to a created illusion caused by perspective perception.

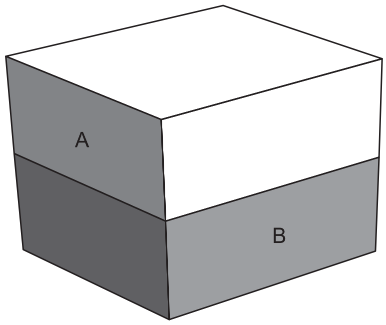

Fig. 2. The effect of a perspective view on the perception of brightness
Source: Grzelka (2022) based on (Wang et al., 2017).

Applying transparency to all surfaces in a 3D model to reduce the occlusion of focused objects is complicated. This can be effective when visualising objects with a single floor; for multiple floors, transparency is ineffective and non-preferred. According to Wang et al. (2017), transparency also affects the user's identification of volumetric objects, specifically their boundaries in 3D models. In summarising this variable, we can conclude that further research is needed. For this, disconnecting certain elements from the object, may be desirable for the potential user. This is based on the argument that it will be simpler to see the part of the object located in its centre. Labels, on the other hand, worked best when placed inside or closest to the symbol being described. The conclusion drawn from the experiment was that the user perception improved when the volume label was placed inside the object. This conclusion agrees with Ware's (2012) assumption that the principle of proximity can help viewers associate text labels with symbols.

RECAPITULATION

The aim of the study was to define the direction of 3D cadastre visualisation. As starting issues, the paper provides descriptions of user needs, visualised data types and the visualisation platforms. It is worth noting here the wide variety of issues that prevail in various countries. Considering user needs, an important issue is the integration of data from multiple sources and the distinction between physical and legal

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objects. With regard to the type of visualised data, the possibility of relying on ISO 19152, BIM issues and the potential use of point clouds are noteworthy. The large number of visualisation platforms in use is also worth noting. For the time being, there is no indication of the dominant popularity of any of them.

The main part of the publication is a study of 3D cadastre visualisation strategies, which was carried out using SWOT/TOWS analysis. The analysis took into account both internal and external factors that can influence the development of 3D cadastre visualisation policies. The result of the analysis is a proposal for an aggressive strategy, based on the use of the strengths and potential opportunities of 3D cadastre visualisation. From this, it can be concluded that this is related to both the development of awareness related to real estate, the property market and urban development and the increasing popularity of 3D visualisation solutions.

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