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The potential of computational methods for the categorization of architectural objects on the example of media architecture

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Abstract
The paper presents an example of the categorization of architectural objects and assessment of the characteristics of urban space, based on the analysis of specific features of architectural objects and urban landscape. The conducted analysis refers to media architecture and is presented in the complex context of the development of media solutions. The field of influence of IT on architecture is also stressed, both on the architect's work and the image of the city, including with regard to smart city strategies. A gradual simplification approach was proposed for a targeted analysis. Data on media architecture were collected and, on their basis, significant features of each architectural object and its surrounding space were identified. The qualification of representative categories of media solutions was made based on the function of the object and the role of the media architecture object in the visual structure of the space, indicating the method of determining the degree of legibility of the space for a given category. The proposed process of categorization is a starting point in the discussion about the need and opportunities to use computational methods and databases supporting the assessment of the architectural typologies and characteristics of space, in reference to urban development.

Keywords:
media architecture, legibility of urban space, assessment of urban space, urban landscape, urban development, computational methods for architecture, smart city, sustainable development

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1. Introduction

In the twenty-first century, with the development of information technologies, architectural objects ceased to be limited to static objects, as they appeared in the urban landscape as modifiable structures and emitting variable visual content. This type of characteristic defines media architecture, using the possibilities both in the field of lighting technology and information technology. It plays a special role in commercial spaces which, through the participation of media solutions, can be defined as intelligent commercial spaces (1,2). As part of the conducted literature studies, the development of media architecture in commercial spaces was considered in the context of civilizational progress, as well as models of city development, society and cultural influences. In the proposed model (Fig. 1), an attempt was made to indicate how these categories of changes directly or indirectly affect the development of media architecture in commercial spaces. Moreover, it was emphasized that media architecture is developing both in the context of the computerization of culture (3) and the profile of the society referred to as "information society" (4), or "network society" (5). At the same time, we observe the development of the visual culture, and the changing images transmitted via media architecture provide new experiences in the commercial space, which attracts the "consumer society" (6). Intelligent commercial spaces therefore become city events (7) that provide an aesthetic framework for commercial activities. They can also stimulate the development of creativity within the "creative city" concept (8), fit into participatory strategies derived from the smart city idea, or use and visualize data collected within smart networks (9). However, they can also arouse controversy related to the criticism of the superficiality of the proposed performance (10). Thus, the development of media architecture in commercial spaces is influenced by factors related to both digitization and interactivity, as well as aestheticization and consumerism (Fig. 1).

Understanding media architecture in the context of the urban development is crucial for preventing light pollution (11) and creating Urban Lighting Master Plans (12, 13). This requires the analysis of both the features of media architecture objects and the features of the surrounding urban space (1,2). This is a premise for determining the potential of computer calculations, including their impact on the categorization of architectural objects, which is the aim of this article. Moreover, without such support, a broader analysis of the media architecture would be difficult. It is worth emphasizing that information technologies are used to support architecture design, an example of which is the wide use of programs ranging from CAD (Computer-Aided Design) and 3ds Max, to Rhino Grasshopper and CATIA. Computer-aided design tools are proposed in different programming languages, e.g. AutoLISP, Python and C#. However, architects more often use programs offering visual interfaces due to their lack of programming knowledge (14). BIM (Building Information Modeling) plays a very important role in the design process, it is a digital record of the features of a building object, used to generate data about an object in the design process – from design, through realization and use – to demolition, which is offered, for example, by Revit and Archicad. BIM is playing an increasingly important role in the context of green buildings (15). Digital tools also play an important role in education in the field of architecture in the above-mentioned areas (3D modeling, BIM, parametric architecture (14)), and are some of the solutions improving architectural structures with new functions (Responsive Environments, media architecture, interactive solutions) (16). 3D modeling and parametric modeling are therefore both important areas of application of computer science in architecture – in the design and in architectural education, through Computer-Aided Manufacturing (CAM) at the implementation stage as well as via simulating and optimizing the processes taking place in the building during its use. Moreover, the integration of different digital tools at different levels of design is very important to make architects' work more efficient - also in terms of sustainable development.

Nowadays, architecture created with the support of computer technologies is becoming a recognizable element of the image of the urban landscape. One of the first more recognized example of parametric architecture is the Guggenheim Bilbao Museum from 1997, designed by Frank Gehry and developed in the CATIA program. Its curvilinear form was built in the "file to factory" technology, enabling the prefabrication of individual elements with complex geometry. This facility is part of the concept of "city product," in which the city builds its brand, among others via architectural icons. Another example of an iconic facility whose parametric architecture is also equipped with media architecture is the Yas Hotel, from 2009, designed by the Asymptote group at the Formula 1 race track in Abu Dhabi. Both of these facilities provided their cities with international publicity, attracting crowds of tourists (in the case of Hotel Yas in Abu Dhabi, also after nightfall).

City development strategies can also use digital tools in a more direct way to stimulate their development, an example of which is the smart city concept that focuses on high quality of life and sustainable development (17). Information technologies are used from traffic optimization, through resource and energy management, up to social needs. However, in the smart city concept, it is very important not to focus only on technological possibilities, but to always put the user of urban spaces, in particular the city dweller and his/her well-being, at the center of considerations. IT support makes it possible to increase the comfort of residents on many levels, ranging from eliminating the problems of traffic jams in the city and optimizing public transport, through the development of the level of e-services to the participation of residents in the city's development strategy under the open governance model (17). The research (18) shows that there is approval for the increased automation of life, for example on the example of the use of unmanned water transport in the city. However, according to these studies, the sense of increased user comfort cannot reduce the sense of security. It should be stressed that the sense of comfort and an acceptable level of safety depend on the individual preferences of the user (19). The same applies to the assessment of the acceptability of solutions in urban space – including solutions in the field of media architecture. Individual assessment is always subjective, but the obtained results of such assessments can be averaged over a larger group of respondents. Here, however, computer support is needed.

Within a smart city, cloud computing solutions play a significant role – they enable the provision of IT services in all locations with direct access to the Internet, while providing high efficiency and security of information processing (20). This is accompanied by Big data – the implementation of the analysis of data with different structures coming from various sources, which can also be used to prevent potential environmental risks and disasters (21). Edge computing is also used, for example in the context of energy prediction (22). You also need enormous performance and computing power which can be scaled to use artificial intelligence, and various connectivity options, so you can easily create sophisticated structures, determine, for example, their resistance to vibration, expand their environment by analyzing dust or the reaction to extreme temperatures, and implement automation. Such hyper-converged IT platforms enable the integration of technology and data centers so the available infrastructure can be managed in an orderly manner. They are, to some extent, an alternative to public clouds (23). A key role in a smart city is also reserved for the Internet of Things (IoT), where computers and artificial intelligence (AI) systems are built into devices, including those for general use, which, thanks to a permanent connection to the Internet, can be externally controlled or can control other devices or automatically transmit information to other systems. Cloud Computing, Big data, the Internet of Things, and mobile internet (ICBM) are the core technologies of smart city solutions (20). Various interfaces building the IoT can also be used within media architecture that is equipped with an interactivity layer, both in creating an artistic message and visualizing data flowing from intelligent networks (24).

In the context of digitization, the urban landscape is therefore undergoing a number of changes – from the presence of curvilinear forms of parametric architecture, through the optimization of processes taking place in the city and the visualization of data through a variety of digital screens, including media architecture. Digital tools are, in a sense, a generator of changes, but they can also be used to assess the effects of these changes. The aim of the article is to show the potential of computing support in the process of assessing the functioning of media architecture in commercial spaces. The article is limited in this assessment to the categorization of media architecture. This categorization may result from the function of the building, but it is the baseline level of analysis. Another degree of this categorization is taking into account the role of the object in the visual structure of the space (25), and here the complexity of the analysis is much higher, which would require support by more complex tools. Currently, there are no such specialized IT assessment tools, therefore our considerations focus on the models and methods of such analysis that are the basis for the development of such tools in the future.

The analysis of media architecture objects requires a selective approach in the selection of a representative group of examples. One of the limiting areas for the choice of media solutions may be the function of objects, and another the time of the object's creation. The difficulty in obtaining relevant data for analysis would be the need to analyze the text within the description of objects on architectural portals, as well as tools

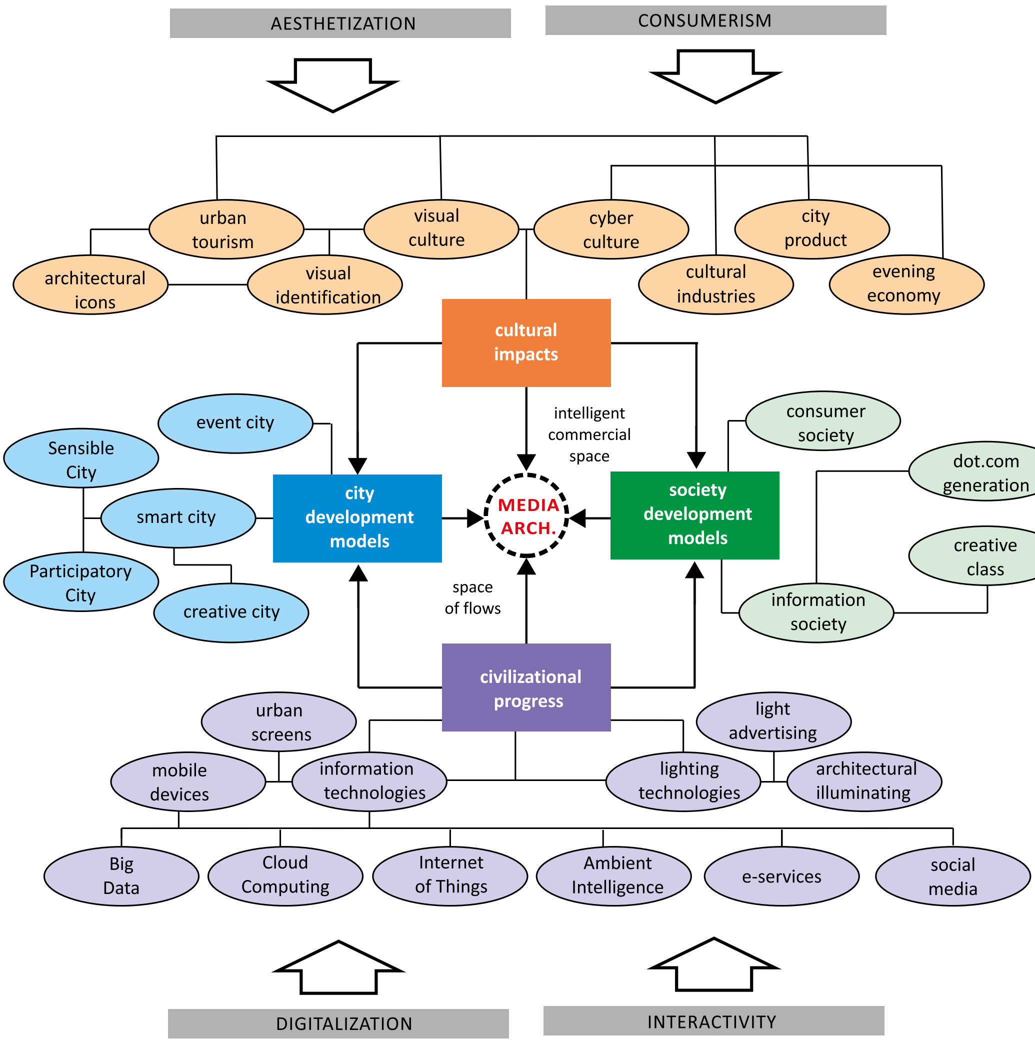


Figure 1. Context of the development of media architecture in commercial spaces (by K. Życzkowska)

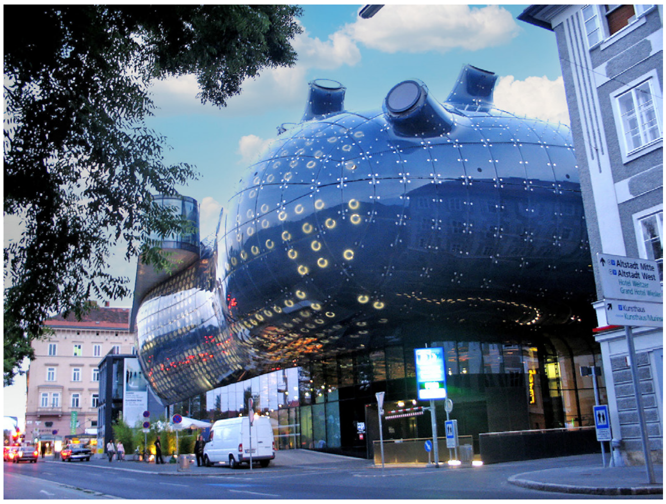
for image analysis – with particular emphasis on maps (site drawings, Google maps), technical drawings (plans, sections, façades) as well as photos showing objects in the space, and video, enabling the analysis of the characteristics of a media message. In the research on media architecture, a database of over 70 solutions from the 21st century was compiled (1,2), including specific data for all analyzed objects. The performed analysis was usually performed manually with the support of only basic IT tools. However, the presented methods are suitable for the gradual implementation of advanced methods of automatic analysis. The input database constituting a collection of media solutions was characterized in Chapter 2. On this basis, the features of media solutions are analyzed (Chapter 3), and then the relationships between the categories of media architecture solutions and the functional categories of objects are analyzed in Chapter 4. The final conclusions present a general overview and a diagram of such an analysis, and the possibilities of supporting some of its stages with computational technology are given.

2. Collection of media architecture objects – initial database

While creating a database for the analysis, 71 solutions in the field of media architecture were found in the literature and on websites (1, 2). The following information characterizing the analyzed object was obtained: designer – object creator, lighting designer, year of construction of the object, function, location (city, country), location (in the city space), area of the object, idea related to the creation of the object's architectural form, geometry and scope of the media façade, technology of the media solution, lighting components, resolution, content of the message, time of broadcasting the message, distance of perception, context of the object, interior design, main features of the object, awards for the object, and photos of the object. This required the analysis of object descriptions as well as graphic material.

The media architectural objects were ranked according to their functions, distinguishing eight functional categories of commercial facilities: museums (category A), other cultural and cultural and entertainment facilities (category B), sports facilities and multi-functional halls (category C), shopping malls, various commercial and shopping and entertainment facilities (category D), boutiques (category E), hotels and multifunctional facilities, combining hotels, offices and services (category F), offices and office buildings with a service function (category G) and public transport stations (category H). Successive solutions of a given category were marked with a consecutive ordinal number, e.g. A.1, A.2, B1, B2, etc. The selected categories of commercial objects (categories A–H) were also supplemented with other media solutions functioning within these objects, marking the subcategory with the letter "r," e.g. Ar.1, Ar.2). Within functional groups, a lower order number meant a larger area of a media façade or other media solution. An example of a media architecture object description card is shown in Table 1.

Table 1. Sample data sheet for a selected media architecture object



A.4 KUNSTHAUS	
architect	Collin Fournier & Peter Cook
lighting designer	realities:united
date of construction	2003
function	art museum
continent	Europa
city (country)	Graz (Austria)
surface of the building	about 2860 m²
features of interior	open interior cut by a moving ramp, dark colors, restaurant on the ground floor, museum above the ground floor
location	outside the city center, on the river (on the other bank from the city center), fitting perfectly into the existing urban fabric, in the vicinity of a café on the water known as "an island in the Mur River," by Vito Acconi (2003)
idea of the design	"friendly alien"
architectural form	standout, rounded form of a blob
geometry of the media façade	curvilinear
scope of the media façade	façade, above the ground floor
surface of the media façade	900 m²
translucency of the media façade	opaque
technology of media façade	display technology
lighting components	930 fluorescent lamps (40 W) on the BIX matrix, closed in the form of rings with a diameter of 40 cm
resolution of transmission	low
content of transmission	noncommercial

broadcast time	after dark
perception distance	close and distant (from the observation hill – Schlossberg)
context of building realization	due to the competition for the European Capital of Culture in 2003
main features	innovation, visibility, discretion, accessible ground floor
architectural awards	award in international conceptual competition
Source of photos (P1, P2), text (T), when different than P1, P2	P1, P2: photo by Karolina Życzkowska; T: http://www.archdaily.com/89408/bix-light-and-media-facade-at-moma/

As part of collecting data related to media architecture and commercial spaces, a survey was also carried out on this topic. The survey contained 30 questions, including information about the user (gender, age, education, etc.), the way of understanding the definition of commercial spaces and the potential development of commercial spaces, their attractiveness and prestige, and the city's competitiveness. The next part of the survey consisted of questions related to the perception of marketing messages in the city (including traditional and digital billboards), landmarks and points of attention in the city (from the perspective of a resident and tourist), understanding the concept of spatial legibility, usefulness of legibility for commercial spaces, reading the functions of buildings from the presented photographs of media architecture objects, determining the level of attractiveness of media solutions, defining the media architecture, its characteristics its quality and development potential, the relationship between media architecture and the prestige of architectural objects, knowledge of interactive solutions, determining the role of interactive solutions, as well as indicating the preferred areas of application of media solutions in relation to the function of the buildings. The survey was conducted on 200 people. It presents eight selected examples of media architecture objects, asking for recognition of the object's function.

This survey could be much more elaborate in the context of the assessment of media solutions, but this would require the support of computer tools. The analysis of the attractiveness of the objects could take into account video recordings and various scenarios of the behavior of media solutions. Such an analysis was carried out by one of the authors for all 71 solutions, which was a subjective assessment, taking much more time than the computer analysis of the survey. Taking into account the opinions of a larger number of people (e.g. 200, as in the case of the survey) in relation to the set of 71 objects would certainly require the use of teamwork and professional computer support.

Both the set of 71 media architecture objects described above and the survey conducted were the starting data for further analysis. It is worth emphasizing that the automation of searching for solutions in the field of media architecture, such as creating and collecting their detailed description, would require the development of a dedicated system based on available Internet services, especially in the case of a significantly increased number of analyzed cases.

3. Analysis of the features of a media solution

The analysis of the features of media architecture was based on an original model of media architecture, showing the synergy of architecture, art and information and lighting technology (Fig. 2). The model is set in the context of the changes of the postmodern city resulting from technological, cultural, and social changes as well as changes in the scope of city models (see Fig. 1). The proposed model makes it possible to describe a media solution (RM) based on three basic components (see Fig. 2). These include:

1. form (i.e. an architectural form – situated on the border between architecture and art);
2. transmission (i.e. media / information message – on the border between art and technology);
3. display element (i.e. an element that enables the emission of an information message – on the border of architecture and technology).

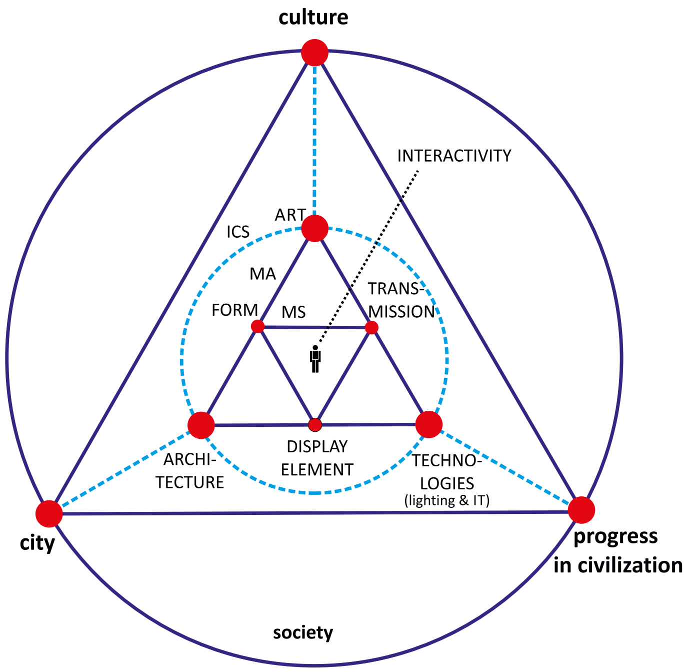


Figure 2. Graphical illustration of the definition of a media solution (MS = form + display element + transmission) and media architecture (MA = art + architecture + lighting and information technology) and the background of the development of the intelligent commercial spaces (ICS) described by: culture + city+ progress in civilization + society (by K. Życzkowska)

The display element is the basic element enabling the functioning of media solutions – without it, the emission of content would not be possible. It was this element that was analyzed in the context of the features of the media solution (including surface translucency and the presence of media detail, as well as its energy efficiency) and the type of integration of the innovative display element with the structure architectural. All three features were analyzed.

In the research on the form, based on literature studies, the set of criteria were chosen to determine the appearance of the form, the essential features of the form and the scope of the media solution. In the context of the message, parameters such as content and image characteristics were considered. Taking into account the detailed characteristics of the display element, transmission, form and interaction possibilities, a more detailed model of the features of the media solution was built, in the form of a fish diagram– see Fig. 3.

This model was used in the description of media architecture solutions in the first stage of the analysis, as shown on the example of Table 2. Building such a model requires systematization of relevant content and many associations, which can be obtained most effectively in an expert team by using, for example, the method of "brainstorming." The full analysis of the set of objects carried out according to this model is presented in Table 2 for objects from category A, i.e. museums.

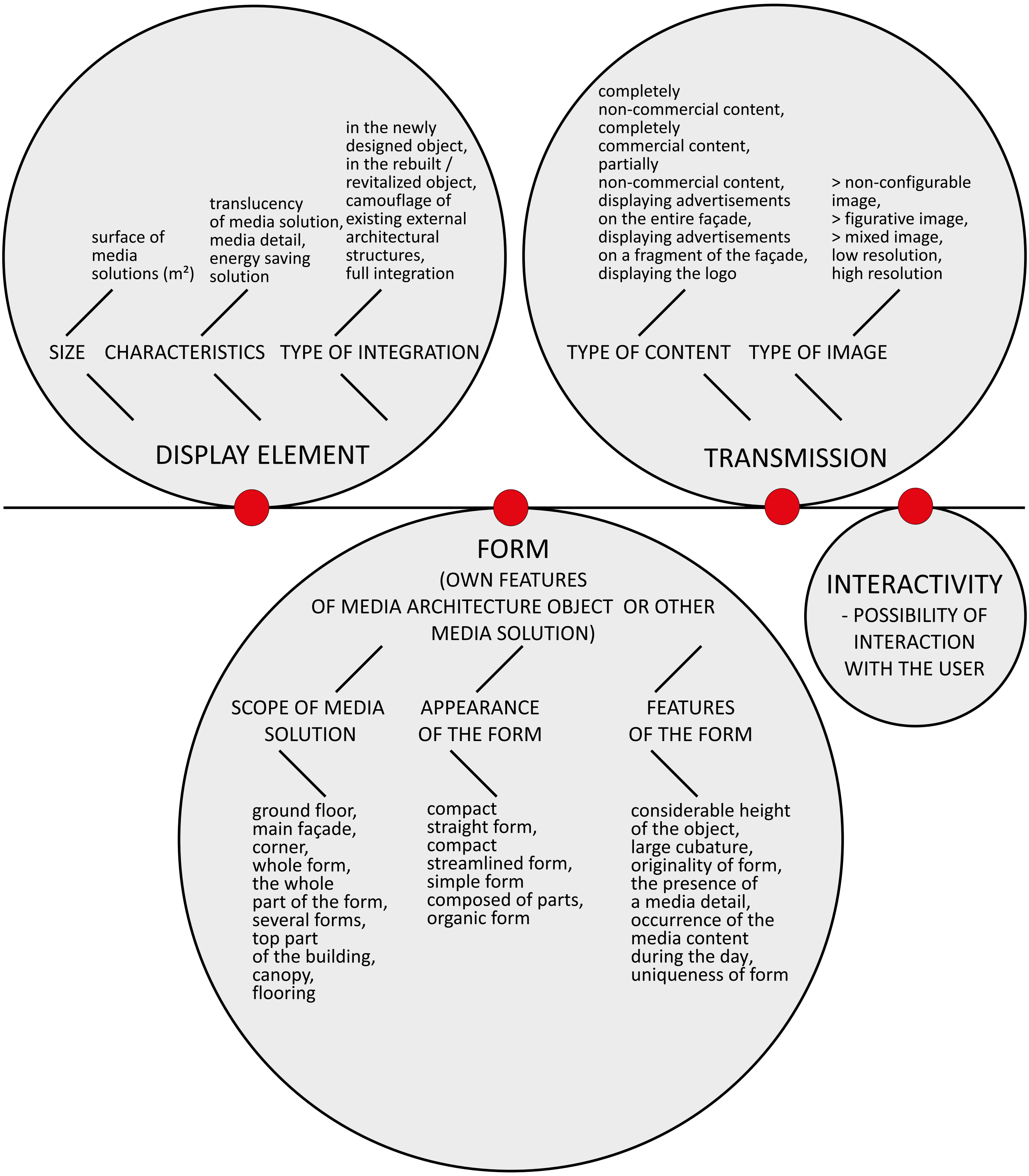


Figure 3. Model of the features of a media solution (by K. Życzkowska)

Table 2. Features of media solutions in the group of museums (category A). (Legend: + – occurs; o – occurs occasionally; p – occurs to some extent; MS – media solution; rows in dark gray – features important for functional category; rows in light gray – broad set of features important for functional category)

		Functional category		A – MUSEUMS						
				A.1	A.2	A.3	A.4	A.5	A.5	A.7
			No. features of media solution	Ars Electronica Center, Linz	C4 Cordoba Contemporary Art Centre, Córdoba	Rockheim, Trondheim	Kunsthaus, Graz	U-Tower, Dortmund	MediaLab Prado, Madryt	FRAC Centre, Orleans
I – DISPLAY ELEMENT	Size	size (surface) of MS (m²)	1	5100	1300	1500	900	625	144	>100
	Features	translucency of MS	2	+	+	+				
		media detail	3		p	p	+		+	+
		energy saving	4							
	Type of integration	in the newly designed object	5	+	+	p	+	p	p	+
		in the rebuilt / revitalized object	6			p		p	p	
		camouflage of existing structures	7							
		full integration	8	+	+	+	+	+	+	+
II – FORM	Scope of media solution	ground floor	9	+	+					+
		corner	10							
		main façade	11		+				+	+
		whole form	12	+		p	p			
		the whole part of the form	13		+	+	+			
		several forms	14							
		top part of the building	15			+		+		
		canopy	16		p					
		flooring	17							
		compact straight form	18		+				+	
	Appearance of form	compact streamlined form	19							
		simple form composed of parts	20	+		+		+		
		organic form	21				+			+
		considerable height of the object	22					+		
		large cubature	23		+					
		originality of form	24	+	+		+			+
		presence of a media detail	25		+	+	+		+	+
		occurrence of media content during the day	26					+		
		uniqueness of form	27	+	+	+	+			+
III – TRANSMISSION	Type of content	completely non-commercial content	28	+	+	+	+	+	+	+
		completely commercial content	29							
		partially commercial content	30							
		displaying advertisements on the entire façade	31							
		displaying advertisements on a fragment of the façade	32							
		displaying the logo	33							
	Type of image	> non-configurable image	34	+	+	+	+			+
		> figurative image	35					+		
		> mixed (partly figurative) image	36	o	o	o	o		+	o
		low resolution	37	+	+	+	+		+	+
		high resolution	38					+		
IV	Int.	possibility of interaction	39	o			o		o	

After the analysis of the detailed features of the media architecture objects, the percentage share of objects from each functional category was calculated, as described by the indicated feature of the media solution. In this area, all 39 features in terms of four groups were considered: form, display element, transmission and possibility of interaction (Table 2). This made it possible to highlight the characteristic features of objects related to a given functional category of media architecture objects. Selected results of this analysis (for nine selected features) are presented in Table 3.

For example, in the context of the analysis of the form, it was noticed that the scope of media solutions results to some extent from the specific features of the architectural form typical for a given functional category. We observed the most repetitive relationships in the group of sports facilities and entertainment halls (category C), shopping malls (category D) and boutiques (category E). The most unpredictable range of media solutions was found in the group strongly associated with the originality of the architectural form, which dictates the diversity of solutions in the field of media architecture in different parts of the form (this group includes museums (category A – see Table 1) and other cultural and entertainment facilities (category B), as well as hotels and multi-functional facilities (hotel + offices + services, category F) (1,2).

In the scope of the analysis of the display element, the presence of media detail was also taken into account. For example, it was noticed that the media detail within the external architectural structure is most often associated with the group of sports facilities and multi-functional halls (category C – 86%), museums (category A – 71%) and other cultural and entertainment facilities (category B – 86%). %), shopping malls (category D – 70%), and hotels or multifunctional facilities (hotel + offices + services) (category F – 67%). Moreover, media detail mostly concerns non-transparent surfaces (56%) (1,2).

It is worth emphasizing that the type of technology used in media architecture objects may be another criterion for the analysis of these objects. Apart from solutions based on various types of media grids, there are also media details of various characteristics – at least 9 types of media details can be distinguished (1,2) as criteria for further analysis.

The conducted analysis concerning the features of the transmission highlighted the relationship between its characteristics and buildings' functions (Table 3). In most cases, the transmission emitted through the media architecture is completely devoid of commercial content (51/71 cases – 70%). We can observe this most clearly within museums (category A – 100%) and hotels or multi-functional facilities (category F – hotel + offices + services) (100%), as well as other cultural or cultural and entertainment facilities (category B – 86%) and sports facilities and multi-functional halls (category C – 71%). This specificity of the message is also typical for media solutions in the vicinity of commercial facilities (r – 73%). Less frequently, it is a characteristic feature of office buildings (category G – 44%) and shopping malls and boutiques (category D and E – 40%) (1,2).

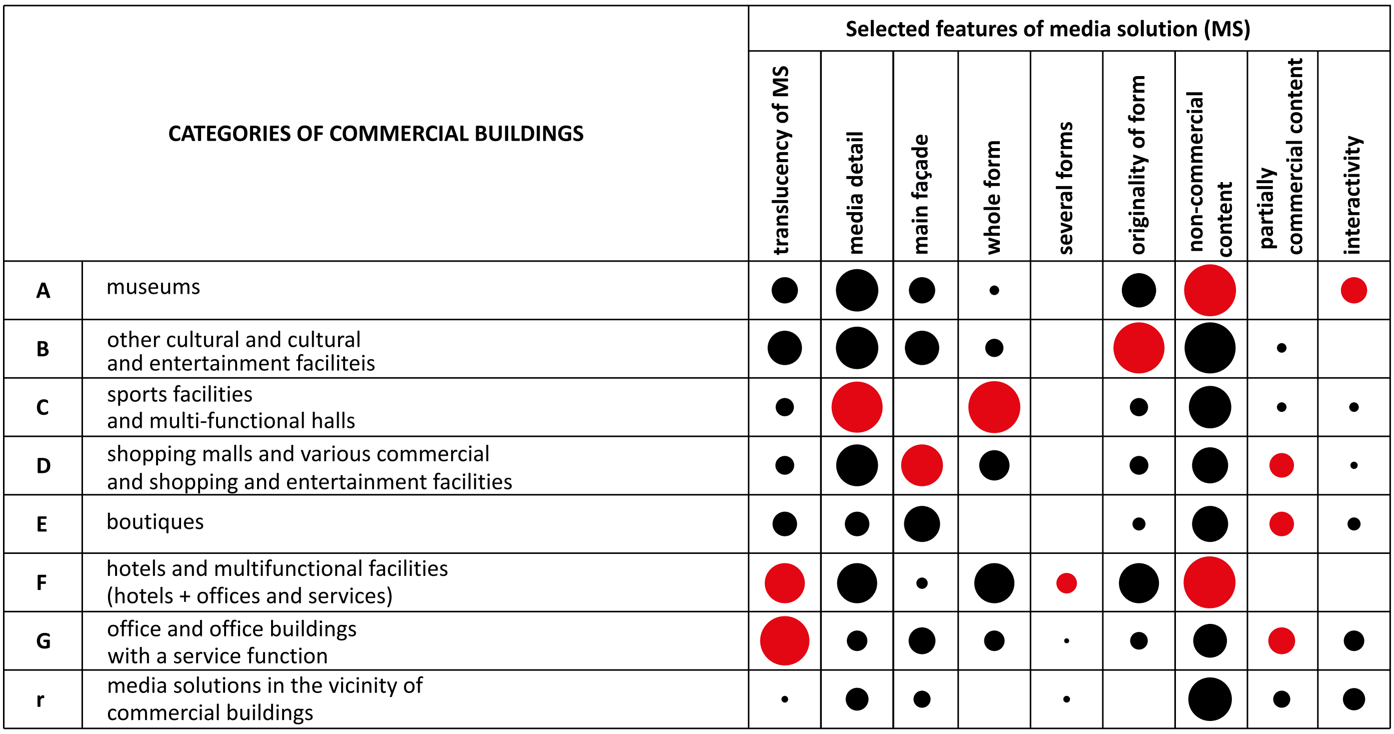
The analysis of the above-mentioned features of the media solution made it possible to define common characteristics in this respect, due to the buildings' functions (Table 3). The graphical presentation of the relations between the significance of selected features of the media solution in a given functional category is shown in Fig. 4. The size of the pin corresponds to the importance of the feature – the larger the feature, the more important the feature is. The most important relationships are marked in red. From the point of view of an architect, visual representation of the results is very desirable, because it makes them more readable. This emphasizes the need, in addition to appropriate calculation methods, to use appropriate visualization methods.

Including this type of analysis for a larger set of objects and in the context of a more complex model of features (e.g. the type of media detail or the characteristics of the transmission related to its discretion) would require more advanced computational methods. The discretion of the transmission is influenced not only by the content, but also the rate of change or the intensity of light. The analysis of specific parameters resulting from the reception of various transmissions requires the analysis of appropriate video files. The perception is always to some extent subjective, however the assessment of media solutions by many recipients will produce a much more objective result through averaging their assessments. In turn, examining the transmission in terms of technology would require specialized measurements (light intensity, luminance, rate of change, etc.).

Table 3. Selected features of a media solution for functional category of buildings

	Group of features as in Table 2	I		II				III		IV
Buildings' functional category		translucency of MS	media detail	main façade	whole form	several forms	originality of form	non-commercial content	partially commercial content	interactivity
	No. of feature as in Table 2	2	3	11	12	14	24	28	30	39
		%	%	%	%	%	%	%	%	%
A	museums	43	71	43	14	0	57	100	0	43
B	other cultural and cultural and entertainment facilities	57	71	57	29	0	86	86	14	0
C	sports facilities and multi-functional halls	29	86	0	100	0	29	71	14	14
D	shopping malls	30	70	70	50	0	30	60	40	10
E	boutiques	40	20	60	0	0	20	60	40	20
F	hotels and multifunctional facilities, combining hotels, offices and services	67	67	17	67	33	67	100	0	0
G	office and office buildings with a service function	83	33	44	33	6	28	56	44	33
r	other solutions in the vicinity of commercial buildings	9	36	27	0	9	0	73	27	36

Figure 4. Selected features of a media solution for functional category of buildings – graphical visualization of data (by K. Życzkowska)



Another difficulty is assessing the scenarios of interactive media solutions, where estimating their acceptability would also require surveying a larger number of recipients – those who participated or at least were observers of such an interaction. Access to such recipients is not easy, so an appropriate estimation of the ratings would be critically important. In addition, a computer analysis carried out in the field of evaluation of energy-saving solutions would require obtaining data on the amount of energy collected within, for example, photovoltaic cells built into a display element and comparing these values with the energy consumption of the transmissions. This is where Internet of Things (IoT) solutions become necessary. It is worth emphasizing that media architecture uses many digital solutions, therefore enriching them with monitoring systems would provide a lot of data necessary to conduct various analyses useful both at the stage of constructing new devices of this type and assessing the feelings of passers-by, e.g. by analyzing the expressions on their faces.

4. Research on the relationships between the categories of media architecture solutions and the degree of legibility of space and the function of objects

The analysis of media solutions in terms of their own characteristics and the relationship between these features and the function of the architectural objects is important, but definitely insufficient in the context of urban space and the complex context of the development of intelligent commercial spaces (see section 2). Understanding the potential and threats of media architecture for the quality of urban space requires an analysis of the complex context of the functioning of such facilities.

Taking into account the characteristics of the post-modern city, it can be noticed that media architecture influences commercial space in various ways, influencing users' perceptions. This is due to the imagery of solutions in the field of media architecture, the nature of the location of the facility and its relationship with the components of the city's architecture. A number of such relationships create the characteristics of intelligent commercial spaces, and their relationship with the legibility of the space is of key importance here. The initial assumption for this type of analysis was the assumption that imagery is a feature of media architecture solutions, while legibility is a feature of space, and therefore also a feature of intelligent commercial spaces (1, 2).

It was noticed that the legibility of the space is influenced both by the imagery of objects, the specificity of the location and the structure of the components of the city's architecture. Describing these three areas in detail in a similar fish diagram as for ICS (see Fig. 3), 40 detail features for object imaging were taken into account, so 29 other features were collected for the next two analyzed areas. Therefore, 69 features were analyzed for each of the 71 media solutions, which gives a total of 4,899 detailed results. Then, the objects were grouped into appropriate categories and subcategories determined by the common features of these objects. 5 groups of features were found to be crucial, such as the location and visibility of objects, the scope of the media solution, the distance of perception, the speed of the recipient and the role in the visual structure of the intelligent commercial spaces. A total of six categories and 14 subcategories of solutions in the field of media architecture were selected. There are such categories and subcategories (in brackets) as: spatial lantern (orienting lantern, nodal lantern), media connector (spatial clip, water connector), media stamp (vertical stamp, volumetric stamp), media signal (object signal, corner signal, frontage signal), media magnet / indicator (magnet, indicator), and media concentrator (wall concentrator, floor concentrator, ceiling concentrator) (1,2).

It should be noted that some examples of solutions in the field of media architecture have been classified into more than one category of these solutions due to the wide range of their features. Moreover, the degree of legibility of intelligent commercial spaces within the selected categories was determined. Here, seven features from a group of 69 features characterizing the legibility of spaces, describing the geometry of the urban structure and the aesthetic values of these spaces, turned out to be key. In terms of the urban structure, the following features were taken into account: 1. the clarity / uniqueness of the spatial composition (including the legibility of the boundaries of intelligent commercial space) and the related role in the visual structure of the space, with particular emphasis on such functions as: 2. creating a node, 3. creating edges, or 4. creating or signaling area. In terms of the aesthetic values of these spaces, the following features were analyzed: 5. The beauty / uniqueness of the place most often associated with the landscape or historical context, as well as 6. The uniqueness of the surrounding buildings and 7. The uniqueness of the forms of media architecture solutions. The percentage of objects in a given category with a given feature was indicated, and then each 1 percent was treated as 1 point, and these points were summed for the overall rating. Thereby, the final score was obtained for each of the subcategories with the highest score representing the highest degree of legibility of the intelligent spaces (see Table 4).

The end result is that the categories of solutions in the field of media architecture did not result from the buildings' function, but from the features characterizing the legibility of the urban space. However, the relationship between the categories of media architecture solutions and the function of objects was also investigated. It was noticed that the strongest relationship can be observed between the water connector and cultural, cultural and entertainment facilities (66.67% of water connectors), volumetric stamp and sports facilities and multi-functional halls (66.67% of volumetric stamp), a magnet with boutiques (66.67% of magnets), indicator and office or office function with service (66.67% of indicators) and a nodal lantern and office or office function with services (64.29% of the nodal lanterns). There is also a clear relationship between the distinctive feature in the frontage signal and boutiques (50%), the keystone with ceiling concentrator with media solutions in the vicinity of shopping and entertainment facilities (50%), and the keystone with flooring concentrator in the vicinity of museums (50%). Also important are the links between the object signal and shopping malls (42.86%) and the keystone with wall concentrator with the group of museums (40%) and media solutions in the vicinity of railway stations (40%) (1,2). The above-mentioned dependencies for media architectural objects are illustrated in Table 5 (solutions in the vicinity of commercial objects – marked as "r" are omitted in this presentation).

Table 4. Determination of the ICS legibility level

	Urban structure								
	spatial comp.	role in the visual structure of space			aesthetic values				
	1	2	3	4	5	6	7		
	clarity / uniqueness of spatial composition	creating a node	creating an edge	creating/ signaling a region	the beauty / uniqueness of the place	the uniqueness of the surrounding buildings	the uniqueness of the form of media architectural object	**sum of points**	**Level of legibility**
spatial lantern	%	%	%	%	%	%	%	1% = 1 pkt	
orienting lantern	44	0	22	11	33	22	78	**211**	**V**
nodal lantern	57	100	0	0	36	29	50	**271**	**IV**
media connector									
spatial clip	75	25	100	25	75	63	50	**413**	**I**
water connector	67	100	100	0	100	33	67	**467**	**I**
media stamp									
vertical stamp	33	0	67	0	33	33	33	**200**	**V**
volumetric stamp	17	33	0	33	17	17	33	**150**	**VI**
media signal									
object signal	57	0	14	0	57	43	71	**243**	**IV**
corner signal	67	0	0	0	33	33	33	**167**	**VI**
frontage signal	100	0	0	0	100	67	50	**317**	**III**
media magnet / indicator									
magnet	100	0	0	0	100	100	33	**333**	**III**
Indicator	67	33	0	33	0	0	0	**133**	**VI**
concentrator									
wall concentrator	80	100	20	20	80	60	40	**400**	**II**
floor concentrator	100	100	25	50	75	25	50	**425**	**I**
ceiling concentrator	100	100	0	0	50	50	100	**400**	**II**

Table 5. Linking the category of media architecture solutions with the functional categories of buildings

		A	B	C	D	E	F	G
	Level of legibility of ICS	museums	other cultural and cultural and entertainment facilities	sports facilities and and multi-functional halls	shopping malls	boutiques	hotels and multifunctional facilities (hotels + offices and services)	office and office buildings with a service function
spatial lighthouse		%	%	%	%	%	%	%
orienting lighthouse	V	11		22	11	11	11	22
nodes lighthouse	IV		7		14		14	64
media connector								
spatial clip	I	25	13	13				25
water connector	I	33	67					
media stamp								
vertical stamp	V	33					33	33
volumetric stamp	VI			67	33			
media signal								
object signal	IV		14		43		14	29
corner signal	VI				33	33		33
frontage signal	III		33		17	50		
media magnet / indicator								
magnet	III		33			67		
indicator	VI						33	67
concentrator								
wall concentrator	II	40	20					
floor concentrator	I		25				25	
ceiling concentrator	II							

5. Final conclusions

The assessment of media architecture in the urban space is a complex task that requires many preparatory activities, such as: gathering adequate examples of solutions, description of the context in which such an architectural object is located, identification of its important features, introduction of criteria and evaluation models requiring, in many cases, an intuitive approach, as well as methods of identifying many parameters indicating representative categories of media architecture. Therefore, it is necessary to use various IT packages. The assessment presented above was performed according to the interactive scheme of conduct in Fig. 5.

Two streams of proceedings have been distinguished, one concerning the conducted analysis and the other emphasizing the necessity to use appropriate IT tools. In the first stream, the basis for considerations was the collection of data on media architecture solutions; in other words, obtaining the largest possible number of reliable and detailed descriptions of these solutions, as well as the possibility of defining evaluation models and presenting them multiple times in order to perform various types of comparative analyses. In the second stream, it was important to use the creation of a repository of such solutions supporting automatic analysis (e.g. statistical analysis or processing of multimedia signals), taking into account additional knowledge from other sources, using available IT tools and creating and saving a new knowledge base based on the conducted research.

The presented scheme of conduct concerned, in principle, the analysis of the degree of legibility of urban space. It can also be used for other analyses with additional IT tools. One of the possible analyses is the use of Saaty's method to determine the degree of relationships between the analysis features, by taking into account the relationship between each pair of such features. In addition, when reading the degree of legibility of urban space, artificial intelligence methods can be used, thanks to which it would be possible, for example, to recognize the uniqueness or beauty of the elements of a given space. In this case, however, adequate data would be needed to train such networks.

GIS analysis systems, enabling the recognition of historic buildings in the vicinity (i.e. exceptional / unique ones), or determining the attractiveness of a space by observing pedestrians in this area, could provide significant help in the analysis of the urban context of media architecture. With such an extensive structure of media architecture, the assessment of its attractiveness and acceptability by city users, and then the visualization of these results, requires large computing resources.

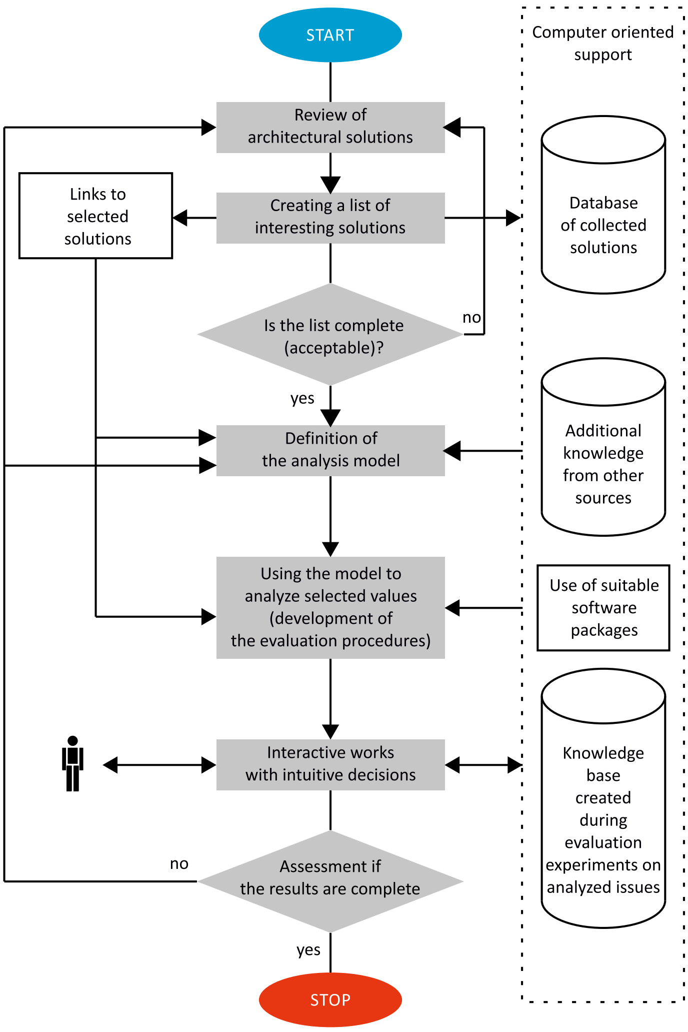


Figure 5. Iterative approach to the assessment of architectural solutions supported by computational techniques (by K. Życzkowska, M. Życzkowski)

It should be emphasized that computer support can be used in an analogous way for other groups of architectural objects and other features of urban space, helping in sustainable, urban development. This would enable the creation of databases for a complex typology of architectural objects, not only for media architecture but also for other categories of objects, such as green architecture, sustainable architecture, waterfront architecture, floating architecture, high-rise building architecture, and others. This would allow for the creation of an extensive database of architectural patterns related to the scale and function of the objects, with regard to the functional, aesthetic or technological solutions, as well as to location conditions. In addition, the systems could also be extended with the description of additional features of urban space and thus make it possible to assess the relationships between a wide range of architectural objects and different characteristics of space, leading to a very complex knowledge base.

With this approach, taking into account the broad scope of various problems, it is advisable to use the technology of Big Data. The 3Vs (volume, variety and velocity) represent the three main properties or dimensions of Big data (26). Big data is commonly stored and processed using, e.g., cloud-based NoSQL systems such as Riak, MongoDB, Google Cloud Big Table, Amazon DynamoDB or CI TaskCloud. Currently, the most popular big data programming languages are Python, Java and R (27).

The Big data community is using the Python programming language for Big data projects because it is open-source, has high-speed code development, and is object-oriented with data processing support as well as multiple Python libraries. For data visualization in Python, there are appropriate libraries (Geopandas, GDAL / OGR, and Arcpy) that are compatible with the formats used, for example, QGIS, ArcGIS. Additionally, the open-source Python enables data visualization without the limitation of local computer resources. For example, the Datashader library is a graphics pipeline system for creating chart representations of large datasets quickly and flexibly. The Datashader library uses the approach of parallel and flexible data reading, e.g. of GIS type, in order to optimally use all available cores of the computing machine. This approach makes it possible to visualize many features of objects on the map, changing them dynamically in a simultaneous way. The use of a dedicated application to track pedestrian activity in the vicinity of architectural objects could visualize the processes that take place between the user and the urban space.

An example of the use of a geospatial Python library for static and interactive visualizations of large spatial data is given in (28). This article describes visualization tools for geospatial data collected by local governments as part of smart city initiatives. Moreover, data gathered in smart city are used to automate processes in city management, helping to improve the results of the decision-making process and strengthen democratic forms of governance by creating accessible knowledge about the city. Presenting the Big data collected as part of a smart city strategies can serve to increase the awareness of residents about the surrounding space and to provide proper development of the city. This knowledge could also be used to assess the legibility or friendliness of urban space – not only in the context of media architecture, as was mentioned before, but as a universal tool for assessing urban spaces, taking into account users' opinions of selected places in the city. With the support of digital tools, and based on storing historical data, it could be possible to read the degree of legibility of the existing urban space (through the 7 proposed features). The degree of legibility of space could also be monitored after introducing new buildings within the space – post-construction or when considering various variants of such new designed buildings – in the virtual space – in order to choose the most suitable solution. In this case, an important role can be played by the Immersive 3D Visualization Lab (16), which enables the visualization of 3D architectural models on a 1:1 scale and their virtual observation. An already prepared questionnaire could be used to evaluate the space in terms of media architecture.

Returning to the real objects of media architecture, it should be emphasized that the analysis of solutions transmitting variable images requires not only the analysis of text but also video files, which is another source of data acquisition for analysis and directs this analysis to the use of Big data methods, moreover, using large computers' computing power. It is the complexity of the issues that will necessitate this type of solution in the future. Assessing the discretion of media solutions or their uniqueness, as well as the uniqueness of the urban landscape or the role of an object in the visual structure of space, related to the legibility of space, requires the ability to read not only the features of objects and their space but also the relationships between them. These types of activities will require interdisciplinary cooperation, also supported by tools related to teamwork.

Summing up, the use of appropriate IT tools shortens the time and increases the scope of analysis, and also leads to the confirmation of hypotheses. Nevertheless, the construction of a comprehensive IT system supporting the profound assessment of architectural solutions, taking into account the very complex background (see Fig. 1), is still a great, interdisciplinary challenge.

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