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Review article

Comparative analysis of multi-criteria models for decision-making in the process of building adaptation

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ABSTRACT

Since adaptations are an increasingly common type of activity architectural practice, and buildings out-of-use are a problem faced by a growing number of cities, the paper discusses the structure and segments of multi-criteria models created in different contexts, which are developed to contribute to better decision-making in the process of adaptation, to achieve maximum economic, environmental and social sustainability. The choice of the appropriate architectural and structural intervention is influenced by several criteria, among which, mostly, the decisive ones are those related to the economic viability of the entire adaptation process. The paper presents a comparative analysis of criteria, applied valorization, and applications of five multi-criteria models. The criteria considered within all types of adaptations have been determined, and those that are specific to a certain type of intervention or context have been pointed out. Regarding applied valorization systems, the advantages and disadvantages of *MCDA* methods used to develop the analyzed tools, quantitative and qualitative scales of evaluation of criteria and indicators are recognized, as well as the possibility of changing their weighting factor. Since the models are intended for non-professional users, the simplicity of the application was considered. Although the focus of research is on the adaptation of office buildings by adaptive reuse, models that include other types of adaptations are also analyzed, because certain segments of these models may be important for creating new models with a greater degree of personalization, which application may extend the period of the useful life of adapted buildings.

1. Introduction

In the last twenty years, instability has been noticed in the market of office buildings around the world, which is reflected in the increase in the percentage of office buildings that are no longer used for that purpose. Within the regular changes in the market, the expected percentage of vacant buildings is 3–8% [1]. In the Netherlands, according to the records from 2013, approximately seven million square meters of office space are out of use, which is 15% of the total fund, half of which has been out of use for more than three years. The situation is similar in the markets of other European cities such as Frankfurt and Paris, where the need for office space exceeds the investments in that area. A high percentage of unused office buildings has also been observed in cities such as Madrid and Dublin, which have been affected by the economic crisis since 2009 [2]. Based on the quality and age of the facility, office buildings in the real estate market are divided into three categories: “A”, “B” and “C” [3]. Category “A” includes buildings of the highest quality that were built or renovated after 1980. Buildings built in the period from 1950 to 1980, in good locations, which need renovation, but are

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not flexible enough to be renovated following contemporary standards for office buildings, are classified as “B” category. Category “C” covers buildings that are in poor condition, without clear indications regarding their use in the future. The conversion of “B” and “C” category office buildings, as a way of solving the problem of unused office buildings, appeared in New York in the first half of the 1980s. A decade later, the conversion of these buildings into residential buildings was present in cities around the world [3]. In Australia, the conversion of unused buildings, which are under a certain degree of protection, is a way to revitalize the architectural heritage [4], while the reactivation of buildings that are not part of the cultural heritage through conversion is one of the sustainable development strategies, where a positive effect of the renewal of the built fund is the reduction of CO2 emissions [2]. In Hong Kong, the percentage of newly built office buildings in 2005 was only 1.1% due to the high building density. Since the design approach is often based on the principles of energy efficiency, the conversion of existing buildings is usually undertaken, instead of their demolition and construction of new ones [5].

The need for conversion is often conditioned by the actual development strategies of a certain city. For example, in the Netherlands, the conversion of office buildings into permanent and temporary housing facilities is a consequence, on one hand, of a large number of business buildings out of use and, on the other, insufficient capacity of the built housing stock [2]. As a type of architectural activity, the conversion of a building function in Belgrade is not represented to a large extent. However, through the analysis of the situation on-site, several cases of conversion of office buildings to hotels were noticed, and the dominant number of these buildings are located in the downtown area, within the zones protected as cultural heritage [6].

Although the conversion of buildings, despite the benefits, is still insufficiently present in building practice, several researches deal with this topic. One of the areas of research is multi-criteria models that were created as instruments in the process of conversion to identify the potential of a particular (office) building out of use for conversion in general, or another specific use. The approaches applied in designing these models differ and they are adapted, to a greater or lesser extent, to the context in which they originated, but their structure is similar: they consist of criteria that are evaluated based on indicators, according to a previously established valorization system based on one of the *MCDA* (multiple criteria decision analysis) methods.

The research aims are to establish a platform for developing a new “Belgrade” multi-criteria model for evaluating the potential of conversion of office buildings into hotels in areas that are protected as cultural heritage in Belgrade, given that there are still office buildings that are vacant in the city center, and that there is a demand for hotel accommodation capacity due to increased attendance by foreign tourists [6]. A comparative analysis of the structural parts of five multi-criteria models is presented in the paper. Given that the research presented in the paper aims to create a platform for the development of new multi-criteria models, the analyzed models were chosen by the contribution they can make to the creation of such a platform. First of all, all analyzed multi-criteria models are intended to evaluate the potential of buildings for adaptation. The *Conversion meter* model was chosen because it is intended for the conversion of office buildings into residential buildings, including hotels, as a form of temporary housing. In addition, it represents a significant source of criteria and indicators for this type of adaptation. One more reason for choosing the Conversion meter model is the “Quick Scan” step, which may contribute to the efficiency of the decision-making procedure. The *TOBUS* model was chosen due to the method of valorization and used *MCDA* method, as well as the fact that it was created in cooperation with several European countries, therefore, the criteria and indicators used are less related to a certain spatial context and there is a greater chance that can also apply in new models. The *ARP* model is based on the age of the building, the possible duration of the physical structure itself, and the period of usability. Given that this criterion is not particularly prominent in the other models, the *ARP* model was considered within the presented analysis. The *iconCUR* model was chosen because of the variable hierarchy between criteria and indicators and the applied *MCDA* method, as well as the graphic representations of the model itself. Finally, the *PAAM* model was analyzed due to the *PCA* method itself, but also because considering the way the *PCA* method was applied, a large number of criteria and indicators were considered during the creation of the model, which is important in the process of adaptation of office buildings.

This analysis is an important step in the whole research since the paper analyzes multi-criteria models intended for evaluating the potential of different types of adaptation, including conversion, to see the similarities and differences between their criteria and indicators, consider the specifics of used *MCDA* methods (types of algorithms) and quantitative and qualitative evaluation scales and compare the application of these models. Outcomes from this research represent guidelines in the process of creating the new multi-criteria model. Although the creation of a new “Belgrade” model is the subject of further research, the draft for a new model will be presented in this paper. This draft could be the basis for further research relating to multi-criteria models for decision-making in the process of other types of building adaptation in Belgrade and other cities. Since the ways of establishing a hierarchy between criteria and indicators to emphasize the variability of the impact that certain criteria have on the outcome are discussed, one of the contributions of this paper is the potentiality to increase the degree of personalization in the new multi-criteria models. Also, this paper contributes to the sustainability of the built environment, because, within the general criteria and indicators, there are criteria and indicators which influence the significant extension of the period of use of adapted buildings without major interventions. Findings from this research related to the valorization systems which include *MCDA* methods based on different algorithms, and, also, qualitative and quantitative measurement scales may be valuable for application in related areas. Besides the mentioned contributions, the novelty of this paper is in the presented comparative analysis of the five relevant models, the creation of a platform with general findings which relate to all multi-criteria models, and the draft of a new possible model.

2. Literature review

Criteria that have an impact on the feasibility and cost-effectiveness in the process of conversion of office buildings were considered in the framework of research which was focused on the analysis of various aspects of the process of conversion of vacant buildings.

In Hilde Remoy’s doctoral dissertation, within the transformation of vacant office buildings into permanent and temporary housing, potential changes in existing buildings to adapt to the new use were analyzed on the examples of 14 already converted business buildings and 31 interviews with participants. The characteristics of the buildings were considered from the economic, functional, technical, legislative, cultural, architectural, and historical aspects. It was concluded that the greatest impact on the potential of the building for transformation, with a focus on the economic aspect, have the type of facade and structural characteristics of the building [1]. On one hand, the costs of interventions on the facade make up 26.7% of the total investment in the conversion process, of which 22.4% goes to the structural part, and 4.3% to the finishing of the facade. They are followed by the costs of finishing interior walls, which account for up to 16.8% [7]. On the other hand, buildings, whose structural systems are insufficiently adaptable, have a reduced potential for conversion. The spatial structure of a large number of office buildings built in the period after the Second World War corresponds exclusively to office use, so adapting these buildings for a new use may take longer and require greater financial investments [8]. The group of authors directs its research towards increasing the degree of adaptability of newly designed buildings, so that, in the future, the process of conversion will be simpler and more economically viable [9].

Remoy and van der Voordt emphasize the importance of the location of the facility as one of the determining factors in the process of conversion of office buildings: greater potential for conversion into permanent or temporary housing have office buildings located in urban centers and residential areas than those buildings which are located in business districts. In addition, the financial ability of potential users of the converted building in the city center is higher, so larger investments in the building during the conversion process are economically more feasible. It has been noticed that a certain degree of protection of a building has a positive effect on the outcomes of conversion of such a building and is often the initiator of the conversion process. The trigger for the conversion of an unprotected building is, most often, the potential of the location where the building is located [2]. However, the conversion of buildings that are part of cultural heritage can be economically demanding due to the need to apply special techniques and materials [10]. The legislative framework has a great influence on the potential of vacant office buildings for conversion, which is considered, on one hand, through urban plans adopted for the spatial coverage in which the observed facility is located, as well as differences in applicable standards for office buildings and the potential new use [9], and on the other hand, through the organization and duration of procedures for obtaining various consents and permits in the process of conversion [11]. The possibility of conversion is greater if the urban plans provide for the possibility of several different uses or if the plans themselves are subject to change. When it comes to the difference in standards since aspects such as permissible noise levels, air quality, and fire protection measures are considered, as well as the floor height and the number of planned parking spaces, buildings that are not designed to meet only the standard limit has a greater potential for conversion [9]. A precise procedure for the conversion of the building affects the duration of the adaptation process, and thus the total costs of the conversion process [11]. In the last twenty years, special attention has been paid to the standards related to the energy efficiency of newly built buildings but also converted ones [12].

3. Multi-criteria models

By evaluating different groups of criteria and establishing a certain hierarchy among them concerning their influence on the adaptation process itself, multi-criteria models have been created. Multi-criteria models for evaluating the potential of buildings for a particular type of intervention are tools that facilitate decision-making in the process of building adaptation.

3.1. The Conversion meter model

3.1.1. Brief description

The first version of the *Conversion meter* called the Transformation meter [13], was developed in the late 1990s when a large number of office buildings in the Netherlands remained out of use. The model was tested on a series of case studies by students of the Faculty of Architecture in Delft and other universities, and then further developed.

3.1.2. Structure

Essentially, the model consists of several checklists of criteria that are used to assess the potential of a vacant office building for conversion into a residential building. The assessment takes place in several steps:

1. Review of databases regarding vacant office buildings or those that could soon be vacant, in a certain area;
2. The first, “quick” assessment of the transfer potential, which does not require much data, consists of four “veto” criteria expressed through several criteria. “Veto” criteria are evaluated with “Yes” or “No”. If any of the above criteria are assessed negatively, it is considered that the building has no potential for conversion, and further assessment is not done;
3. The next step is based on the assessment of potential by filling in two checklists of criteria, which relate to the location and characteristics of the building. They are valued as positive/negative and do not have a “veto” character, but indicate a greater or lesser potential for conversion. Each positive answer is worth one point. Positive responses to the set of criteria of the location are added and multiplied by a weight factor of 5 and positive responses to the set of criteria of the object are added and multiplied by a weight factor of 3. These values are added. The obtained result is positioned within the scale on which the limit values for five levels – the class of potential of the building for conversion are determined. The weight factors are temporarily determined and are subject to change depending on the specifics of individual cases. Depending on the target group, there may be variations within the criteria. Also, depending on the specificity of individual cases, there is a possibility that one of those criteria becomes a veto criterion;
4. If, based on the previously conducted assessment, it can be concluded that the building has a satisfactory potential for conversion, the fourth and fifth steps are approached. The fourth step is to assess the financial feasibility of the process of conversion of a

particular office building and is based on several criteria: acquisition costs, the current condition of the building, level of renovation or modification work required, finishing and comfort level of the housing units, number of (extra) dwelling units that can be created in the building, shape, and opening on façade, project yield by rental income and/or sales prices which depends on a target group of users (different users have different preferences when it comes to the type of home, number and layout of the rooms, access, appeal and the size of the outdoor area);
5. The last step is to present a list of potential risks and problems during the process of conversion of the office building, which may be due to market conditions, location, and facility characteristics. With the consideration of risks, a list of possible solutions is offered [14].

3.1.3. Valorization and results

The assessment of the potential for conversion of an office building into a residential building using this model is based on criteria that primarily relate to the location and characteristics of the building itself. The presented criteria are considered guidelines that indicate the high potential of the building for conversion. The evaluation system is an appraisal method-checklist scale and it is simple: each criterion that is fulfilled carries a point; the more fulfilled criteria the better. Five conversion classes were determined (from "No Transformation potential" to "Excellent Transformation potential") based on the range of the minimum and maximum score, which was divided into five equal parts (maximum score is 202, class 1 is from 0 to 40 points, class 2 is from 41 to 80, etc.) [15].

3.2. The *TOBUS* (*tool for selecting office building upgrading solutions*) model

3.2.1. Brief description

The *TOBUS* is a multi-criteria model for assessing the current state of an office building and evaluating the potential for different types of renovation and the cost of these processes, as well as the required amount of energy. It was developed within the European research program *JOULE III* and is the result of joint research by experts from Denmark, France, Greece, Switzerland, and the Netherlands [16]. This model enables the better organization of the adaptation process depending on the chosen method but does not elaborate on the implementation phase. Two main tasks can be identified:

1. Diagnostics - involves assessing the current state of the office buildings;
2. Interventions - defining the renovation method.

3.2.2. Structure

To facilitate the application of the *TOBUS* approach when renovating office buildings, the *TOBUS* software has been developed. It includes databases related to the territory of Switzerland, so the software itself corresponds only to that country, but due to the flexibility of its structure, it is possible to easily adapt it for use in other countries [17]. The assessment of the most adequate intervention that would be used to renovate an office building takes place through four steps:

1. Assessment of the physical condition and degree of degradation of the building elements which are broken down into parts, for easier consideration – The entire building is divided into objects and types for building construction and services. They were determined from a diagnostic point of view, as possible. For each object, several types are identified indicating different materials and designs. Physical degradation of each object and existing type is described through one of four degradation codes (qualitative evaluation, i.e. type exists – "good condition", type "possibility for installing."- "not possible to install"). The action for retrofitting building objects is defined, again, through four intervention codes (qualitative evaluation, i.e. type exists – "replacement or extensive repair", type does not exist (new object) – "install object and make all necessary arrangements") and costs are considered. This process is repeated for each building element that needs to be improved;
2. Assessment of the functional obsolescence of installation systems in the facility is a step where the possibility of the facility being improved to a stage that meets the needs of modern users is assessed – The sub-criteria of functional obsolescence are defined: user needs, flexibility, divisibility, maintainability and compliance with regulations. Because for each object (same object as previously explained) one code per functional obsolescence criterion is needed, but not all criteria are applied to each object, a matrix for indication of which building object or service is to be connected to which obsolescence criterion was created. Further, the typical set of upgrading actions is proposed the and amount of energy consumption is considered;
3. Estimation of energy consumption – The main modules (sub-criteria) of energy consumption are defined: as heating, cooling, and ventilation, heat for service hot water, lighting, equipment, electromechanical installations, and water use. After the definition of criteria, information on the current energy performance of the building is required, to consider various energy savings retrofit measures;
4. Space indoor environmental quality – The sub-criteria of indoor environmental quality are defined: as thermal comfort, indoor air quality, lighting, and noise. Data collection is based on: a checklist about building structure and services filled out by the building manager and technical staff, a questionnaire about perceived comfort and complaints from building users (employees, mostly), and a checklist about auditor(s) impression during a visit to the building. After analysis of the answers, the possible problems could be identified and potential action considered [18].

3.2.3. Valorization and results

The selection of an adequate alternative intervention is based on the evaluation of a set of criteria that was based on practical

Table 1
Comparative analysis of criteria and indicators of multi-criteria models.

MODEL I			**The *Conversion meter* model**
Phase I – Quick Scan: an initial appraisal of unoccupied offices using veto criteria			
veto criteria			indicators
market			There is a demand for housing for local target groups;
stakeholders			Presence of influential project initiator;
			Meets criteria for the region, location, and accessibility;
			Meets criteria regarding size and character of the building;
			Willingness to sell the building;
			Willingness to buy and transform the building;
			The positive attitude of the municipality;
location			The zoning plan permits modification;
			No serious public health risk (pollution, noise …);
building			Free ceiling height >2.60 m;
Phase II – Feasibility scan: a further appraisal			
criteria	sub-criteria		indicators
location	functional	Urban location	Building in a suitable area;
			Good daylight/sunlight exposure;
			Good view from >75% of floor space of a building;
		Distance and quality of facilities	Shop for daily necessities <500 m;
			Neighborhood meeting places (square, park) <500 m;
			Food service industry <500 m;
			Bank/post office <5 km;
			Basic medical facilities <2 km;
			Sports facilities <2 km;
			Educational facilities <2 km;
		Accessibility by public transport	Distance to railway station <2 km;
			Distance to bus, tram, underground <1 km;
		Accessibility by car	Good flow, normal street quality;
			Distance to parking sites <250 m;
			>1 parking lot per 100 m^2 of office space;
	cultural	Representative impression	Situated centrally (not near highway locations);
			Other buildings present in the direct neighborhood;
			Lively neighborhood;
			Direct availability of green environment;
			Area has a good reputation/no vandalism;
			Area has good air quality and low pollution and noise;
	legal	Urban location	Noise load on facade <50 dB (max for office building is 60 dB);
		Ownership of location	Land in property or with a short lease;
building	functional	Year of construction or renovation	Building >3 years;
			Renovation >3 years;
		Vacancy	Complete building is vacant;
			Building vacant >3 years;
		New housing	Building capacity >20 units/50 m^2;
			Lay-outs adaptable for local target groups;
		Extendibility	Horizontal building extension possible;
			Vertical building extension possible;
			Possibilities for constructing the basement;
	cultural	Representative impression	Identifiable compared to surrounding buildings;
			Own identity recognizable;
		Cultural heritage	Not a cultural heritage; simplifies process;
		Access (entrance, elevators, stairs)	Clean, safe and clear building entrance;
	technical	Condition of maintenance	Well maintained; maintenance up-to-date;
		Dimensions of support structure	Depth of building <10 m;
			Grid support structure >3.60 m;
			Height dimension between floors < 6 m;
		Support structure	Condition support structure is good
			Possible connection inner walls on grid <5.40 m
		Facade	Facade/openings well adaptable
			Facade windows can be reused/opened
		Installations	Sufficient service ducts can be constructed;
	legal	Environment	Absence of large amount of hazardous materials in the building;
			Acoustic insulation of floors >5 dB;
			Good thermal insulation of facades and roof;
			Sufficient daylight factor >90% floor surface for new units;
		National Building Decree, escape and access routes	Elevators available/easy to install in building >4 stories high;

(*continued on next page*)

Table 1 (*continued*)

MODEL I		**The *Conversion meter* model**	
		(Emergency) stairways available/realizable;	
		Distance of new units to stairs/elevators <50 m;	
MODEL II		**The *TOBUS* model**	
criteria	sub-criteria	indicators	
Physical state of degradation of building elements	Building elements	objects	types
	[a]roof (e.g.)	roof covering (e.g.)	(for objects "roof covering") tiles
			(for objects "roof covering") roofing membrane
Functional obsolescence of building service	User needs	Compliance with user's professional activities in office spaces;	
	Flexibility	Capacity to easily modify the interior space partitioning and general office layout without any major intervention in building installations and structure;	
	Divisibility	Capacity to divide the buildings into separate and independent zones;	
	Maintainability	Capacity to facilitate easy maintenance of the premises;	
	Compliance with regulations	The capacity of the various installations to comply with national regulations;	
Energy consumption	Heating	Calculations for heating energy balance and savings from retrofit actions (heating systems);	
	Cooling and ventilation	Calculations for cooling energy balance and savings from retrofit actions (passive and hybrid cooling techniques – ceiling fans, night ventilation..; controls in air handling units, …);	
	Heat for service hot water	Calculations for savings from retrofit actions (instantaneous water heaters, ice and chilled water storage);	
	Lighting	Calculations for saving from the use of energy-efficient lamps/luminaires and daylight assessment;	
	Equipment	Calculations for energy consumption and savings for office equipment (low energy office equipment);	
	Electromechanical installations	Service quality and energy consumption of existing lifts (zoning of elevators and service quality);	
	Water use	Water conservation for sanitary services (sanitary water savings);	
[b]Indoor environment quality	Thermal comfort	Draught (e.g.)	
		Temperature balance (e.g.)	
		Temperature changes (e.g.)	
		Floors (e.g.)	
		Surfaces (e.g.)	
		Control of temperature (e.g.)	
	Indoor air quality (humidity, pollutants, ventilation)	Air (e.g.)	
		Smells (e.g.)	
		Static electricity (e.g.)	
		Control of ventilation (e.g.)	
	Lighting	The intensity of light (e.g.)	
		Sufficiency of light (e.g.)	
		Level of glare (e.g.)	
		View (e.g.)	
		Control of light (e.g.)	
	Noise	Level of noise (e.g.)	
MODEL III		**The *ARP* model**	
criteria	sub-criteria	indicators	
Expected physical life (in years)	Environmental context	Distance from the coast <1 km;	
		Stable soil conditions;	
		Level of rainfall;	
		"Greenfield" site;	
		Exposure to potential flood or wash-away conditions;	
		Exposure to severe storm activity;	
		Exposure to earthquake damage;	
		Bushfire zone;	
		Area of civil interest;	
		Presence of animals or insects that can damage the building fabric;	
	Occupational profile	Main use during normal working hours;	

(*continued on next page*)

Table 1 (*continued*)

MODEL I		**The *Conversion meter* model**
		Industrial-type activities are undertaken within the building; Availability to the general public; Presence of tenant occupancy; Presence of building manager or caretaker; Long-term asset; Hazardous material storage or handling; Occupation density >1 person per 10 m^2; Protection by security surveillance; Insurance;
	Structural integrity	Massive construction; The main structure over-designed; Complex or unconventional building structure; Highly durable building components; Presence of other structures immediately adjacent to the building; Foundation on solid rock; Workmanship standard; Possibility of roof leaking in bad weather conditions; Protection against accidental fire events; Public monument or landmark;
Physical life	Building age (in years)	Current building age;
Obsolescence	Physical	Level of maintenance;
	Economic	Building location/distance from other facilities;
	Functional	Level of flexibility/adaptability;
	Technological	Energy consumption - required energy to achieve comfort for the users;
	Social	The position of the use of the building within the market demand;
	Legal	The quality of the original design;
	Political	The level of interest of the public and the local community in the building;

MODEL IV		**The *iconCUR* model**
criteria	sub-criteria	indicators
Condition	Structure	Design standard; Maintained service level; Regulatory compliance;
	Exterior envelope	Design standard; Maintained service level; Regulatory compliance;
	Interior finishes	Design standard; Maintained service level; Regulatory compliance;
	Engineering services	Design standard; Maintained service level; Regulatory compliance;
	External works	Design standard; Maintained service level; Regulatory compliance;
Utilization	Internal space	Demand or relevance; Fitness for purpose; User satisfaction;
	External space	Demand or relevance; Fitness for purpose; User satisfaction;
	Outdoor site area	Demand or relevance; Fitness for purpose; User satisfaction;
	Equipment and fit out	Demand or relevance; Fitness for purpose; User satisfaction;
	Engineering systems	Demand or relevance; Fitness for purpose; User satisfaction;
Collective utility	Operational viability	Economic performance; Culture and heritage; Environmental values;
	Locational contact	Economic performance;

(*continued on next page*)

Table 1 (*continued*)

MODEL I		**The *Conversion meter* model**
		Culture and heritage;
		Environmental values;
	Risk and opportunity	Economic performance;
		Culture and heritage;
		Environmental values;
	Asset valuation	Economic performance;
		Culture and heritage;
		Environmental values;
	Profile/mission	Economic performance;
		Culture and heritage;
		Environmental values;
Stakeholder interest	Building owner	Short-term perspective;
		Medium-term perspective;
		Long-term perspective;
	Building user	Short-term perspective;
		Medium-term perspective;
		Long-term perspective;
	Facility manager	Short-term perspective;
		Medium-term perspective;
		Long-term perspective;
	Sponsor/financier	Short-term perspective;
		Medium-term perspective;
		Long-term perspective;
	Community	Short-term perspective;
		Medium-term perspective;
		Long-term perspective;

MODEL V		**The *PAAM* model**
criteria		indicators
Physical and size		Number of storeys;
		Gross floor area;
		Property Council of Australia building quality grade;
		Degree of attachment to other buildings;
		Typical floor area;
		Site access;
Land		Street frontage;
		Vertical services location;
		Property location;
Social factor		Historic listing;
		Age in 2010;
		Aesthetics;

[a] Only examples of sub-criteria and indicators are presented for this criterion due to many possible different combinations of building elements which improvement required consideration.

[b] Only examples of indicators are presented for this criterion, due to the fact that indicators is based on checklists and questionnaire with many items.

experience. The set of criteria consists of quantitative criteria that are measurable and numerically expressed, but also qualitative criteria that are flexible and immeasurable. To obtain a unique result, it is necessary to find a way to translate the qualitative values into a numerical and comparable form. In multi-criteria (and multi-variate models, such as this one), methods, based on different families of algorithms, are used to evaluate the proposed criteria and assign initial weighting factors to them. The *COPRAS* method was used in this model. This method was used to evaluate the criteria that describe the potential interventions of each building element (windows, walls, …). To create a unique scale for measuring qualitative and quantitative criteria and indicators, this method uses codes [19]. After the analysis of each building element through a set of criteria, also as functional obsolescence of building service, energy consumption, and indoor environment quality, a set of interventions is proposed that could improve the observed building element, and thus the quality of the facility as a whole. In addition to the type of intervention, potential costs are considered [18]. The result is a proposal for the renovation of the building, which includes the interventions needed to improve each element. In this way, a large number of different combinations of interventions are considered, so the final renovation proposal is specific for each building [19]. The model was first tested in a pilot project to develop the application process. It was then tested on individual cases in the countries participating in the research [18]. It is important to point out that this model proposes many different combinations of actions and, consequently, consists of many criteria and indicators which are not all used every time, so criteria and indicators used for consideration of building solutions are not the same for different buildings. Given that, in Table 1, only examples of sub-criteria and indicators are presented for some criteria.

3.3. The ARP (*adaptive reuse potential*) model

3.3.1. Brief description

The *ARP* model is a multi-criteria model used to evaluate the potential of building conversion. The model is based on the estimation of the physical life of a building and its current age, expressed in years [20].

3.3.2. Structure

The assessment of the physical life of a building is based on a list of criteria, which relate to the environment, the way the building is used, and its constructive characteristics, formulated in the form of questions, which are answered positively or negatively. Some criteria are marked and their value is doubled [21]. An Excel calculation template is used to evaluate this part of the assessment. The calculation algorithm, as a starting value, uses the physical life of a building of 100 years, and then, adds or subtracts years depending on the answers to the questions. The calculation was created based on a review of the literature, ISO standards, and the personal experience of the author of the model [22]. It is considered that the physical and useful life of the building is influenced by different types of its obsolescence, which are the basic criteria of the model:

1. Physical obsolescence is a consequence of inadequate maintenance of the facility. Concerning the initial construction costs, the optimal budget required for the maintenance of the facility is calculated;
2. Economic obsolescence is perceived through the location of the facility. The economic obsolescence is also affected by the potential of other investments, which are not related to the facility, but are of interest to the owner of the facility;
3. Functional obsolescence is the lack of flexibility of the building to be transformed, which leads to higher costs during conversion;
4. Technical obsolescence is expressed through the amount of energy required to provide user comfort;
5. Social obsolescence represents the position of the building type on the market;
6. Legal obsolescence refers to the quality of the original design (derived) solution and compliance with applicable standards;
7. Political obsolescence has arisen from various changes within the regulations (zoning, acquisition of cultural property status, etc.) and is seen through the level of interest of the public and local community for the building [21].

Criteria are evaluated as a percentage, from 0% to 20%. This multi-criteria model is expressed by a diagram according to which each building reaches its maximum potential for conversion at the end of the exploitation period for the original purpose [23]. The values of the diagram are obtained using an algorithm, composed of several equations that establish relationships between criteria:

1. Useful life of a building is defined as the estimated duration of the building discounted by obsolescence factors. The established method of discount is used and the sum of obsolescence factors is taken as the "discount rate", on an annual basis: $L_u = Lp/(1 + \Sigma O_i)^{Lp}$, where L_u is the useful life of a building, L_p is the physical life, and O_i represents the obsolescence (*i* has a value from 1 to 7 since seven types of obsolescence have been defined).
2. The values of effective building life (EL_u), effective building age (EL_b), and effective physical life (EL_p) are determined by simply multiplying L_u, L_b (the current age of the building in years), and L_p by 100 and dividing by L_p. This way allows a maximum value on the x-axis in the diagram of 100 (100% of the building's life cycle), because the values obtained for EL_u, EL_b, and EL_p are, in fact, the percentages of the period of use of the building, the current age and duration of the building as a physical structure in the life cycle of the building.
3. Adaptive reuse potential of the building is presented on the y-axis of the diagram and takes values from 0 to 100% (Wilkinson et al., 2014). The curve used in the model is the "obsolescence function" that the authors of the model believe is being used (Langston et al., 2008). The field on the diagram that is considered a "feasibility zone" for the ARP model is marked with a field below the descending curve defined by the equation: $y = 100 - x^2/100$.
4. Increasing adaptive reuse potential: A. $[100 - (EL_u^2/100)]*EL_b/EL_u$ and decreasing adaptive reuse potential: B. $[100 - (EL_u^2/100)]*(100 - EL_b)/(100 - EL_u)$, is defined by the presented equations, which derive from the geometric statement about the proportionality of the parallel sides of similar triangles (Wilkinson et al., 2014). Effective useful life (EL_u) is the moment when the building reaches the maximum adaptive reuse potential, so the increasing or decreasing potential is considered concerning effective building age (EL_b) and effective useful life (EL_u). Buildings with a current age lower than the age of the building at the time of reaching the maximum potential for conversion have a growing potential for conversion, while buildings with a current age greater than the age of the building at the time of reaching the maximum potential have declining potential.

3.3.3. Valorization and results

Results above 50% are considered as high potential, values between 20% and 50% moderate potential, and values below 20% as low adaptive reuse potential of a building (Wilkinson et al., 2014). When it comes to evaluation tools or software programs, the ARP model uses the *SINDEX* methodology [24], which uses multi-criteria analysis to calculate the sustainability index and rank projects. SINDEX could verify potential calculated with ARP using a range of financial, social, and environmental criteria. The key objectives of *SINDEX* are expressed through four criteria: maximizing wealth or return on investment, maximizing utility or functional performance, minimizing resource or energy consumption, and minimizing habitat impact or loss. All four criteria are measured in different units [20].Return on investment is an economic criterion and is measured as a ratio of benefits to costs with all life cycle costs. Functional performance is a social criterion and is measured by a weighted assessment matrix. Energy consumption is also an economic criterion and is measured as annual GJ or GJ, comparing actual (or expected) energy with a target based on normal practice or legal limits.

Habitat loss is also a social criterion and is measured by a risk assessment questionnaire. When the values of all criteria are obtained, an indexing algorithm is used, based on which the final result is obtained and it is possible to rank the projects concerning their contribution to sustainable development. The algorithm is called the “sustainability index” [25].

3.4. The iconCUR model

3.4.1. Brief description

The IconCUR model is a model that uses multiple criteria to visually present the characteristics and capabilities of an existing building at any point in its life, in a spatial mode [21].

3.4.2. Structure

The model is based on the following criteria:

1. Condition – this criterion describes the physical characteristics of the building and is considered through three key attributes: design standard with durability and appearance as indicators, which refers to quality; maintained service level with different maintenance activities as indicators, which describes maintenance needs of a building during the period of exploitation and regulatory compliance with indicators such as certification and public safety, which is related to the level of compliance. Using these key attributes, the different aspects of the building, such as construction (which includes foundations and superstructure), exterior envelope (refers to façade and roof), interior finishes (containing subdivision, finishes, equipment, and furnishings), engineering systems (mechanical, electrical, and hydraulic services) and external works (site works and external services), are separated and considered in more detail;
2. Utilization – this criterion describes the occupancy characteristics of the building. Three key attributes of this criterion are: demand or relevance with occupancy rates and capacity as indicators, analysis the level of building use, then, fitness for purpose with flexibility and technology support as indicators, which considers what extent the design of the building is suitable to its purpose, and user satisfaction with indicators such as comfort and perceived utility, which refers to approval level of the property. Using these key attributes the building has divided into discrete zones: internal space (completely closed and covered area without primary functional and service area), external space (unenclosed covered area), outdoor site area (land area excluding the building footprint), equipment and fit-out (primary functional space) and engineering systems (services space);
3. Reward is seen through the two sub-criteria: collective utility and stakeholder interests (potential financial, social, and environmental benefits). Sub-criterionriterion ‘collective utility’ reflects the net benefits of the building all stakeholders and it is considered through three key attributes: economic performance with indicators such as payback and investment risk, describes the level of financial contributions a building provides, culture and heritage with indicators such as community enhancement and a sense of place, considers the level of social contributions a building provides, and environmental values with indicators such as carbon footprint and habitat protection, through which the level of sustainability of the building is analyzed…. Using these key elements the building is split into several discrete goals such as operational viability (recurrent feasibility), locational context (proximity to the marketplace), risk and opportunity (future proofing), asset valuation (investment growth), and profile/mission (reputation enhancement). Sub-criterion ‘stakeholder interest’ express the engagement strength with asset delivery through three key attributes: a short-term perspective which considers utility within the first five years, medium-term perspective which considers utility within the next fifteen years, and long-term perspective includes the utility over the remaining building useful life. Using this approach building is considered from the point of view of many stakeholders: building owner (controlling organization), building user (employees and customers), facility manager (custodian or site manager), sponsor/financier (government authority or private investor/banker), and community (general public). The value of criterion ‘reward’ is a result of the score for collective utility multiplied by the score for stakeholder interest and divided by 5. When all stakeholders have excellent engagement short, medium, and long term, then the value of the reward criterion would be equal to the value of sub-criterion collective utility [26].

3.4.3. Valorization and results

The criteria, in the spatial model, are represented through axes with evaluation scales from 0 to 5. The values related to the current state of the building are on the x-axis, the usability of the building on the y-axis, and the relevance on the z-axis. Concerning the current condition and usability of the facility, a type of intervention is proposed (maintenance, renovation, extension, reconstruction, recycling, conversion, adaptation, …) as the best choice. The feasibility of the proposed intervention is evaluated by the third criterion. If there are several buildings for which the potential for intervention is considered at the same time, using this model, their potential can be compared. Also, a change in the potential of the same building, after certain interventions, can be presented.

The spatial model has the shape of a cube. Each vertical edge of that cube represents one of the potential interventions. Each building, with coordinates - values of criteria, is positioned in space. Coordinates - criteria must be quantified in a certain way. Therefore, a set of key attributes has been developed for each criterion, evaluated according to the established scale (from 0 to 5), and within certain categories [21]. The model uses a weighted matrix approach to provide key attributes for each criterion or sub-criterion in the model and to assign weighting factors to them according to their importance proportional to each group [26]. The same criterion, in different cases, may have a different share. By changing the share of attributes in the final value of the criteria, the value of the criterion itself changes [21]. The evaluation system used in this model belongs to the group of visual *MCDA* methods and it is based on the *PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluations)* family of algorithms, particularly the *GAIA* (geometrical analysis for interactive assistance) procedure [26]. The *PROMETHEE* methods are outranking methods that use partial aggregation (allows both qualitative and quantitative criteria to be considered without the need for coding). These approaches compare the actions pairwise, and under certain conditions check if one of the two actions outranks the other or not from these comparisons [27]. Six types of preference functions are suggested to the decision-maker by the *PROMETHEE method* [28].

3.5. The PAAM (preliminary assessment adaptation model) model

3.5.1. Brief description

The *PAAM* model is a multi-criteria model designed to assess the potential for the extension of different types of office buildings [29]. Although the model focuses on another type of transformation to the one that is the topic of our research, the methodological approach applied in this model may have an impact on the process of forming a new model.

3.5.2. Structure

As a part of the research related to the development of this model based on an extensive literature review, six groups of the building attributes, which are important for different types of adaptations, were considered: the attributes of economic category (which include current value, investment value, yields, increase in value post adaptation, construction and development costs, convertibility), the attributes of physical category (containing building height or number of storeys, floor plate size, shape of floor plate, service core location, elasticity or ability to extend laterally or vertically, degree of attachment to other buildings, access to building, height of floors, structure, floor strength, distance between columns, frame, deconstruction, expandibility, flexibility, technological and convertibility, reusability or recyclability), the attributes in relation to location and land use (refer to transport, acess to airports, motorways, train stations, public transport nodes, buses and trams, land uses, existing planning zones, rezoning potential, density of occupation), the attributes of legal category (including ownership, occupation, building codes, fire codes, access acts, health and safety issues, convertibility), the attributes of social category (community benefits/historic listing, transport noise, retention of cultural past, urban regeneration, aesthetics, provision of additional facilities, proximity to hostile factors, stigma, age) and the attributes of environmental category (which include internal air quality, internal environment quality, existence of hazardous materials, sustainability issues) [29]. Based on statistical data, which would be explained in detail in sub-section 3.5.3, the criteria and indicators for this model from a previously considered wider list of attributes important for building adaptations is selected.

The *PAAM* model consists of three main criteria:

1. Physical and size: according to *PCA*, the influence of this criterion on the final result is 44.86% (weighting factor). It is measured by the following indicators: number of stories (weighting factor relative to criterion: 19.19%), gross floor area (weighting factor relative to criterion: 19.19%), Property Council of Australia building quality grade (weighting factor relative to criterion: 16.46%), Degree of attachment to other buildings (weighting factor relative to criterion: 15.52%), typical floor area (weighting factor 14.88%) and site access (weighting factor relative to criterion: 14.76%);
2. Land: according to *PCA*, the influence of this criterion on the final result is 19.78% (weighting factor). It is measured by the following indicators: street frontage (weighting factor relative to criterion: 36.28%), vertical services location (weighting factor relative to criterion: 35.26%), and property location (weighting factor relative to criterion: 28.46%), and
3. Social factor: according to *PCA*, the influence of this criterion on the final results is 9.32% (weighting factor). It is measured by the following indicators: historic listing (weighting factor relative to criterion: 42.42%), age in 2010 (weighting factor relative to criterion: 32.58%), and aesthetics (weighting factor relative to criterion: 25.00%).

The model ignores the criteria and indicators that, in the opinion of the authors of the model, equally affect the potential for a given type of transformation in all analyzed cases [29].

3.5.3. Valorization and results

The method of valorization is based on statistical data collected from the analysis of a large number of buildings on which this type of transformation was performed. The starting point is a set of criteria measured by certain indicators and the estimated impact (in percent) of each indicator on the final value of the criteria, and then, the percentage impact of each individual criterion on the entire transformation process. The percentage of criteria and indicators is determined using the mathematical method *PCA* (Principal component analysis) [29]. The main idea of this technique is to reduce the dimensionality of a data set consisting of a large number of interrelated variables, while preserving, to the greatest extent, the variation present in the data set [30]. This is achieved through orthogonal transformation which is used within the *PCA* for a conversion of a set of conceivably correlated variables into a set of values of linearly uncorrelated variables named principal components. The transformation is defined in such a way that the first principal component has the greatest possible degree of variability. With this method, numerous initial variables are compressed into smaller sets of new factors with as little loss of input data as possible. This mathematical approach is used as a tool in data analysis to create predictive models [29]. The outcome of the analyses is a smaller number of factors with a table of identifiable factors, as a final result. Within the *PAAM* model, the qualitative assessment of the adaptation potential of each criterion is based on the percentage frequency of that attribute in a given value in many previous cases of adaptation. The percentage values of the recognized potentials are standardized on a scale showing five levels. This scale valorizes all the indicators to obtain the values of individual criterion, and then valorizes the criterion, to obtain final estimates [29].

Besides criteria and indicators of the *PAAM* model, for comparative analysis of criteria and indicators in Discussion, an extended list of criteria and indicators that affect the potential of the adaptation facility, from which the criteria and indicators for the *PAAM* model

Table 2
Comparative analysis of principles of valorization of criteria and indicators of multi-criteria models.

	Principles of valorization	The hierarchy between criteria	Type of valorization/ applied *MCDA* method/ evaluation software
The ***Conversion meter*** model	● veto criteria - the assessment of potential is stopped if one of the criteria is not met;	● The weights of the criteria and sub-criteria are not explicitly defined, but a difference in the interpretation of criteria values depending on the target group of users appears;	Quantitative/Appraisal method-checklist scale
	● a set of criteria and indicators that are not of an elimination character is evaluated by collecting positive answers to the criteria of location, i.e. building, sums are multiplied by determined coefficients, and then the final result is ranked within a predetermined quantitative scale. The potentials of buildings for conversion are determined by the value range, which, according to the potential for conversion, are classified into five categories; ● financial feasibility is determined based on the ratio of invested and potentially achievable funds.	● the values of the coefficients multiplying the sums of positive responses to the location and facility criteria are provisional and are 5 and 3, to suggest a greater influence of the location parameters; the possibility of change for specific cases.	
The ***TOBUS*** model	● a separate scale has been established for each criterion, which evaluates these criteria descriptively, through codes; ● in the software of this model, qualitative estimates of criteria are quantified using an algorithm; ● each criterion represents a module based on which certain types of interventions on the facility are proposed; ● the result is given in the form of different scenarios with presented costs, energy needs, and the degree of improvement of the interior space.	● there is no hierarchy among the criteria, but the focus in the decision-making process is on energy needs and the achieved comfort of the interior;	Qualitative and quantitative/*COPRAS* method
The ***ARP*** model	● the physical life of the building is determined based on a set of criteria and indicators that are evaluated positively/negatively;	● there is no hierarchy between criteria;	Quantitative/*SINDEX* methodology
	● the impact of different types of obsolescence on the useful life of the building is evaluated as a percentage of 0–20%; ● the useful life of the building is calculated by a mathematical formula (discount rate) which establishes a connection between the physical life of the building and all types of obsolescence; ● the maximum and minimum adaptive reuse potential of the building is calculated based on a series of equations (the curve – "obsolescence function" and equations that derive from a geometric statement about the proportionality of the parallel sides of similar triangles); ● a scale of potential facilities for adaptation in percentages has been established, within which several levels have been determined.	● great influence of the expected duration of the facility and the current age on the final result.	
The ***iconCUR*** model	● criteria are determined by indicators that are evaluated on a scale from 0 to 5; ● the influence of the indicators on the total value of the criteria is determined by the percentage share (variable); ● the final result is obtained in a 3D diagram where the object is positioned within the spatial grid with criteria whose values are entered as coordinates. The edges of the spatial lattice represent possible types of interventions. The decision on the intervention is determined by the distance in the coordinates of the object from some of the edges (type of intervention) of the spatial grid.	● the hierarchy between the indicators within the criteria is established by their percentage share, which changes the value of the criteria, and thus the outcome of the evaluation.	Quantitative/Visual *PROMETHEE* method (*GAIA*)
The ***PAAM*** model	● indicators are evaluated by a descriptive scale whose qualitative values are quantified; ● the value of the indicator is determined by the percentage of the same value of the same indicator in the analyzed case studies on which the analyzed intervention has already been conducted and the maximum and minimum value of this criterion in cases of adapted buildings;	● the hierarchy between criteria and indicators within the criteria exists and is expressed by their percentages.	Qualitative and quantitative/*PCA* method

(*continued on next page*)

Table 2 (*continued*)

	Principles of valorization	The hierarchy between criteria	Type of valorization/ applied *MCDA* method/ evaluation software
	● the obtained criterion values are qualitative; ● the final result is determined by the percentage of criteria and their values.		

have been extracted, will be taken into consideration.

4. Comparative analysis of multi-criteria models

To form a starting point that will be important when creating new multi-criteria models, a comparative analysis of criteria and indicators, valorization principles, and application of multi-criteria models *Conversion meter*, *TOBUS*, *ARP, iconCUR,* and *PAAM* are presented.

4.1. Criteria and indicators

In Table 1 criteria, sub-criteria, and indicators used in analyzed multi-criteria models are presented, to form a valuable base of criteria and indicators which are important for office building adaptation.

4.2. Valorization of criteria and indicators: MCDA methods for evaluation - qualitative and quantitative scales

In Table 2 the principles of valorization of analyzed multi-criteria models are presented. For each multi-criteria model, types of applied scales and *MCDA* methods (type of algorithms) are determined, also, the presence of hierarchy (variable or invariable) between criteria is considered.

4.3. Application of the models

Therefore, analyzed multi-criteria are intended for different users, in Table 3 the application form of models is presented.

5. Discussion

In this section discussion of the analyzed structural parts of five multi-criteria models is presented.

5.1. Criteria and indicators

In Table 1 the criteria and indicators of multi-criteria models are presented, based on the potential of a building for which one or more types of adaptation are estimated [14,18,21,29]. Depending on the degree of specialization of the model for a certain type of adaptation, the criteria, and especially the indicators, are adapted to the specific type of intervention. The criteria and indicators presented in Table 1 are considered to extract the criteria and indicators which may be appropriate for the potential new multi-criteria

Table 3
Comparative analysis of the application of the multi-criteria models.

	Application of the models
The ***Conversion meter*** model	● veto criteria and indicators; ● a list of criteria and indicators through which the office facility whose potential for conversion is considered; ● the sums of positive responses multiplied by coefficients; ● the final value is the final sum ranked within the scale;
The ***TOBUS*** model	● the criteria with a group of indicators are separated as modules that are individually evaluated and for each module possible software interventions are proposed; ● the final value represents several intervention scenarios;
The ***ARP*** model	● the lists of criteria and indicators based on which the duration of the building as a physical structure is estimated; ● an evaluation of types of obsolescence; ● calculating the final value based on equations; ● the final value is the potential expressed as a percentage ranked within the scale;
The ***iconCUR*** model	● list of indicators for each criterion; ● the criteria values as coordinates in the spatial model; ● matrix in which the percentage of indicators and the final value of criteria change; ● the final result is a diagram showing the distance from the edges of the spatial model;
The **PAAM** model	● a list of indicators that determine the three key criteria; ● the final value is descriptive and represents the sum of individual descriptive values of the criteria;

models. Within the comparative analysis of the criteria and indicators of five models, it is noticed that a number of them are presented in all models, regardless of the type of adaptation the model is intended for. Another number of criteria and indicators are applicable to the models intended for a certain type of adaptation. Also, some criteria and indicators are only related to the aspecific country in which the model was created. Given this, the criteria and indicators can be divided into three groups:

1. General criteria and indicators;
2. Specific criteria and indicators determined by the type of adaptation, and
3. Specific criteria and indicators that are a consequence of the specific context for which the multi-criteria model is intended.

General criteria and indicators are those that are recognized in all or almost all analyzed models as factors influencing the decision-making process within any type of adaptation. Based on Table 1 and the description of the multi-criteria models, it can be concluded that the criteria related to the building location, building characteristics, energy consumption, quality of interior space, and financial feasibility are an integral part of every adaptation process, because, in some form, they are an integral part of all models. The indicators by which these criteria are measured differently depending on the type of adaptation and the observed context, but, within each criterion, several general indicators can be observed. Traffic infrastructure connectivity and distance from the different types of other content in the environment are general indicators by which the location criterion is measured. The possibility of modifying the building's physical structure is a general indicator of criteria related to the building's characteristics. The general indicator of energy consumption refers to the energy required to achieve comfort for the users (thermal comfort, light comfort …). Different types of comfort factors (e.g. temperature balance, control of ventilation, level of noise …) are general indicators for the quality criteria of interior space. The current condition of the building, the necessary additional work, and the value of the building after the intervention are general indicators that measure the criterion of the financial feasibility of the adaptation process. The market is considered only in the *Conversion meter* and *ARP* models. In the *Conversion meter* model, the influence of participants is one of the veto criteria, which is considered through six indicators. On one hand, the positive attitude of the local self-government, investors' interest in buying and transforming, as well as the owner's interest in selling the building are indicators that, without a doubt, must be met to adapt (in this case, realize a conversion). On the other hand, the participation of an influential project initiator can have a positive impact on the project development (e.g. shorten the time required to obtain various permits, which are part of the procedure), but this should not be a veto parameter, as the adaptation project can be done even if this indicator is not met. In the *ARP* model, this criterion is represented through political obsolescence and its impact on the final result is equal to the impact of other criteria. In the *iconCUR* model, user impact is a sub-criteria of a criterion related to the assessment of project relevance, and its weighting factor is variable. The other sub-criteria of this criteria represent the interests of several participants such as owners, users, managers, investors, and the community, which can be useful when creating a new model, as it refers to different types of participants, their different roles, and interests. These sub-criteria are measured through short-term perspective, medium-term perspective, and long-term perspective. Although the criterion related to the impact of market conditions is found only in the *Conversion meter* and *ARP* models, this criterion should be included in future multi-criteria models. Market conditions, based on which information on a specific building function can be obtained, can, to a large extent, influence the choice of the type of adaptation that will be carried out. If there is a greater need in the market for the current building use, with the possibility to achieve greater economic profit during the period of exploitation, and with costs of intervention being lower, it is more likely for the building to be renovated than reused. However, if the adaptation of the building by contemporary standards related to its current use requires a lot of time and a large financial investment or requires interventions prevented by the degree of protection, it is more likely that the building will be reused, regardless of the current status on the market. When developing new multi-criteria models, general criteria and indicators can, to a large extent, be implemented.

Specific criteria and indicators determined by the type of adaptation are a direct consequence of the type of intervention that would, potentially, be performed in the facility. Among the analyzed multi-criteria models, the *Conversion meter* and *ARP* deal with the assessment of the potential of office buildings for conversion. The *Conversion meter* model is more precisely determined and is intended for the conversion of office buildings into temporary or permanent housing buildings, designed as a checklist. Therefore, it consists of several criteria and indicators in relation to the *ARP* model. Specific criteria and indicators, which are a consequence of this type of conversion, in the *Conversion meter* model, refer to the assessment of building capacity through the number of possible new housing units of a certain area (20 units of 50m2), criteria resulting from current standards for housing (e.g. distance from the stairs for new units), facade cladding and the number and layout of openings and potential financial gain in the period of exploitation seen through the market criteria of housing (rental price per m^2 and selling price per m^2). Specific criteria and indicators of the *ARP* model are within the assessment of the physical life of a building and relate to the manner and frequency of use. The *PAAM* model focuses on the possibilities of the building for different types of extension, so the specific criteria and indicators refer to the possibilities of upgrades and connections with neighboring facilities. The *iconCUR* and *TOBUS* models assess which intervention is the most adequate in the case of a specific building, so there are no criteria and indicators from this group in these models. The possibilities of applying specific criteria and indicators determined by the type of intervention in new multi-criteria models depend, first of all, on the type of model: whether the model is intended to evaluate the potential of a building for a certain type of intervention or to select the most appropriate intervention for a building. If the model belongs to the first group and is intended, for example, to evaluate the potential for conversion, of importance is the similarity of spatial needs and applicable standards, for current and potential new use of the new model and models analyzed in the paper (the *Conversion meter* and the *ARP* model).

The third group of criteria and indicators includes those that are a consequence of the specifics of the context in which the model was created and/or for which it is intended. As mentioned earlier in the paper, the *Conversion meter* model originated in the Netherlands and has been tested on buildings from that context, so this group of criteria and indicators can be explained in the example of that model. The location criterion is, among other things, defined by the indicators related to the distance of certain contents from the buildings for which the potential for conversion is estimated. These distances (e.g. distance from the nearest bank or post office <5 km, basic medical services <2 km, education facilities <2 km) correspond to the context of Dutch cities, but are not appropriate for cities like Belgrade, which are designed so that these facilities are much closer to residential buildings. Also, as previously mentioned in the analysis regarding the conversion of business to residential buildings, greater potential for conversion have business buildings that are not located in monofunctional (business) neighborhoods [21]. If this statement were entered into the model as a criterion, such a criterion would belong to the third group of criteria and indicators and could be applied to the context of cities in which, like the Dutch, there are monofunctional city blocks. For the context of cities where strict zoning of purposes is not recognized, such as Belgrade, this criterion would not be significant. The different contexts of the potential new models are considered through a group of criteria related to the context, so the model should be edited following the locally applicable regulations. The weighting factors can also be adjusted to local cultural values. The extent to which criteria and indicators from this group can be implemented in new multi-criteria models depends on the similarity of the context of the analyzed models and the new model. Multi-criteria models, such as the *TOBUS* model, are adapted to different contexts (contexts of the countries that participated in the development of the model) [16], but the *TOBUS* software, which is, actually, in use, is based on data from the context of one country (Switzerland) with the possibility of entering data from other contexts [17].

5.2. Valorization of criteria and indicators: MCDA methods for evaluation - qualitative and quantitative scales

Table 2 the results of a comparative analysis of the principles and types of evaluation of criteria and indicators of multi-criteria models, the presence or absence of hierarchy between criteria and indicators in relation to the outcome of the conversion process, the way the hierarchy is achieved and *MCDA* methods used for valorization in multi-criteria models, are presented [14,18,21,24–30].

To thoroughly analyze the potential of the building for some types of adaptation, the evaluation process includes several criteria and indicators that differ not only according to the on which they are based (economic, technological, environmental, social) but also in the way their value expressed (numerically, graphically, textually …). According to the measure in which their value is expressed, criteria and indicators can be divided into quantitative and qualitative. Quantitative criteria and indicators are based on measurable data. In addition to the above, the criteria and indicators to which is described through the number are also considered quantitative, but, in that case, the weight factor is not objective. Qualitative criteria and indicators are descriptive and flexible, and may not be as precise as quantitative ones [19]. Given that both groups of criteria and indicators are an integral part of the same evaluation procedure if a common result is sought, the principle of valorization is reduced to a single scale, quantitative or qualitative. In addition, it is necessary to consider whether the criteria and indicators of one multi-criteria model always have the same impact within the process of evaluating the potential of different buildings for some type of adaptation. To use a systematic, but also complex approach to valorization in multi-criteria models, *MCDA* methods, which are based on different types of algorithms, are used.

The principles of valorization of the *Conversion meter*, *ARP*, *iconCUR,* and *PAAM* models imply the evaluation of several criteria that are measured by a certain number of indicators. In the *Conversion meter* model appraisal method/checklist scale is used. In the *ARP* model quantitative scale is used through discount rate, "functional obsolescence" curve, and *SINDEX* method. The *iconCUR* model uses one of the *PROMETHEE* methods for valorization, named *GAIA*, which is explained earlier in the paper. In the *PAAM* model, using the PCA method, the indicators are first evaluated qualitatively, then these values are quantified to obtain the criteria value. The final value of the criteria in the *PAAM* model is again translated into qualitative. The principles of valorization in the *TOBUS* model are based on the evaluation of each criterion with a special, qualitative scale using the *COPRAS* method. After the evaluation of each criterion, an intervention is proposed. Each criterion represents an individual module and can be observed individually or together with all or some of the remaining criteria. The obtained result is in the form of several possible scenarios - interventions or combinations of interventions that can be done. Since this model is applied through software, the qualitative values of the criteria are transformed into codes (the *COPRAS* method). In the *Conversion meter* model, there is a set of criteria and indicators that are eliminatory, and, if they are not met, the process of evaluating the potential of an office building for conversion into a residential building does not continue. Criteria and indicators of other models are not eliminatory.

In the *Conversion meter*, *TOBUS,* and *ARP* models, there is no clear way to establish a hierarchy between criteria, but it can be noticed that the outcome of the evaluation process as a whole depends greatly on individual criteria. In the *iconCUR* and *PAAM* models, there is a hierarchy between the criteria, concerning the outcome of the evaluation process, and between the indicators, to the value of the criterion, which is expressed as a percentage. The difference is in the fact that, in the *iconCUR* model, the percentage is variable and can be adjusted to the specifics of different cases, while in the *PAAM* model, the percentage is a consequence of the statistical analysis of case studies in which the intervention has already been implemented and, consequently, it is not variable.

In the *Conversion meter* model, the valorization of buildings that pass the veto criteria is based on filling in two checklists of criteria and indicators related to the building location and building characteristics, where each met indicator is evaluated by one point. Positive responses are collected within each checklist and then multiplied by a coefficient of 5 for the criteria and indicators of the location, and a coefficient of 3 for the criteria and indicators of the building. The obtained values are added up, and the final result is ranked on the determined scale of potential for conversion, which is divided into five levels. On one hand, this method of evaluation makes it easy to obtain a unique result. On the other hand, awarding an equal number of points to each met indicator equals the impact of those indicators on the outcome of the assessment, which cannot be objective, given that in some cases meeting certain criteria is crucial and in other cases is not of great importance. The coefficients by which the sums within the checklist are multiplied are, as emphasized in the description of the model [14], subject to change, but, in any case, the question arises as to how much is possible to establish an objective hierarchy between the criteria of location and criteria of building, as described.

Similar failings occur in the *ARP* and *iconCUR* models, where, in the first case, the effects of different types of obsolescence on the physical life of a building are evaluated from 0% to 20%, and in the second case, the indicator for criteria and then the criteria are evaluated on a scale from 0 to 5. The difference between the valorization methods applied in these two models is that the *iconCUR* model envisages a change in the weight factor of the indicators, which allows flexibility in relation to the specifics of individual cases.

The valorization of the *TOBUS* model is qualitative in the model itself, but it is transformed into codes in the software so that a

Table 4
The proposal of the draft of the new multi-criteria model.

	Part I: Criteria and indicators	
	Criteria	Indicators
Group I: general criteria and indicators	Building location	Traffic infrastructure connectivity (availability of bus, train, …); Distance from different types of content (hospital, bank, …);
	Building characteristics	Possibility of modifying the building's physical structure;
	Energy consumption	The energy required to achieve comfort for the users;
	Quality of interior space	Different types of comfort factors (temperature balance, level of noise, …);
	Financial feasibility	Current condition of the building; Necessary additional work; Value of the building after the intervention;
	Market	Demand for a new use;
	Stakeholders	Interests of stakeholders;
Group II[a]: specific criteria and indicators determined by the type of adaptation	Building capacity	Number of possible new functional units (of a new use) of a certain area;
	Current standards for a new use	e.g. Distance from the stairs for new units;
	Facade	Number and layout of openings;
	The potential financial gain in the period of exploitation	Rental price per m^2; Selling price per m^2;
	The expected physical life of a building	Manner and frequency of use;
Group III[b]: specific criteria and indicators determined by the specific context	Building location[c]	Distance from different types of content (hospital, bank, …) (acceptable distances from the different contexts are the consequence of the urban structure of a certain city);
	Building environment	Presence of different types of contents in the building environment;
	Part II: Valorization	
MCDA algorithm	As a potential *MCDA* algorithm (which appears to be the most appropriate, among methods used in analyzed multi-criteria models) for the new multi-criteria model, the *PROMETHEE* method is selected. The *PROMETHEE* method is presented as a three-step procedure focused on the aggregation of a performance table into weak order. The steps of the procedure are: 1. Preference modeling (creation of valuated preference relation for each criterion); 2. Aggregation (of previously created valued preference relations into one global preference relation), and 3. Exploitation (of the global preference relation to obtain a weak order, using a net flow procedure) [33].	
Weighting system	The relative importance of the different criteria is presented through the weights which are defined as non-negative numbers, independent from measurement units of the criteria. Using appropriate software (e.g. *PROMCALC* and *DECISION LAB*), the user can introduce arbitrary numbers for the weights involving the priorities and perceptions of the decision-maker. The weights are automatically normalized by dividing the entered numbers by their sum [32]. The weighting factors for the criteria related to the current standards and building and location characteristics (from a professional point of view) should be determined by the experts.	
Preference detection system	Using the approach *ordinal scale with a degree of preference* the decision maker can relate a "degree" of preference of one alternative over another with every pair of compared alternatives [33]. The difference between the evaluations obtained by two alternatives into preference degrees (from 0 to 1) is translated for each criterion. There are six basic types of preference functions proposed: 1. Usual criterion; 2. U-shape criterion; 3. V-shape criterion 4. Level criterion; 5. V-shape with indifference criterion, and 6. Gaussian criterion [31].	
Problem statement	The problem statement is defined as *sorting*. The norms, which are defined to determine each category, are modeled as prototypes of alternatives belonging to a category. These norms would result from conventions, interaction with the decision maker, and analysis of past decisions [33].	
	Part III: Form of the application of the multi-criteria model	
Potential form of application of the multi-criteria model	To enable using of the new multi-criteria model by different users, the software may be an adequate form of application. It should contain a checklist of criteria and sub-criteria, with the possibility to neglect some criteria and change weighting factors.	

[a] Presented criteria and indicators are the result of multi-criteria models analysis, but in this group, there should be more criteria and indicators which are the result of analysis of many other aspects, which are not the topic of this paper.

[b] Presented criteria and indicators are the result of multi-criteria models analysis, but in this group, there should be more criteria and indicators which are the result of analysis of many other aspects, which are not the topic of this paper.

[c] Note that a criteria building location is mentioned in both the general and specific criteria and indicators determined by the specific context, due to its importance for both criteria groups.

unique form of values is obtained. The applied method avoids translating qualitative into quantitative (which, earlier in the paper, was commented on as insufficiently objective), but it is likely that qualitative value translates into a quantitative range, thus quantitatively losing precision.

In the *PAAM* model, criteria and indicators are evaluated qualitatively with the values "very high", "high", "medium", "low" and "very low", but the final result is obtained by counting these values and adopting the most frequent or medium values, if the values are from different ends of the range for example, among the five indicators, there are three values of "very high", two values of "very low" and one value of "high", the final result will be "very high/high", because the two values of "very high" and two values of "very low" cancel each other [29]. This process of synthesizing qualitative results is, in fact, quantitative and nullifies the initial hierarchy among criteria, and indicators, because their qualitative values equally affect the result.

The principles of valorization in the new multi-criteria models should include both a quantitative and a qualitative scale, and depending on whether a unique result is needed, the translation of different types of values into the same type should be performed by using one of the *MCDA* methods. Given that Table 1, which refers to the criteria and indicators of the analyzed multi-criteria models, shows a significant impact on participants and their interests in the process of implementing some kind of adaptation, multi-criteria models need to be flexible in terms of the impact of certain criteria and indicators for the outcome of the assessment, because it can be expected that the triggers for the implementation of building adaptation are different. On the other hand, statistical data on the impact of certain criteria and indicators on the outcome of the assessment (the impact of the intervention on the facade concerning the financial feasibility of the process as a whole) are not subject to change, which leads us to the second group of criteria and indicators. The second group of criteria and indicators must be assigned a constant weight factor.

5.3. Application of the models

In Table 3 different applications of multi-criteria models are presented. All models contain lists of criteria and indicators that are, in some way, evaluated. The user fills in checklists, which are assumed to be part of the software (highlighted only for the *TOBUS* model), which, based on the explained procedures, evaluates the answers entered. The final results appear as a numerical value in the *Conversion meter* and *ARP* models, as descriptive, and qualitative in the *PAAM* model. In the *TOBUS* model, the final result is a proposal for one or more interventions, and in the *iconCUR* model, the final result is a diagram showing the distance of the observed building from the edges of the spatial model/intervention. The variable weighting factors of criteria and indicators in the *iconCUR* model allow the possibility of several results for the same building. It can be concluded that all analyzed models are relatively simple to apply.

5.4. Draft of the new model

To summarize the presented analysis, there is a proposal of the draft of the new multi-criteria model in Table 4. The following draft of the new multi-criteria model was created based on the analysis of five multi-criteria models. Through the analysis of five multi-criteria models, three main parts of their structure are considered: the criteria and indicators, valorization of the criteria and indicators including MCDA methods for evaluation, and forms of applying models. Therefore, the proposed structure of a new model is:

1. Part I: Criteria and indicators

In the first part of the draft of the new multi-criteria model, a list of criteria and indicators selected based on the analysis of the proposed models is presented. The list consists of criteria and indicators.

The assessment from all groups of criteria recognized in this paper (general criteria, specific criteria determined by the type of adaptation, and specific criteria that are a consequence of the specific context in which the multi-criteria model was developed and/or for which it is intended). To include the criteria from the third group, an analysis of the spatial context (Belgrade) is needed, so, in this paper, only the draft of the new model is presented. Since the draft of the new multi-criteria model only contains the criteria and indicators which are a result of the presented analysis, the final version of a new multi-criteria model should also include criteria and indicators which would be the result of other analyses which are not the topic of this paper, the eliminating character of some criteria analyzed would be the subject for further consideration;

2. Part II: Valorization

In the second part, the basic features of the valorization system of the new multi-criteria model are presented. Considering the methods which are used in valorization systems of the analyzed multi-criteria models, the PROMETHEE method, which is used in the iconCUR model, is seemed as the most suitable method for the valorization system of the new multi-criteria model. The PROMETHEE method is intended for a limited number of alternatives (the iconCUR model has a limited number of possible interventions (types of adaptation)), in contrast to the COPRAS method (the TOBUS model has a much larger number of combinations). The PROMETHEE represents an outranking method with a quite simple conception and application in comparison with the other methods for multi-criteria analysis and applies to practical multiple-criteria decision problems in many different fields [31]. Given that a certain level of personalization of the new multi-criteria model is desirable, the variability of weighting factors (which is introduced based on the iconCUR model) is required. In the PROMETHEE method, the priorities and perceptions of the decision-maker influence weighting factors [32], and the decision-maker can relate a "degree" of preference for one alternative over another [33]. Regarding, for example, the PCA method which does not allow variable weighting criteria, and at the same time, requires an extremely large number of buildings where this type of adaptation has already been implemented (the analysis for creating the PAAM model includes all adapted office buildings in the period from 1998 to 2008, which, in the case of Belgrade, where the number of converted office buildings in districts into hotels is limited, is not applicable), it may be concluded that this method may not be appropriate for the new multi-criteria model. Although in the new multi-criteria model, the variability of weighting factors is one of the ways to achieve personalization of the model and, therefore, the decision maker's influence is desirable, the weighting factors for some criteria (mostly, the criteria from the second group) should be determined by the experts.

3. When it comes to the application of a new model, software in which the user fills in a checklist, and, additionally, can personalize the multi-criteria model to a certain extent (e.g. by determination of weighting factors), seems like an adequate choice. Also, there are two *PROMETHEE* software packages (*PROMCALC* and *DECISION LAB*) that have been developed to facilitate the *PROMETHEE process*. The *DECISION LAB,* the current method of the *PROMETHEE* methods, may support the decision makers to improve the quality and reliability of the decision-making processes due to the structured procedure, computational help, and analytical aids [31].

6. Conclusion

Multi-criteria models can greatly help to decide whether to undertake building adaptation in contemporary architecture. Based on the research conducted in this paper, it can be concluded that, within previous research, models were formed as tools, on one hand, to select the most appropriate intervention to adapt a particular building (the *TOBUS* model, the *iconCUR* model), and on the other, to evaluate the potential of the facility for a particular type of intervention (the *Conversion meter* model, the *ARP* model, the *PAAM* model). The paper analyzes the criteria and indicators of these models, applied principles of valorization, and forms of application, to identify guidelines for creating a new multi-criteria model.

Three groups of criteria and indicators have been singled out: the first group includes criteria and indicators that can become an integral part of the new model (general criteria and indicators), and the second group contains criteria and indicators, some of which are potential components of the new model (specific criteria in relation to the type of intervention) and the third group of criteria and indicators whose application in the new model depends on the similarity of the context of the existing models and the new model (specific criteria in relation to the context). The criteria related to the location of the building, building characteristics, the energy consumption required to ensure user comfort, quality of interior space, financial feasibility of adaptation, market, and stakeholders are important for each model, regardless of the concept and context for which the model is intended. On the other hand, the possibility of extension is one of the indicators for assessing the flexibility of the building, but the fulfillment of these indicators is much more important for models that analyze the potential of the building for extensions as a type of adaptation (the *PAAM* model) compared to those models which analyzes the potential of the building for conversion (the *Conversion meter* model), given that, in the case of conversion, the existing capacity may be enough and the extension would not be financially feasible. Traffic infrastructure connection and distance of other contents can be considered as general indicators of location parameters, however, the defined distances in the second indicator are variable and will differ depending on the arrangement of the city in which the building is located and the difference is a consequence of the fact that functional zoning is more pronounced in some cities. It can be concluded that the specifics of criteria and indicators are the consequences of the type of intervention that would potentially be implemented, urban planning, and current regulations of the country in which the model originated. One part of one of the analyzed models has an eliminatory character. There is a conception that the new multi-criteria model would, also, include a set of criteria and indicators of an eliminatory character, to effectively eliminate buildings without the potential for adaptation (conversion), but that would be the subject of further research.

Considering the principle of valorization and the hierarchy between criteria and indicators, it was determined that the principle of valorization corresponding to the new multi-criteria model is based on quantitative and qualitative scales, with the use of the *MCDA* method to obtain a unique result and establish a hierarchy between criteria and indicators which will be, for a certain type of criteria and indicators, which demonstrate constant relation between criteria and the final result determined by the experts, and for another group, adaptable, allowing the decision makers to determine weighting factors of those criteria and indicators, by the specific case. Because the new multi-criteria model is intended for the assessment of the potential of the building for conversion, therefore, one type of adaptation, and it should enable variability of weighting factors of a certain type of criteria and indicators, among presented *MCDA* methods, the *PROMETHEE* method was chosen for the draft of the new model.

The analysis of the existing models indicated the probable type of application of a new model, which included software, in which the user fills out checklists, in which answers are evaluated, and the result can be numerical, descriptive, or graphical.

This research represents a significant platform for creating new multi-criteria models in the field of adaptation of the building fund with a greater degree of personalization, the application of which may significantly extend the period of use of adapted buildings. The flexibility of the platform enables research aimed toward the creation of a new model to easily adjust to local needs and conditions. Outcomes from this research related to the valorization systems may be valuable for application in related areas.

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All authors listed have significantly contributed to the development and the writing of this article.

Data availability statement

Data included in article/supplementary material/referenced in article.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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