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A structured managerial model for the decision making process for enhancing building sustainability in all life cycle phases

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Abstract

Nowadays the sustainability is one of the primary concerns worldwide, especially in the construction industry, taking into account that the buildings have a major impact on the overall energy use and greenhouse gases emissions. There are many studies focusing on particular aspects of the topic, but a holistic, interdisciplinary and long-term approach is needed in order to reconcile the competitive objectives. Starting from a literature research, the authors have formulated a decision making algorithm aiming to respond to professionals needs to apply a structured model in their daily activities. In the second part it is presented how this model can be applied, using a practical case-study – a building in the renovation phase, emphasizing how to optimize the project even when dealing with conflicting criteria.

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Keywords: sustainability; building; decision making alghoritm; life cycle; renovation

1. Introduction

During the last three decades the primary energy consumption and the CO2 emissions caused by the building sector have significantly grown reaching a share of more than one third worldwide (Molina-Solana, et al., 2017). In this context, immediate actions are required. One of the improvement directions sought by the European Union is refurbishment of the private buildings and enhancement of the appliances performance in buildings. Making decisions taking into account the sustainability principles is significant even from the early design phases, but also

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during the entire life cycle of a building. There is a need of using a structured managerial approach, oriented towards sustainable goals.

The present paper is aiming to propose a structured managerial model for the decision making process in case of buildings through their entire life cycle, seeking to get the most out of the sustainability principles. Based on the analysis of different approaches and tools found in the literature, the model shows a simplified step by step plan.

In the first part, the paper identifies and evaluates the existing instruments and tools by their scopes and area of applicability, suggesting the phases when they could be used by practitioners, in order to promote sustainability.

Next, the paper proposes a decision-making algorithm valid for the entire life cycle phases, aiming to assist decision makers in the process, taking into account more conflicting criteria and scenarios. For exemplification, a case study is presented, showing how the decision process is passed through all the phases of the model proposed. Finally, the findings and limitations are outlined, expressing some assumptions which could represent the starting point for new researches in an interdisciplinary field.

2. Background

Sustainability is defined from a time perspective, with reference to „future generations" (WCED, 1987), which in author's vision makes the life cycle approach unavoidable. Each life cycle stage has specific features in terms of applying the principles of sustainability.

The main sustainability principles are shown in the table below (Kibert, 2013):

Table 1. Sustainability principles after Kibert (2013).

Reduce resource consumption
Reuse of resources
Use of renewable resources
Protect nature
Eliminate toxicity
Lifecycle cost assessment
Focus on quality

Some authors (Blengini & Di Carlo, 2010; Bastos, Batterman, & Freire, 2014) consider only three phases of the life cycle (construction, use and demolition), but in this paper is considered relevant to break down the life cycle in five stages as follows: design, construction, operation, renovation and demolition or deconstruction. The life cycle phases and the defining elements of the decisional processes in each of them in relation to sustainability are further detailed.

2.1. Design phase

It is considered that the design phase has the greatest subsequent impact on the energy consumption of the building, as it's the moment when the building's defining elements are formulated, such as location, architecture, structure, building services, etc. (Tian, et al., 2015).

Architects and engineers need support tools to efficiently analyze the energy consumption of buildings in order to achieve sustainable development (Burdova & Vilcekova, 2015; Chen & Ng, 2015). Some popular energy simulation tools for buildings are: eQuest, EnergyPlus, HAP, HEED, TRNSYS. Crawley (2008) compares 20 of the energy simulation tools, concluding that at the present time there is no common language of the capabilities of these tools, and moreover, it is a question of certainty whether they provide correct information.

The most of the energy is consumed during the operating phase (80-90%), the production of materials represents a fraction of 10-20%, while the demolition impact is very low - around 1% (Jagtap & Dhawade, 2016; Ramesh, Prakash, & Shukla, 2010). However, rigorous selection of early-stage materials is essential to extend the life of the building, thus reducing possible future costs with renovation. The choice of materials must take into account their thermal and durability properties (Ramesh, Prakash, & Shukla, 2010), but also production and transport costs, reaching the most favorable option.

So, in the design phase occurs one of the most important decision-making processes with an impact on the building's sustainability, which can be divided into two sub-processes: design alternatives and material selection. The design criteria are the same as those of a construction project but should introduce a perspective of sustainability: energy consumption, indoor comfort, ecological materials, low costs, advanced technologies, healthy buildings.

2.2. Construction phase

The construction phase may be confused with the project management phase, which in this case must effectively and efficiently manage the application of the sustainability principles. The role of the project manager is seen as a central one, which can significantly influence the sustainable approach, and under the current society's needs a paradigm shift for the manager is required, assuming responsibility for achieving sustainable development (Silvius, et al., 2017).

Although the sustainability features may be embedded in the design specifications already from the design phase, their integration on the site is one of the challenges of the project manager, who must have knowledge in the field and the availability to drive in this direction.

A current topic is the change of the project management paradigm by reconfiguration of the project manager profession. Under today's increasingly demanding society for integrating sustainability into all aspects of life, the skills and competencies of a project manager must evolve in the same way. It must be able to lead to the application of sustainability principles throughout the project, while overcoming budget, time and quality constraints and ensuring safety and health on the site.

2.3. Operation phase

Usually, the performance of a building is influenced by a number of parameters: physical characteristics (surface, insulation), internal services and equipment, and external environment (climate, solar radiation, wind) (Picon, et al., 2013). In addition, a determinant role is played by the behaviour of the occupants and their activities ((Pachauri, 2004; Page, et al., 2008); Yu, et al., 2011). Their assessment is a complex process, very sensitive to social and cultural influences and to daily behavioural variations.

For the operation phase, one of the most common approaches is the energy assessment. Moreover, a clearer understanding of patterns of use allows building management to take action to conserve energy and implement advanced environmental technologies.

Building Information Modeling (BIM) is defined as a digital representation of the physical and functional characteristics of the building, providing a reliable basis for decision making (Volk, Stengel, & Schultmann, 2014). One of the benefits of using BIM is that it allows the use of multidisciplinary information in a unitary model, creating the opportunity for sustainability measures to be embedded in design (Jalaei & Jrade, 2015). The same idea is supported by Ahuja (2016), who sees BIM as a facilitator for green buildings.

2.4. Renovation phase

Building renovation is a good opportunity to streamline energy consumption in a building, and to implement measures for: efficient use of resources, indoor environment improvement, reduction of costs for operation and maintenance.

Some of the reasons for renovating a building include: the need to extend the life of the building, replacement of degraded components, space resize for new functions or improvement of the indoor environment. The renovation process may target only some building components, such as building envelope, ventilation and heating systems, lighting systems, or the introduction of alternative energy generation systems.

In order to initiate a refurbishment, an exhaustive investigation of all possible solutions is required, based on the following factors: the cost, the annual energy savings after renovation, the recovery time of the investment, the impact of materials used on human health, aesthetics, maintainability, functionality, comfort, sound insulation and durability (Kaklauskas, Zavadskas, & Raslanas, 2005). Though, in practice it is not feasible to perform a complete assessment, so the project objectives have to be established beforehand. The renovation implies several decision levels: meeting functional requirements, improving energy performance, cost optimization, reducing environmental impact and increasing occupant welfare (Chantrelle, et al., 2011).

To simultaneously respond to all these constraints, researchers in the field have tried to develop multi-criteria decision-making models and tools. Chantrelle et al. (2011) propose a tool for optimizing refurbishment operations, with emphasis on building envelope, heating and cooling systems and control strategies. De Larriva et al. (2014) address the theme of renovation through the provision of decision-support information based on lifecycle assessments and the level of comfort obtained. Decisional aspects of a refurbishment from a more complex qualitative and quantitative perspective could mean to integrate stakeholders' requirements into a design team's analysis process and then to confront themd with the results of computerized optimization (Shao, Geyer, & Lang, 2014). Human dimension is a key factor for the decision (Kim & Todorovic, 2013; Wells, et al., 2015). Multi-criteria optimization models could be used to improve the energy efficiency, considering as many alternatives as possible (Diakaki, Grigoroudis, & Kolokotsa, 2008; Asadi, et al., 2012; Antipova, et al., 2014; Wang, Xia, & Zhang, 2014).

The authors' conclusion is that the decision-making process based on multi-criteria optimizations often focuses on particular aspects rather than on the overall picture of the problem. Furthermore, in reality the energy issue is more difficult to model than the simulation techniques can capture it.

2.5. End of life phase

The last phase of a building's life cycle is the deconstruction or demolition phase (also known as end of life), which is often neglected by studies, especially since its impact on the environment is much lower compared to other phases.

It is opportune to distinguish between deconstruction and demolition. Deconstruction is the dismantling of a structure in the reverse order of how it was constructed, the subsequent completions being all removed, and the materials being dismantled in reverse order (Guy, 2000). Demolition is the mechanical destruction of the construction and its transformation into waste after all previously hazardous materials have been removed. Deconstruction is a more environmentally friendly alternative than mechanical demolition, yet requires more expertise and effort. The deconstruction phase may include the following sub-phases (Silvestre, de Brito, & Pinheiro, 2014):

- Deconstruction, dismantling, demolition, including an initial sorting of elements;
- Transport of the dismantled items as part of the recycling process (at the recycling point) or the shipment of the waste (at the final disposal destination);
- Waste processing (collection of waste resulting from deconstruction, processing of residues resulting from the processing of elements for re-use, recycling);
- Waste elimination, including physical pre-treatment and storage management (Silvestre, de Brito, & Pinheiro, 2014).

Consequently, the impact of building materials after the building's lifetime requires a detailed analysis, on a case-by-case basis, considering options (re-use, recycling) in a lifecycle approach. Obviously, the economic component cannot be excluded from the analysis, being the one that will considerably influence decision-makers in choosing the optimal solution.

3. Model proposal

As sustainability is nowadays an imperative target for construction projects, sustainability criteria have to be integrated in the decision making process. But, this process involves more perspectives with competing requirements; hence, it is crucial to develop practical tools which can consider multiple criteria and evaluation of alternatives having in mind the sustainable needs.

The present paper proposes a decision making model applicable in all stages of the building’s life cycle, aiming to support the professionals to reach the optimal solution for their construction projects.

3.1. Decision algorithm

The process of decision making involves 6 main steps: problem definition, information, alternatives identification and criteria selection, simulation, alternatives evaluation and final decision, some of which are divided into sub-processes, as shown in Figure 1.

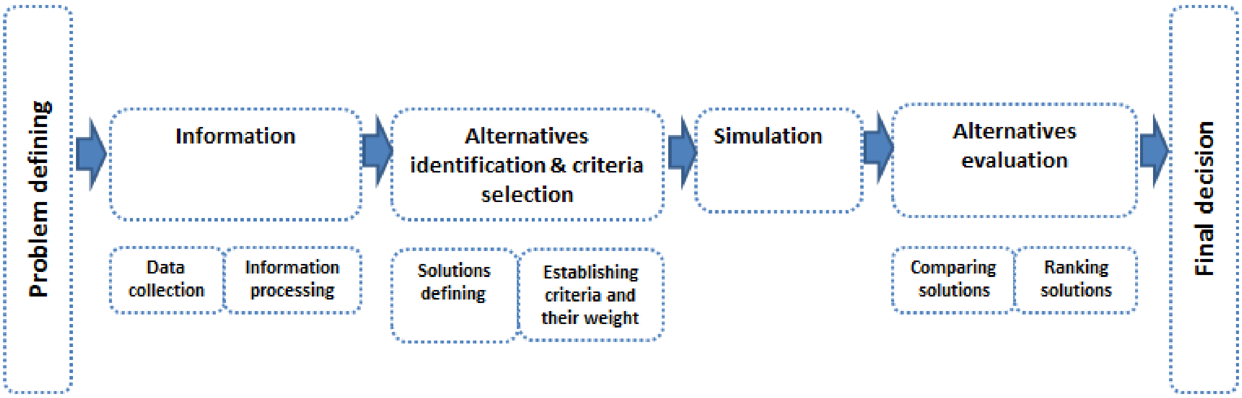

Fig. 1. Decision algorithm.

This algorithm is a structured approach for all type of construction projects found in any phase of their life cycle, seeking to achieve an organized way of including the sustainability principles. Its application could generate benefits for the evaluations processes, reducing the risk of deciding based on bias and previous experiences of the professionals involved in the project.

3.2. Decision algorithm steps

As in any decisional process, the initial step is to identify the general problem, the sub-problems and to establish the objectives, which in this case will include also the implementation of sustainability principles besides stakeholders' requirements.

As first part of the information process, the data collection refers to gathering the necessary information from all stakeholders, and related to sustainability which can be: information on the environment and climate, data on the position of the sun and air currents, regulations in the field, producers and suppliers of building materials, the costs of different construction materials, heating system options, indoor environment control technologies, and so on. In addition to technical data collected, it is necessary to write down information regarding the economic limitations and occupants of the building (information on functionalities and the comfort level of the indoor environment).

In the next step, the specialists analyse the information collected and process them to formulate clear requirements concerning the building components.

Next, the identified requirements are filtered through the sustainability perspective and the alternatives for each sub-problem are defined, establishing their evaluation way (qualitatively, quantitatively).

Further, a significant step in the decision-making process is establishing the selection criteria and the assignment of a weight to each of them according to importance, fixing an acceptance threshold. This approach is based on the qualitative reflections of the involved specialists and other stakeholders (beneficiaries, partners).

The alternative simulation stage refers to the application of energy simulation tools, lighting simulations, modelling the building behaviour or applying a sensitivity analysis (evaluation of financial and economic performance indicators: return of investment rate, net present value). Simulation and feasibility assessment should be done by considering the life cycle of the building, not just the present moment.

The results from the previous stage are compared to each other based on common or reference criteria. The comparison will lead to a hierarchy of solutions, which will once again be evaluated by specialists to ensure the overall purpose of the project is met.

The last phase of the proposed algorithm represents the actual decision, through an optimization process, considering the options and rankings identified. Usually, there should be applied a multicriterial instrument whose complexity depends on the requirements formulated in the initial phase.

During the entire process, the knowledge of specialists involved is essential for achieving most appropriate outcomes.

3.3. Briefing of tools

To support the decision making process, field professionals have developed a variety of tools which may prove useful in different stages of the decisional process. A few of them are listed in the table below:

Table 2. Tools used in each step of the decision process.

	Information		Alternatives identification and criteria selection		Simulation	Alternatives evaluation		Final decision
Problem defining	Data collection	Information processing	Defining solutions	Establishing criteria and their weight		Comparing alternatives	Ranking alternatives	
Specialists & stakeholders' evaluation	ABK LEKOS (Kovacic & Zoller, 2015)	Microsoft Excel	Specialists evaluation	AHP (Saaty R. , 1987)	IMPACT (Azzouz et al., 2017)	LCC -DGNB/BNB (Kovacic & Zoller, 2015)	AHP (Saaty R. , 1987)	Specialists evaluation
	Questionnaire	BIM (Gerrish, et al., 2017)	BIM-DIT (Ahmad, Aibinu, & Thaheem, 2017)	QFD	ECOTECT 12 (Anand, Deb, & Alur, 2017)	ABK LEKOS (Kovacic & Zoller, 2015)	CBA (Mossman, 2013)	
	BAPS (Coma & Jones, 2015)	RENO-EVALUE (Jensen & Maslesa, 2015)		FWH-TS (Abdul-Rahman, et al., 2016)	mkSchedule (Bustamante, et al., 2017)	LEGEP (Kovacic & Zoller, 2015)	TOPSIS (Govindan, Shankar, & Kannan, 2016)	
	IMPVP (Ginestet, Marchio, & Morisot, 2013)	HBIM (Khodeir, Aly, & Tarek, 2016)		ANP (Saaty T. , 1996)	MultiOpt (Chantrelle, et al., 2011)	KBDSS-QFD (Singhaputtangkul, et al., 2013)	Pair comparison	
				Fuzzy method (Bansal, Biswas, & Singh, 2017)	TRNSYS (Gustafsson, et al., 2017)			

Firstly, it would be necessary to mention that some phases of this algorithm cannot be supported by actual tools, but only by the human judgement. Clearly, the initial and the final stages are dedicated to the stakeholders and specialists assessment, as they are decisive factors of decision making. Further, for the process of collecting data, both raw data regarding the project and the possible technical solutions are undertaken by the specialists who gather relevant information from their close environment, but in these phases they can appeal to certain evaluation tools (ABK LEKOS, BAPS, IMPVP).

Some of the tools identified are easily to use methods which structure the information and offer the possibility for a better overview on the problem stated (AHP, ANP or QFD), while others require more technical knowledge (TRNSYS, mkSchedule) and therefore are more difficult to be used in practice. Other tools are developed in order to answer specific aspects of a construction project: ECOTECT takes into consideration the thermal comfort of the occupants (Anand, Deb, & Alur, 2017), mkSchedule provides simultaneous thermal and lighting simulations (Bustamante, et al., 2017), BAPS tool analyse the renewable energy and battery storage potential (Coma & Jones, 2015). As designing process requires also a human judgement, studies focalizing on integrating all stakeholders' requirements like RENO-EVALUE are very useful in practice (Jensen & Maslesa, 2015).

Currently, sustainability became an imperative target for development; hence sustainable principles have to be a component of refurbishment projects today and in the near future. However, financial resources and time are often limited, so choosing an appropriate method for decision-making could bring benefits for a sustainable development.

4. Application

The authors have proposed a practical case study in order to test the applicability of the algorithm, for which all the above mentioned stages were exemplified. The example chosen is a building located in Cluj-Napoca, Romania in a university campus - a student dorm, which needs renovation works.

Firstly, it was stated the situation and the problem, followed by defining the objectives. The targeted building is found in the renovation phase of the life cycle, while the general objective is the restoration of the building facade to increase thermal comfort and to reduce the energy consumption. The secondary objectives established are: to answer occupants needs of comfort, to improve natural lighting use, to improve sound insulation, to offer an esthetic appearance, to perform the renovation works within 3 months.

After the building assessment, there were some issues detected:

- degradation of extended areas of the exterior walls;
- overheating in rooms located on the south side;
- complaints about windows' isolation resulting in infiltration and air currents;
- possibility to locally control the heating;
- no ventilation system in place.

In the next stage, a project team consisting of 3 construction professionals and 2 university representatives, collected relevant information for the project: technical data about the building – physical and functional, occupants needs, environment data (location, climate, sunlight), site data. By mean of some working groups, the team processed the data gathered, in order to formulate some clear requirements for the project, which were sent to three external construction companies in order to receive offers. A total of 6 offers were obtained: company A sent 2 offers, company B sent 1 offer and company C sent 3 offers.

Before assessing the offers received, the team has established the criteria for evaluation:

- price
- durability
- thermal transmission coefficient
- air sound insulation
- payback period
- occupants' comfort
- warranty
- work duration
- energy use reduction
- recyclability of materials
- health of building
- aesthetics

and for defining their weightage, it was applied the AHP to the above criteria identified:

Table 3. AHP application.

	price	durability	thermal transmission	air sound insulation	payback period	occupants' comfort	warranty	work duration	energy use reduction	recyclability	health of building	aesthetics	average daylight	TOTAL SCORE	WEIGHTAGE
price	1.00	3.00	5.00	9.00	5.00	9.00	7.00	5.00	5.00	7.00	9.00	9.00	9.00	83.00	0.17
durability	0.33	1.00	5.00	9.00	1.00	7.00	7.00	3.00	3.00	7.00	9.00	9.00	9.00	70.33	0.14
thermal transmission	0.20	0.20	1.00	7.00	0.20	7.00	3.00	0.14	1.00	9.00	9.00	9.00	9.00	55.74	0.11
air sound insulation	0.11	0.11	0.14	1.00	0.14	3.00	0.14	0.11	0.11	7.00	7.00	9.00	5.00	32.87	0.07
payback period	0.20	1.00	5.00	7.00	1.00	9.00	5.00	0.14	0.33	7.00	9.00	9.00	7.00	60.68	0.12
occupants' comfort	0.11	0.14	0.14	0.33	0.11	1.00	0.14	0.11	0.14	3.00	7.00	1.00	1.00	14.24	-
warranty	0.14	0.14	0.33	7.00	0.20	7.00	1.00	0.20	0.20	7.00	9.00	9.00	7.00	48.22	0.10
work duration	0.20	0.33	7.00	9.00	7.00	9.00	5.00	1.00	3.00	9.00	9.00	9.00	9.00	77.53	0.16
energy use reduction	0.20	0.33	1.00	9.00	3.00	7.00	5.00	0.33	1.00	7.00	9.00	9.00	7.00	58.87	0.12
recyclability	0.14	0.14	0.11	0.14	0.14	0.33	0.14	0.11	0.14	1.00	9.00	7.00	3.00	21.41	-
health of building	0.11	0.11	0.11	0.14	0.11	0.14	0.11	0.11	0.11	0.11	1.00	5.00	0.20	7.37	-
aesthetics	0.11	0.11	0.11	0.11	0.11	1.00	0.11	0.11	0.11	0.14	0.20	1.00	0.20	3.43	-
average daylight	0.11	0.11	0.11	0.20	0.14	1.00	0.14	0.11	0.14	0.33	5.00	5.00	1.00	13.41	-
														487.24	

For the purpose of a quicker assessment, the last five criteria were ignored, their weightage being negligible.

Due to lack of time and material resources, the simulation stage was skipped, so next step in the process was the evaluation of the final three alternatives selected.

For ranking the solutions provided by the construction companies, it was used the pair comparison where to each solution a score from 1 to 3 was assigned, where 1 – means the best result and 3 – the worse; it may happen that two options receive the same score, meaning that they were placed on the same position by the specialists. The final score takes into account the weightages previously determined.

Table 4. Pair comparison table.

	price	durability	thermal transmission	air sound insulation	payback period	warranty	work duration	energy use reduction	TOTAL SCORE
	0.17	0.14	0.11	0.07	0.12	0.10	0.16	0.12	
Solution 1	1	1	2	1	3	2	2	1	**1.62**
Solution 2	2	1	1	2	2	2	1	2	**1.58**
Solution 3	3	2	3	2	1	1	3	3	**2.34**

The assessment was performed by the project team, major input coming from the three construction professionals involved in the decision process. As it can be seen the final results filtered by the established set of criteria may be surprising compared to a simple evaluation taking into consideration the main objective – the price. It came out that although the price criterion is better fulfilled by the solution 1, the solution 2 brings more benefits to the project, so it is the final choice. Due to the fact that the difference is very small between the two options, the project team posed the question if they should not choose the solution 1 instead, based on the smallest price. Though, the time constraints imposed the solution 2 as final option.

So, this method facilitates a more objective assessment of the alternatives, based on technical criteria. Though, it presents some limitations, one of them being the subjective perspective of the professionals, which interferes in each phase of the process. Moreover, it can be constraint by the lack of knowledge related to the available tools and their application. Usually, the choice of the tool is based on their availability, price and specialist's skills.

Besides that, it has to be mentioned that this is a simplified model, which might not take into considerations all the particularities of a project, and uncertainty may occur in real life.

5. Conclusions

A very first important assumption is to recognize that the sustainability achievement in buildings domain is no longer a technical "privilege", but it is more a managerial problem. A main responsibility represents the decision making process, which always poses challenges due to opposing needs from different dimensions and which seems to be more and more complex. There are available integrative and specific tools aiming to support the entire process or just limited parts, but it has been observed a lack of a holistic systematic thinking approach. To overcome the increased environmental demands and in the same time the social and economic ones, the professionals should shift their standpoint towards an interdisciplinary perspective, focusing on the whole picture. Decision should not be taken by one single person, but by a group of specialists (in different areas) which can bring valuable inputs.

The practical algorithm proposed by this paper introduces a structural approach for the decision-making process, which can consider conflicting criteria simultaneously. It aims to be used in all the phases of the life cycle irrespective of the project goals. Future development of it could include automation or embedding assistive tools in the general framework.

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