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Research paper

Expert studies on the impact of risk on the life cycle costs of buildings

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Abstract: The main goal of the studies was to collect information on the impact of the identified risk factors on the amount of costs incurred in the life cycle of buildings. The own studies were focused especially on residential and non-residential buildings. The studies consisted in obtaining expert opinions on the subject of the research involves in the non-random (arbitrary) selection of a sample of respondents from among specialists corresponding to the industry purpose of the studies and the research material. The research used the expert questionnaire method. The studies were divided into three stages. In the first stage, the identification and division of risk factors in the life cycle of buildings was performed. Then, experts assessed 45 selected risk factors that may affect the amount of costs incurred in the life cycle of buildings. In the last step, the research results were developed in the form of a checklist knowledge base, containing information about the potential impact of the identified risk factors in the life cycle of buildings on the amount of the corresponding components of life cycle costs.

Keywords: life cycle, life cycle costs, risk, risk identification, risk quantification, risk management

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1. Introduction

Risk management in construction may be described and analysed or assessed in the perspective of risk management of construction projects or risk management of construction companies. As noted in the publications [1, 2], the risks inherent in construction projects are addressed not only at the initial stage of project programming and design, but also during project execution. The works cited here also indicate that the economic efficiency of construction projects is highly correlated and dependent on the risk management approach adopted. The hypothesis proposed by the authors of the above-mentioned works may therefore also be correct in the case of the entire life cycle of construction projects.

This paper explains the concepts of risk and risk management of construction projects (sections 2.1 and 2.2). It also discusses groups of methods that can be used in risk identification, quantification and response processes (section 2.3). In the part of the paper concerning own research on the influence of risk factors on the amount of life cycle costs of buildings, (sections 3 and 4), the authors identified and categorised risk factors in the life cycle of buildings. They also presented the results of expert assessment of risk factors that may influence the amount of life cycle costs of buildings.

The main objective of the paper is to gather information on the impact of the identified risk factors on the amount of costs incurred in the life cycle of buildings based on the results of own research which the authors performed between 2017 and 2020 in Poland. The research focused on residential and non-residential buildings, as well as those intended for multiple uses (for example, where a residential building is to house office and service space at the same time). The final result of the research is the development of the obtained results in the form of a checklist knowledge base, which will contain information on the potential impact of the identified risk factors in the life cycle of buildings on the amount of the corresponding life cycle cost components.

2. Risk in construction – a literature overview

2.1. Definition of risk in construction

Risk in the construction industry is often discussed in relation to construction projects with focus on the possibility of exceeding the agreed contractual deadlines and implementation costs [3, 4]. There are many definitions of risk in the literature. The authors of numerous publications that deal with risk in construction define it as:

– a situation where specific random events may occur with known probability and give rise to specific consequences [5];
– the product of the probability of an event taking place and the impact of that event occurring [6];
– probability of an adverse event occurring during project execution multiplied by the consequence (effect) of its occurrence [7];
– the probability of an adverse event occurring in the project [8];

– the likelihood of unforeseeable and undesirable events occurring, which, if they occur, may affect the viability of a given undertaking [9].

Sometimes the concepts of risk and uncertainty are treated either identically or interchangeably in publications, which is a mistake. This important aspect is emphasized by, for example: [5,6] and ISO standard 15686-5:2017 Buildings and constructed assets – Service life planning – Part 5: Life-cycle costing [10]. Knight [5] proposes that risk should be distinguished as the so-called measurable uncertainty, that is a case for which the probability distribution of the consequences of an event is known. If, on the other hand, the possibility of certain events is anticipated but the probability of their occurrence is unknown or cannot be determined (for example, due to a lack of statistical data), such a situation, according to the author, should be considered as uncertainty. An analogous approach to risk as a measurable uncertainty is presented in ISO 15686-5:2017 [10].

Among the definitions of risk mentioned above, it is possible to identify those according to which risk:

– involves a negative effect, that is damage, loss, disadvantage or hazard; these definitions are taken from the works of [7–9]);
– is neutral, which means that there is no clear indication that the risk can only have a negative effect; these definitions are proposed in [5,6]).

As the literature review shows, it is difficult to provide a definition of risk that would clearly state that risk can have a positive effect, namely, translate (despite its occurrence) into an advantage or additional (equivalent) profit.

2.2. Definition of risk management of construction projects

Risk management of construction projects is also defined in a variety of ways. The authors of the following publications define the term risk management as:

– the process of effectively controlling all procedures in each phase of the project, which may be affected by different risk factors [1];
– a procedure involving three basic links, that is the identification and quantification of risk factors and responses to risks [3];
– the process of identifying, assessing, minimising and monitoring (controlling) risk in order to mitigate the consequences of adverse events and the spill-over of risks to other parties or to other phases of the construction project [9, 10, 12, 13];
– a process consisting of four distinct steps, which include risk classification, risk identification, risk assessment and risk response [14];
– a process consisting of assessing the riskiness of a project, planning a risk management strategy, and monitoring it [15].

2.3. Methods of identification, quantification and response to risk

The risk identification process consists of the compilation of all risks that may occur during the execution of a construction project [12]. As a rule, risk factors are also classified at this stage according to their nature (category) or the phase of the life cycle in which they are expected to occur. The methods that are commonly used in the procedure for identifying risks in construction projects are summarised in Table 1.

Table 1. Methods commonly used in the risk identification procedure in construction projects (own study based on [13, 15–18])

Method	Method description (specification)
network analysis	based on the methods of two- and one-point diagrams, which graphically and analytically illustrates the logical relationships between all tasks or groups of activities in a construction project
expert survey	consisting of formulating questions asked once to experts focused on a given type of construction project, from whom information is obtained on the risks and possible threats in the situation of its occurrence
case-based reasoning	based on data from archived documentation for similar, previously implemented construction projects, which are analysed to find convergence with the processes, solutions used, analyses performed, and results achieved, as well as results obtained during monitoring (controlling) activities
data mining	involving a detailed analysis of documentation (including technical and cost documentation) and literature sources that are related to the implementation of similar construction projects
specialist (expert) recognition using the Crawford method	involving a process of asking the same questions ten times to experts, who each time present their opinion on the formulated problem anonymously and in writing, which leads to the acquisition of a very large amount of information about the risks that may occur in the project
specialist (expert) diagnosis with the use of the Delphi technique	consisting in the survey of opinions of a group of experts on a given subject, which leads, for example, to the identification of risk factors, while the survey is performed at least twice

In contrast, the main objective of risk quantification is the detailed analysis of each identified risk factor, which leads to its quantitative description through a numerical value [18]. Thus, it becomes possible to determine the degree of influence of a risk factor on a construction project in terms of, for example, a delay in the forecast time of its execution or exceeding the assumed budget. Methods commonly used to quantify risk are outlined in Table 2.

Considering the definitions of risk management in construction specified in [26, 27], which are presented in section 2.2, the final stage of risk management is the risk response process, which is a proposal for the adoption of a strategy for reducing the risks of a construction project. In this stage, it is necessary to identify measures that will minimise the consequences of adverse events in terms of the successful implementation of the construction project. Approaches suitable for the risk response procedure are summarised in Table 3.

Table 2. Methods commonly used to quantify the risk of construction projects
(own study based on [19–25])

Method / Approach	Method / Approach description (specification)
sensitivity analyses	examine the degree of sensitivity of a construction project to changes in the values of the input variables to determine the impact of individual variables in the context of the success of the construction project
probability and probability calculus	including operations on normal distributions, likelihood ratios of individual quantities, variances, standard deviations, and coefficients of variation, which make it possible to determine the magnitude and distribution of the deviations of a parameter from its initial level, due to various risk factors
computer simulations for risk	make it possible to study the effects of multiple simultaneous risk factors on the results achieved for a construction project
fuzzy logic	this group of methods consists of the fuzzy set theory and the so-called possibility distributions; it is used to model phenomena vaguely defined in nature; using a defined conceptual apparatus resulting from the fuzzy set theory, it is possible to formally describe linguistic variables in the form of measurable values
artificial neural networks	provide very accurate outputs but are characterised by complex mathematical computations and an extensive input database structure
decision trees	are one of the most frequently used techniques due to the simplicity and readability of the algorithm for analysing decision options and their consequences
bayesian networks	using a theorem linking the conditional probabilities of two mutually contingent events, allowing an accurate assessment of the impact of risk factors, while being computationally robust and characterised by low nature and degree of uncertainty in the results of the analysis

Table 3. Approaches commonly used to respond to risk in the management of construction projects
(own study based on [26, 27])

Approach	Approach description (specification)
risk transfer	understood as the direct transfer of costs (in the form of a potential loss) associated with the risk incurred to another construction project participant, a contracting party or an insurer
elimination of risks	elimination (or reduction) of risks through early alterations, such as those applied to the planned organisation of construction work
risk avoidance	that is not using solutions that may generate losses
risk absorption	the conscious assumption of, for example, financial responsibility by an entity towards which a threat has been identified and quantified

Table 1, Table 2 and Table 3 describe the methods that are used for each of the processes (stages) of construction project risk management. As the authors of [16], note, there is, however, a group of methods related to the process of risk identification in construction projects itself, which may also have a subordinate use in other risk management planning processes. These are expert methods, the use of which for the identification of risk factors is of primary application. Expert surveys and the Delphi technique can provide a sufficiently large amount of risk data that can also be used for the other processes that make up the risk management procedure, that is quantification and planning of the risk response.

3. Own studies of the impact of risk on the amount of the life cycle costs of buildings

The main objective of the own research was to gather information on the impact of the identified risk factors on the amount of costs incurred during the life cycle of buildings. The authors conducted the research between 2017 and 2020 in Poland. The own research focused especially on residential and non-residential buildings, as well as buildings intended for multiple purposes (for example, when a residential building shares both an office and service space). The research had the character of a purposeful sample, which in studies connected with obtaining expert opinions about the research consists in non-random (arbitrary) selection of the sample of respondents from among specialists connected with the industry-related research objective and the research material.

The research was divided into the following three phases:
1) identification and distribution of risk factors in the building life cycle;
2) expert assessment of risk factors that may influence the amount of building life cycle costs;
3) development of the results in the form of a checklist knowledge base containing information on the potential impact of the identified risk factors in the building life cycle of on the amount of the corresponding life cycle cost components.

Figure 1 presents the individual stages of the authors' own research. In particular, the sources of information on risk factors and the possibility of using the research results in

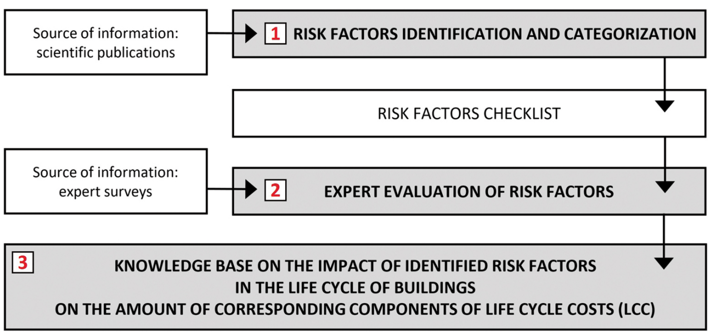


Fig. 1. Scheme presenting the stages of own studies

the constructed module of fuzzy risk assessment in the building life cycle are indicated. It will be possible to use the results obtained about the potential impact of the risk factors occurring as information about one of the two input variables (the effect of the occurrence of a given adverse event), necessary for the fuzzy inference model about the impact of risk on the size of the building life cycle costs, which has been described in the previous authors' publications [28].

3.1. Identification and division of risk factors in the life cycle of buildings

The first stage of the own research involved the identification and breakdown of risk factors in the life cycle of buildings. The primary method used to identify the risk factors was data mining. The authors reviewed and analysed the literature on risk in construction projects involving implementation, operation and decommissioning of residential, non-residential, commercial, and multi-purpose buildings. This stage of the research made it possible to select a list of 45 risk factors, which were then subjected to an expert assessment of their impact on the life cycle costs of buildings.

All the identified risk factors were subjected to a process of classification. The following divisions were adopted as the basic classification criteria:

– due to the entity involved in the construction project that may be responsible for the risk;
– due to the category (nature) of risk;
– due to their occurrence in one or more phases of the building life cycle.

For construction projects involving the construction of buildings (residential, non-residential, service and mixed-use) and their subsequent operation until decom-missioning, risk factors can be generated by the entities associated with a construction project at each stage of its life cycle. As the authors of [9] note, risk can affect all participants involved in a construction project. These include:

– the investor, understood as the entity in whose name the construction project is performed, but also as the user of the building who is responsible for its maintenance in the operation phase;
– the designer;
– building contractor.

Each of the identified risk factors was assigned one of the natures (categories) of its impact, which are presented in Table 4.

Risk factors can also be identified in the subsequent phases of the building life cycle, i.e. programming (planning), implementation, operation and decommissioning. Therefore, Table 5 provides a breakdown of the risk factors identified by the authors, both in terms of the construction project participants involved and the phase of the building life cycle in which they may occur. Moreover, Table 5 presents risk factors with only two selected natures (categories) of impact, that is technological and legal risk (factors 1 to 9 and 43 to 45, respectively).

Table 4. Categories of risk in the life cycle of residential, non-residential, service and mixed-use buildings (own study based on [29–31])

Risk category	Risk description (specification)
technological	risks associated with the inappropriate adoption of material, construction and technological solutions at the design stage of a construction project or the execution of construction work using inadequate human labour or equipment resources
construction	risks resulting from the execution of works or accompanying construction processes in specific external conditions
financial	risks relating to the internal financial affairs of construction companies or relating to patterns observed in the financial market or the economy
political	risk meaning dependence on government action
ecological	risks relating to environmental issues
legal	risks related directly to legal acts and the procedure of administrative decisions (e.g., on location or building permits)

Table 5. Division of risk factors according to the nature (category) of the impact, the entity in-volved and the phases of the life cycle (own study based on [29])

Id.	Risk factor	Entity[1]			Life cycle phase[2]			
		In	Des	Con	PP	IP	OP	WP
	TECHNOLOGICAL RISK							
1	design faults		X		X			
2	shortcomings in designs		X		X			
3	non-compliance of designs with applicable standards and/or regulations		X		X			
4	erroneously identified ground conditions		X		X			
5	erroneous assumptions of construction and material solutions		X		X			
6	unavailability of suitably qualified staff		X	X	X	X	X	
7	variable labor productivity of construction workers			X		X	X	
8	poor quality of construction equipment			X		X	X	
9	exposure of construction equipment to failures			X		X	X	
	LEGAL RISK							
43	difficulties in obtaining permits	X	X		X			X
44	non-compliance with legal acts	X	X	X	X	X	X	X
45	discrepancies in documentation		X		X	X	X	X

[1] In – investor and/or user, Des – designer, Con – contractor.

[2] PP – programming phase, IP – implementation (construction) phase, OP – operation phase, WP – withdrawal phase.

3.2. Description of studies related to expert assessment of risk factors

The second part of the own research consisted of assessing the identified 45 risk factors using the opinions of experts with theoretical knowledge and practical experience in construction projects of different types, nature, and complexity. The research was conducted over a nearly three-year period between 2017 and 2020.

The expert survey method was used to perform this part of the research. Since the research questionnaire was addressed to experts involved in the implementation of construction projects of different types, nature and degree of complexity, a variant of formulating questions using the expression "life cycle of a construction object" was allowed. Polish Classification of Building Objects (PCBO) [32] defines both the term "building facility" (as a structure permanently connected to the ground, made of construction materials and components, and resulting from construction work) and the term "building" (as a roofed construction including built-in installations and technical equipment, used for permanent occupation, and adapted to the accommodation of people, animals or the protection of objects). Thus, the term building is included in the term building facility and, on this basis, it was decided to extend the survey material to building facilities in order to avoid the return of unfilled survey questionnaires in case the expert did not have theoretical or practical experience due to the lack of building projects involving of buildings.

The selection of respondents corresponded to the research assumptions of a purposive sample. A group of specialists related to the aim and subject of the research, i.e., to the issues of life-cycle costs of buildings and risks affecting buildings in the various phases of their life cycle, was selected. Efforts were made to ensure that the group of respondents related to the performance of scientific research activities was roughly equal to the group of interviewees performing work in construction companies.

The research questionnaire was divided into the following two parts:
1) identification of expert areas of activity;
2) examining the impact of risk on the life-cycle costs of buildings.

A total of 32 respondents took part in the research, although the research questionnaire was originally addressed to 36 experts (including 17 research staff and 19 employees of construction companies). The return of the questionnaires given to the experts was approximately 89%.

At this point, the following two assumptions of the authors of the study need to be clarified. Firstly, the identification of the experts' fields of activity (including the need to specify the type of buildings and construction works) was planned only for those respondents who indicated one or more answer options in the first question, with the exception of option "c" (researcher related to the field of technical sciences: construction). This assumption was based on the fact that, in the case of academics, the research questionnaire was addressed exclusively to Polish scholars who deal with risk management and cost management of construction projects on a daily basis in their scientific work.

Secondly, given that to assess risks, it is necessary to provide information not only on the effect of the identified risk factor, but also on the extent of its probability, it would also be necessary to perform a study on the magnitude of the probability of each identified risk factor occurring during the life cycle of buildings. An attempt to quantify probabilities for risk factors using expert knowledge was consciously abandoned, because, in the opinion of the authors of the study, risks can nevertheless be individual (unique). A given risk factor may occur multiple times, once or not at all. If a given risk factor does not occur or occurs only once (possibly more than once), the expert assessing its impact on the life cycle costs of a construction project will be able to determine the probability of the risk occurring, stating (based on his/her own experience in similar construction projects) that, for example, the probability will be:

- 0 – because the risk has never occurred;
- 1 – because the risk occurred in 100% of the construction projects implemented by the expert;
- 0.4 – because the risk occurred in 40% of the construction projects implemented with the involvement of an expert.

4. Results analysis and discussion

4.1. Identification of areas of expert activity

Bearing in mind that the research questionnaire was addressed to experts who are both academics and experts working in construction companies, a full analysis of the collected results was made taking into account the division of specialists into the following groups:

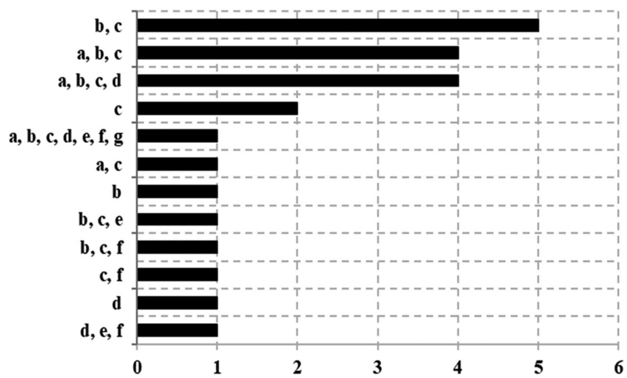
- I – academics;
- II – academics who also work in construction companies;
- III – employees working exclusively for construction companies.

In question one: “what is the nature of your connection to the construction industry”, 17 experts marked the answer variant “c” – researcher related to the field of technical sciences construction. However, 8 of them belong to the second group of specialists, who also work in construction companies. On the other hand, a few experts indicated the nature of the relationship as different (answer variant “f”). The following functions were listed for 8 questionnaires:

- f_1 – court expert (1 indication);
- f_2 – investor’s supervisor (4 appointments);
- f_3 – cost estimator (2 indications);
- f_4 – quality control specialist (1 indication).

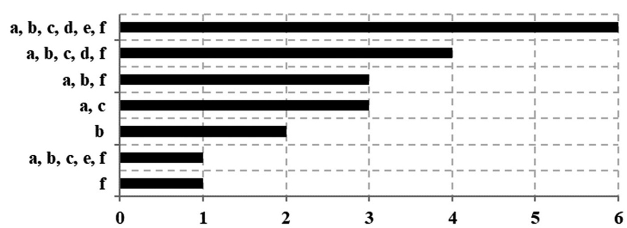
In the second question: “which type of building facilities do you deal with in your professional work”, 2 experts marked answer options only from the range “d” to “f”, which means that their experience comes down to the implementation of construction projects unrelated to volume construction. One respondent also indicated that in their work they had dealt with every type of building listed as response options for question two (from “a” to “f”) and additionally with listed buildings which were categorised under response option “g” (as other). Figure 2 presents all combinations of answers obtained from the 23 experts who were required to provide information on the types of building structures they had dealt with in their professional work. The second question was not answered by 9 respondents, who in the first question marked only answer variant “c” (indication of a research worker, related to the field of technical sciences: construction).

The third question: “what type of construction work do you deal with in your professional work” was of a subsidiary nature and supplemented the information on the implementation (execution) nature of the construction projects in which the experts participated. This question was answered by 20 experts. Excluded from having to pro-vide information on types of construction work were academics and architects and/or designers, namely those respondents who marked only answer options “a” and/or “c”. Figure 3 shows the profile of responses to question three. None of the respondents in-dicated a type of construction work other than those listed in response options “a” to “f”.



a. single-family residential buildings; **b.** volume multi-family residential buildings and collective residential buildings; **c.** volume non-residential buildings (commercial, office, cultural buildings, hospitals, schools, agricultural buildings, etc.); **d.** civil engineering works related to traffic engineering (roads, railways, airports, bridges, viaducts, tunnels, culverts, earthworks, hydrotechnical structures, technical networks, etc.); **e.** civil engineering objects related to municipal buildings (sewage treatment plants, waste disposal sites, water treatment plants, water supply networks, sewage systems, gas systems, electrical systems, etc.); **f.** buildings and civil engineering volume buildings related to industrial construction (production halls, silos, flyovers, chimneys, cooling towers, mine shafts, etc.); **g.** historic buildings.

Fig. 2. Experts’ answers to question 2 (“which type of building facilities do you deal with in your work”)



a. construction works (for newly erected buildings); **b.** assembly works for prefabricated normal structures (steel, timber, reinforced concrete, prestressed concrete, etc.); **c.** modernisation construction works (consisting of the reconstruction, extension, and superstructure of existing buildings); **d.** renovation works (consisting in the restoration of the original state of a building object); **e.** installation works; **f.** finishing works.

Fig. 3. Experts’ answers to question 3 (“what type of construction work do you deal with in your professional work”)

4.2. Study of the impact of risk on the amount of the life cycle costs of uilding structures

In the next part of the research, the experts were asked to answer a question about their own perceptions on the issue of taking into account the risks associated with the phases of the life cycle of buildings in which investors may incur costs.

Of the possible response options to the fourth question "do you think investors take into account the risks associated with the life cycle costs of construction projects", 16 respondents (50%) indicated that, in their opinion, investors pay attention to risks with a cost dimension that are borne by them during the life cycle of construction projects (of which 3 experts – about 9%, marked the response option "definitely yes", and 13 experts – about 41% chose the response option "rather yes"). 14 respondents (approx. 44%) expressed the opposite view, that in their opinion investors "possibly did not" take life cycle cost risks of buildings into account, and 2 respondents (approx. 6%) did not express an opinion on the subject. None of the experts marked the answer option "definitely not". All the responses of the 32 respondents to question 4 are shown in Figure 4.

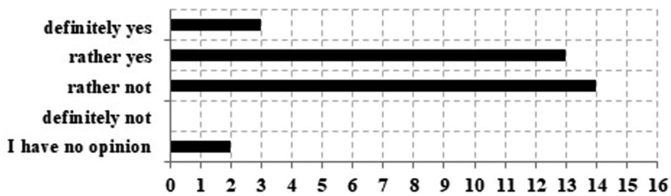


Fig. 4. Experts' responses to question 4 ("do you think investors take into account the risks associated with the life cycle costs of construction projects")

In question five, the experts were required to identify the impact of individual risk factors on the costs incurred during the life cycle phases of construction works. The following scale was adopted: 1 – impact negligible; 2 – somewhat negligible; 3 – moderately significant; 4 – significant; 5 – very significant; 0 – I cannot assess this.

The experts provided a total of 1800 impact assessments for the 45 identified risk factors. The calculated values of the impact of the risks on the size of the life cycle costs of a construction project are presented from the perspective of the assessments averaged for all the respondents and for the case of the division of the respondents into specialist groups (from I to III). This presentation of the results is, according to the authors, justified because it differentiates between experts with experience gained through academic work (combined or not with work for construction companies) or work exclusively for construction companies. However, due to the expected subjectivity of experts' assessments, the research questionnaire was sent again at the end of the research to 8 randomly selected respondents (25% of all experts participating in the research) in order to re-assess the risk factors. The results obtained in both research trials – the first (1440 impact assessments) and the second (validation – 360 impact assessments) are presented in Table 6.

Table 6. Average risk impact ratings by expert (own study)

Id.	Risk factor	1st trial – Average values[1]				2nd trial – Validation[2]		
		I	II	III	Overall	Overall	s	V_s
	TECHNOLOGICAL RISK							
1	**design faults**	4.22	4.50	4.00	**4.19**	4.13	0.0442	1.07%
2	shortcomings in designs	3.78	3.38	3.27	3.44	3.38	0.0442	1.31%
3	**non-compliance of designs with applicable standards and/or regulations**	4.22	3.83	3.60	3.83	**4.00**	0.1179	2.95%
4	**erroneously identified ground conditions**	4.67	4.50	4.33	**4.44**	4.50	0.0442	0.98%
5	**erroneous assumptions of construction and material solutions**	4.44	4.38	4.53	**4.53**	4.75	0.1547	3.26%
6	unavailability of suitably qualified staff	3.11	3.38	3.07	3.16	3.71	0.3910	10.53%
7	variable labor productivity of construction workers	2.56	2.00	2.53	2.41	2.75	0.2431	8.84%
8	poor quality of construction equipment	2.67	2.50	2.93	2.75	3.13	0.2652	8.49%
9	exposure of construction equipment to failures	2.89	2.25	2.67	2.63	3.13	0.3536	11.31%
	CONSTRUCTION RISK							
10	unfavorable weather conditions	3.11	2.50	2.67	2.75	2.75	0.0000	0.00%
11	failure to comply with the rules of occupational health and safety during the performance of work	3.44	2.38	1.93	2.47	2.38	0.0663	2.79%
12	suspension of works because of designer's faults	3.25	2.43	3.00	2.93	3.00	0.0488	1.63%
13	changes to the originally approved scope of work	3.33	2.88	3.07	3.09	3.25	0.1105	3.40%
14	**poor quality of the works**	4.33	3.75	3.93	**4.00**	4.50	0.3536	7.86%
15	poor management quality	3.67	2.63	3.67	3.41	3.88	0.3315	8.55%
16	delays in construction works	3.89	2.88	3.27	3.34	3.38	0.0221	0.65%
17	failure to settle liabilities with subcontractors and suppliers	3.56	2.50	2.57	2.84	3.57	0.5181	14.51%
18	**limited availability of reliable subcontractors**	3.89	3.13	3.40	3.47	**4.13**	0.4640	11.25%
19	poor quality of cooperation with subcontractors and suppliers	3.11	2.88	3.00	3.00	3.75	0.5303	14.14%

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Table 6 – *Continued from previous page*

Id.	Risk factor	1st trial – Average values[1]				2nd trial – Validation[2]		
		I	II	III	Overall	Overall	s	V_s
20	**suspension of works because of contractor's faults**	4.11	3.71	3.53	3.74	**4.00**	0.1825	4.56%
21	limited availability of building materials	3.33	3.00	2.73	2.97	3.63	0.4640	12.80%
22	ensuring continuity of supply of construction materials and systems	3.22	2.71	2.60	2.81	3.25	0.3136	9.65%
23	**use of scarce building materials**	3.56	3.14	4.07	3.71	**4.25**	0.3821	8.99%
24	**use of unsuitable building materials**	4.22	3.88	4.43	**4.26**	4.63	0.2595	5.61%
25	limited availability of specialist construction machinery	3.56	2.25	2.71	2.84	3.38	0.3792	11.24%
26	risk resulting from accompanying processes (e.g., transport services)	2.89	1.75	2.86	2.58	3.00	0.2965	9.88%
FINANCIAL RISK								
27	lack (or delay) of payment for completed works	3.50	2.63	3.47	3.26	3.38	0.0827	2.45%
28	**loss of the entity's financial liquidity**	4.22	3.00	3.60	3.63	**4.13**	0.3536	8.57%
29	**poor cost control**	4.33	3.13	3.46	3.63	**4.00**	0.2593	6.48%
30	**increase in the price of building materials**	4.00	3.88	4.33	**4.13**	4.00	0.0884	2.21%
31	increase in energy prices	3.44	3.13	3.73	3.50	3.63	0.0884	2.44%
32	**increase in labor prices**	3.78	3.63	4.13	3.91	**4.00**	0.0663	1.66%
33	increase in equipment rental prices	3.44	3.63	3.73	3.63	3.75	0.0884	2.36%
34	inflation	3.22	2.63	3.07	3.00	3.13	0.0884	2.83%
35	interest rate fluctuations	3.00	2.75	2.86	2.87	2.71	0.1108	4.08%
POLITICAL RISK								
36	changeability in tax systems	3.22	2.63	3.20	3.06	3.25	0.1326	4.08%
37	changeability in customs system	2.33	2.25	2.67	2.45	2.86	0.2891	10.12%
38	changeability in legislative system	2.56	2.25	3.50	2.90	3.25	0.2452	7.54%
39	instability of economic development	3.22	2.38	4.08	3.37	3.71	0.2458	6.62%
ECOLOGICAL RISK								
40	**wrong design assumptions on environmental issues**	3.63	3.63	3.87	3.74	**4.00**	0.1825	4.56%
41	lack of a legislative system on environmental issues	3.00	2.50	3.00	2.85	3.43	0.4078	11.89%

Continued on next page

Table 6 – *Continued from previous page*

Id.	Risk factor	1st trial – Average values[1]				2nd trial – Validation[2]		
		I	II	III	Overall	Overall	s	V_s
42	changeability of the state's position on environmental issues	3.25	2.63	3.38	3.14	3.71	0.4075	10.97%
	LEGAL RISK							
43	difficulties in obtaining permits	3.11	2.75	3.71	3.29	3.50	0.1483	4.24%
44	**non-compliance with legal acts**	4.50	3.29	3.57	3.76	**4.43**	0.4737	10.70%
45	discrepancies in documentation	3.56	3.14	3.60	3.48	3.63	0.0998	2.75%

[1] I – academics; II – academics who also work in construction companies;
III – employees working exclusively for construction companies.
[2] s – standard deviation; V_s – coefficient of variation.

In Table 6, the red and blue colour indicate those risk factors for which the mean value of the total responses obtained respectivelly in the first and the second research trial was equal to or exceeded the level of significance (4.00). In the case of a risk factor impact score of "0" from the expert (I cannot assess this), this score was excluded from the process of counting averages.

4.3. Results discussion

After analysing the results of the research on the impact of risk factors on the multiple components of the life cycle costs of buildings, the following conclusions were drawn.

The experts indicated an impact of at least significant level (average total impact score equal to or above 4.00) for 6 of the 45 identified risk factors in the different phases of the life cycle of construction works in the first research trial and for 9 additional in the second, which represents approximately 33.3% of the share in the set of all identified risk factors. The risk factors with the most significant level of impact, according to the average assessments of 32 experts obtained in the first research trial, are:

– design faults (factor 1) – overall average score 4.19;
– erroneously identified ground conditions (factor 4) – 4.44;
– erroneous assumptions of construction and material solutions (factor 5) – 4.53;
– poor quality of the works (factor 14) – 4.00;
– use of unsuitable building materials (factor 24) – 4.26;
– increase in the price of building materials (factor 30) – 4.13;

and according to the average assessments of 8 experts obtained in the second research trial:

– non-compliance of designs with applicable standards and/or regulations (factor 3) – overall average score 4.00;
– limited availability of reliable subcontractors (factor 18) – 4.13;
– suspension of works because of contractor's faults (factor 20) – 4.00;
– use of scarce building materials (factor 23) – 4.25;
– loss of the entity's financial liquidity (factor 28) – 4.13;

– poor cost control (factor 29) – 4.00;
– increase in labor prices (factor 32) – 4.00;
– wrong design assumptions on environmental issues (factor 40) – 4.00;
– non-compliance with legal acts (factor 44) – 4.43.

It is worth noting that 4 risk factors (factors: 1, 3, 4 and 5) are risks categorised under technological risk factors, another 5 risk factors (factors: 14, 18, 20, 23 and 24) are risks classified in the group of factors belonging to the category of construction (execution) risks. 4 risk factors (factors: 28, 29, 30 and 32) come from the group of risks of a financial nature and two risk factors (factors: 40 and 44) are respectively ecological and legal risk.

After the validation trial, in Table 6, standard deviations and values of coefficients of variation were calculated for both research trials. The maximum value of the coefficient of variation ($V_s = 14.51\%$) was obtained for risk factor failure to settle liabilities with subcontractors and suppliers (factor 17). This value is much lower than 25%, so it can be concluded that the assessments given by the experts in the first and the second research trial are low in variability. In addition, the coefficients of variation for all 15 risk factors with the most significant level of impact range from 0.98% to 11.25%, which also proves the high convergence of expert assessments in both research trials.

5. Conclusions

This paper discusses the results of the authors' research on the impact of the identified 45 risk factors on the size of costs incurred in the life cycle of buildings, which was conducted by the authors between 2017 and 2020 in Poland. The research was focused on residential and non-residential buildings and those intended for multiple uses (for instance, when a residential building is to have an office or service space allocated at the same time).

The end result of the research is the development of results in the form of a checklist knowledge base, which contains information on the potential impact of the identified risk factors in the life cycle of buildings on the size of the corresponding life cycle cost components (Table 6). The results obtained will provide information on one of the two input variables: the effect of the occurrence of a given adverse event (in addition to the probability of its occurrence), which is necessary as an input to the fuzzy inference model on the impact of risk on the size of the life cycle costs of a building, described in the authors' publications [19–21].

According to the authors, the cognitive and practical values of their own research include: (i) developing a checklist for 45 risks, categorised as technological, construction (implementation), financial, political, environmental or legal ones (Table 6), (ii) mapping of individual risk factors among the entities involved and to the phases of the life cycle of buildings, as well as (iii) identification of those risk factors (of different nature, categories) whose impact on the life cycle costs of construction works is the most significant (level of impact different or above the average score of 4.00). Moreover, the compilation of the results of the authors' own research has a practical value as it divides the average assessments of the impact of risk factors on the life-cycle costs of buildings, according to the opinions of specialists classified in expert groups I to III. This way of presenting data can be helpful for specialists to support the decision-maker in assessing the impact of risks identified in the life cycle of buildings on the size of the corresponding life cycle cost components using a fuzzy life cycle risk assessment model.

In the future, the authors plan to update their research on the impact of the identified risk factors on the size of life cycle costs of buildings due to the economic and geopolitical situation after 2021/2022. Additionally, the authors allow for the possibility of extending their research to the Czech Republic, Lithuania, and Slovakia.

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Ocena ekspercka wpływu ryzyka na koszty cyklu życia budynku

Słowa kluczowe: cykl życia, identyfikacja ryzyka, koszty cyklu życia, ryzyko, zarządzanie ryzykiem

Streszczenie:

Celem głównym artykułu było zebranie informacji na temat wpływu zidentyfikowanych czynników ryzyka na wielkość kosztów ponoszonych w cyklu życia budynków w oparciu o wyniki badań własnych, które zostały przeprowadzone przez autorów w latach 2017–2020 na terenie Polski. Ba-

dania zostały ukierunkowane na budynki mieszkalne i niemieszkalne oraz przeznaczone do wielu celów (np. gdy w budynku mieszkalnym ma być wydzielona jednocześnie powierzchnia biurowa lub pod usługi).

Badania miały charakter próby celowej, która w badaniach związanych m.in. z pozyskaniem opinii eksperckich na temat przedmiotu badań polega na nielosowym (arbitralnym) doborze próby respondentów spośród specjalistów związanych branżowo z celem badań i materiałem badawczym.

Badania podzielono na trzy następujące etapy:

1) identyfikacja i podział czynników ryzyka w cyklu życia budynków;
2) ocena ekspercka czynników ryzyka mogących mieć wpływ na wielkość kosztów ponoszonych w cyklu życia budynków;
3) opracowanie wyników w postaci bazy wiedzy o charakterze tzw. checklist, zawierającej informacje o potencjalnym wpływie zidentyfikowanych czynników ryzyka w cyklu życia budynków na wielkość odpowiadających im składników kosztów cyklu życia.

W badaniach wzięło udział 32 respondentów, choć kwestionariusz badawczy został skierowany pierwotnie do 36 ekspertów (w tym 17 pracowników naukowo-badawczych i 19 pracowników przedsiębiorstw budowlanych). Zwrot kwestionariuszy przekazanych ekspertom wyniósł ok. 89%. Przy czym ze względu na oczekiwaną subiektywność ocen ekspertów, kwestionariusz badawczy został ponownie rozesłany pod koniec badań do 8 losowo wybranych respondentów (25% wszystkich ekspertów biorących udział w badaniu) w celu ponownej oceny czynników ryzyka.

Eksperci wskazali wpływ na poziomie co najmniej istotnym (średnia ocen wpływu ogółem równa lub powyżej 4.00) dla 15 spośród 45 zidentyfikowanych czynników ryzyka w poszczególnych fazach cyklu życia obiektów budowlanych, co stanowi ok. 33.3% udziału w zbiorze wszystkich zidentyfikowanych czynników ryzyka. Czynniki ryzyka o najistotniejszym poziomie wpływu to zdaniem ekspertów:

– błędy w projektach – ocena średnia ogółem 4.19 uzyskana w pierwszej próbie badawczej;
– niezgodność projektów z obowiązującymi normami i/lub przepisami – 4.00 w próbie walidacyjnej;
– błędnie rozpoznane warunki gruntowe – 4.44 w pierwszej próbie badawczej;
– błędnie przyjmowane założenia rozwiązań konstrukcyjno-materiałowych – 4.53 w pierwszej próbie badawczej;
– słaba jakość wykonanych prac – 4.00 w pierwszej próbie badawczej;
– ograniczona dostępność solidnych podwykonawców – 4.13 w próbie walidacyjnej;
– wstrzymanie robót w wyniku błędów wykonawcy – 4.00 w próbie walidacyjnej;
– zastosowanie materiałów budowlanych deficytowych – 4.25 w próbie walidacyjnej;
– zastosowanie nieodpowiednich materiałów budowlanych – 4.26 w pierwszej próbie badawczej;
– utrata płynności finansowej podmiotu – 4.13 w próbie walidacyjnej;
– słaba kontrola kosztów – 4.00 w próbie walidacyjnej;
– wzrost cen materiałów budowlanych – 4.13 w pierwszej próbie badawczej;
– wzrost cen robocizny – 4.00 w próbie walidacyjnej;
– błędne założenia projektowe w kwestiach środowiskowych – 4.00 w próbie walidacyjnej;
– niezgodności z aktami prawnymi – 4.43 w próbie walidacyjnej.

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