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Research paper

Defects as risk factors in housing construction

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Abstract: The article presents an analysis of defects in residential construction as key risk factors for the effectiveness of a construction investment. In a very competitive market, investors have to compete with each other with the organization of construction production and the quality of the product, which is a building structure. One of the basic criteria for evaluating the quality of building structures is the number and type of construction defects. Therefore, the analysis of the risk of such failures and statistical studies of the frequency and type of their occurrence were the crux of the research process presented in the article. An extensive and detailed theoretical analysis of the problem of defects in housing construction was supported by an empirical analysis. Based on the results of research on completed construction investments, the structure of the database was developed, and then a quantitative and objective analysis of defects in residential buildings was carried out. The whole is summarized with research conclusions and recommendations regarding the implementation of residential construction investments.

Keywords: construction, defect, housing, risk

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1. Introduction

Decision theory describes risk as a situation in which the choice of a given variant entails the possibility of negative consequences. These consequences can be identified and quantified. This gives the opportunity to evaluate them, and this is defined as the fundamental value of risk analysis. In other words, risk analysis generally makes it possible to predict threats and prepare the organization to reduce or completely neutralize them. The semantic origin of the term *risk* comes from the Italian verb *riscare*. It means to be bold or dare, that is, to take risky challenges [1]. The problem of risk, the possibility of its identification and assessment, is considered by scientists and practitioners. This area has become so important that in some countries the risk assessment procedure has been formalized and made mandatory. In Poland, the obligation of risk analysis applies to certain economic areas. For example, the Ministry of Finance has imposed on all budget entities, ie those financed from the state budget, the obligation to introduce a risk management procedure. Managers of the above-mentioned budgetary units are obliged to submit annual reports on the identification of risk factors, the effects of their possible occurrence and the possibility of reducing the level of risk. The entire procedure is called management control and is described in the Public Finance Act [2].

Returning to the issue of defining risk, it should be noted that it is interpreted differently. The method of interpretation and creation of definitions on this basis very often depends on the type of construction project. Therefore, the article focuses on a separate type of building objects. However, in order to emphasize the complexity of the issue of risk assessment, it is worth quoting a few of its definitions [3, 4].

For example, in the monograph [5], the semantic origins and basic concepts of risk analysis are presented. It has been described that the concept of risk is understood and defined in a variety of ways. Risk is a term that is generally known and often used in everyday life. However, the definition and understanding of risk are different. In practice, the descriptive understanding of risk prevails over its quantitative interpretation. Risk is understood differently by economists, who usually focus only on financial aspects, and differently by engineers who relate the problem of risk to disruptions in the operation of machines or production processes.

However, in the publication [6] risk was defined as the probability of loss or damage to someone or something as a result of some hazard. According to the author of the definition, risk is defined as the product of identified factors or events with their impact on the enterprise. The author of the work [7] defines risk as a phenomenon objectively correlated with the subjective uncertainty of the occurrence of an undesirable event. A different definition was presented by the author of [8] who is considered a classic of risk theory and the creator of the measurable and immeasurable theory. He claims that risk is measurable uncertainty, and uncertainty in the strict sense is immeasurable uncertainty. Author of [9] defined that risk is a combination of hazards and is measured by probability, and uncertainty is measured by the level of belief.

According to Kasprowicz [10], natural uncertainty or natural risk is generated by spontaneous random events in connection with the natural, internal, random characteristics of physical, chemical, biological, technical, technological, organizational and economic phenomena related to a given project, which are difficult to reduce. Model uncertainty or model risk is a risk or uncertainty related to the formal description of engineering and construction projects using models, in the conditions of random phenomena. With regard to construction projects, Kasprowicz proposes the division of risk into: "Risk or uncertainty of works, i.e. random phenomena and events characterizing a given building structure, occurring at a given time, place, environment and systemic environment, directly related to the type and size of the structure, generated only by physical, chemical, technical, technological, organizational and operational properties. Risk or uncertainty of resources, i.e. technical, technological, organizational, operational, systemic, etc., and thus directly related to the type and quantity of resources, level of qualifications, specialization and professional discipline of people, reliability and availability of tools, machines and materials at disposal. Situational risk or uncertainty, i.e. random phenomena and events characterizing the system environment and project implementation environment, occurring at a given time and place, affecting the use of possessed resources and the execution of works" [10].

When writing about risk assessment methods in construction projects, it is worth mentioning specialist methods, developed especially for this type of projects, and moreover recognized in the world. These certainly include the RAMP (Risk Analisys and Management for Project) methods, ICRAM (Internacional Constraction Risk Assessment Model) and the proprietary MOCRA (Method of Construction Risk Analisys) method. The methods were described in detail by one of the authors, e.g. in the publication [11].

2. Risk in housing construction

Taking into account the advantages of risk identification and quantification methods, it can be said that they are perfect for the analysis of construction projects. Construction projects, due to their complexity, time-consuming and cost-intensive nature, are burdened with a very high risk. The risk most often relates to the possibility of exceeding the budget, construction time or quality of construction. The authors of the article claim that risk analysis should be one of the most important elements of a construction investment management system, including buildings intended for housing purposes. It is often a decisive element for the success of a construction investment. A utilitarian effect of risk analysis may be, for example, emergency schedules. Emergency schedules enable a detailed assessment of the impact of risk factors on the implementation of a construction investment. It is possible to develop several variants of emergency schedules. They differ in the specification and quantification of risk factors in a construction project. The development of several variants of emergency schedules allows the project engineer to assess the impact of individual risk factors on each of the tasks being performed. The assessment concerns a possible change in the time or cost of construction works.

When analyzing construction investments, we can distinguish a division that differentiates them in terms of risk assessment, i.e. cubature, industrial and linear investments. Building investments, which are the subject of research, have a clearly defined and relatively small area in which they are implemented. Due to this, the process of obtaining the necessary building permits and environmental approvals is simpler than in line and industrial projects. The logistics process is easier and cheaper. However, in cubature projects, the quality and precision of the construction works play a much greater role. For example, minor shortcomings in road works are acceptable. For example, in earthworks, where high precision of the work performed is almost impossible. It is different in the case of cubature investments, especially residential buildings, where the quality of work has a very large impact on the success of the investment. One of the key areas determining the quality of a construction project, and therefore also its business effectiveness, are defects. They have a significant impact on the technical condition and aesthetics of the building. They also have a very large impact on building the contractor's brand, and thus on its business success. It can therefore be assumed that the identification, specification, quantification and mitigation of construction defects significantly reduces the risk of failure of a construction project. At the same time, the identification of potential faults should consist in building statistical data of the tested type of building objects. In this case, residential buildings. The specification will then make it possible to list defects according to their hierarchy and frequency of occurrence in construction production. The quantification of construction defects will focus on quantifying the effects of their occurrence. On the other hand, fault mitigation is a procedure aimed at reducing the probability of their occurrence. These assumptions are part of extensive analyzes conducted by the authors of the publication. Some of the conducted research is presented in the further part of the publication. In Poland, this area of management is still underestimated, but the increasing competition on the market will certainly result in attempts to implement it more widely in the construction process. Hence the authors' research interests.

3. Results of testing defects in residential construction

Technical acceptances concern all visible and verifiable elements of a residential property at the completion stage of construction.

In particular, inspections cover:
- Floors (evenness, levelness),
- Walls, which must be straight, without irregularities and air bubbles,
- Windows and balcony doors, which should open and close easily,
- Glass panes, which should be free from scratches or cracks,
- Doors, which should open and close easily,
- The functionality of the electrical installation,
- Supply and drainage of the water and sewage installation.

Every investor expects a defect-free property. However, defects in construction are common. In most technical inspections and acceptances of individual units or buildings, there is no doubt that defects will be identified during the inspection.

3.1. Characteristics of the Investments

Technical inspections were carried out in buildings with both 'reinforced concrete' and 'reinforced concrete-masonry' construction, conducted from 2017 to 2020. During the inspections of residential units, over 9300 construction defects were documented in 669 residential units with a total usable area of 36,920 square meters. Table 1 contains basic information about the buildings where inspections were conducted. Buildings with seven and eight floors have a reinforced concrete structure, while shorter buildings have a mixed reinforced concrete-masonry structure [12].

Buildings with a 'reinforced concrete' structure are constructed using monolithic technology. The main structural system of these buildings consists of column-slab systems, with reinforced concrete load-bearing pillars located transversely. Longitudinal walls made of limestone-sand blocks serve as infill and provide rigidity to the building. Spatial stability of the structure is ensured by stairwell walls, elevator shafts, and the infill of longitudinal walls.

Table 1. Summary of Buildings Subject to Examination

No.	**Investment**	**Usable Area [m^2]**	**Number of Units**	**Main Structure**	**Building Volume [m^3]**	**Number of Floors**	**Year of Commissioning**
1	A	3500	34	Reinforced Concrete-Masonry	15425,21	2	2018
2	B	6682	141	Reinforced Concrete	54 336,16	8	2017
3	C	6370	135	Reinforced Concrete	52 447,02	7	2019
4	D	4031	82	Reinforced Concrete-Masonry	19 030,95	4	2019
5	E	1907	24	Reinforced Concrete-Masonry	9001,04	4	2019
6	F	3579	67	Reinforced Concrete-Masonry	16892,88	4	2019
7	G	4804	78	Reinforced Concrete-Masonry	22674,88	4	2020
8	H	6047	108	Reinforced Concrete	42455,60	8	2019
	Total	**36920**	**669**				

Buildings with a 'reinforced concrete-masonry' structure are those with a reinforced concrete frame construction. The load-bearing system of the building consists of reinforced concrete columns, concrete walls (panels), and beams that provide support for reinforced concrete floor slabs. Load-bearing walls are designed using silicate blocks with a cement-lime mortar and vertical joint filling.

3.2. Identification of defects in residential buildings

As part of this task, defects were identified in 8 residential developments, in accordance with Table 2.

Table 2. Investment Data

No.	Investment Name	Usable Area [m^2]	Number of Apartments/ Units
1	Investment A	3500	34
2	Investment B	6682	141
3	Investment C	6370	135
4	Investment D	4031	82
5	Investment E	1907	24
6	Investment F	3579	67
7	Investment G	4804	78
8	Investment H	6047	108
	Total	**36920**	**669**

Defects were reported by apartment buyers during technical inspections of units and within the warranty period. During on-site inspections, defects were assessed for their validity. Identified defects were recorded in a database. The database contains the following information:

– Type, nature of the defect: warranty, acceptance,
– Description of the defect,
– Status of defect resolution: rejected, repaired,
– Date of report submission, moment of defect removal,
– Property information: investment (name), symbol, and address.

The following defect locations (attributes) were specified: balustrade, common areas, dirt, roof, doors, electrical installation, facade, others, water and sewage installation, windows, insulation, windowsill, tiles, floor, glass panes, plaster, ventilation, moisture on building elements.

3.3. Quantitative summary of defects identified in individual properties

In Table 3, numerical data regarding defects identified in individual buildings are presented, categorized into defects located within the units (8769 pcs.) and defects located in common areas (594 pcs.). The table also includes numerical data on the average number of defects per unit and the average number of defects per square meter of usable area. The data presented in this way will help to better illustrate the research being conducted and present the idea behind the analyzes performed by the authors. The analysis of the conducted research will be continued in subsequent articles.

Table 3. Quantitative Summary of Defects in Inspected Buildings

No.	**Investment**	**Number of Units**	**Usable Area [m^2]**	**Number of Defects in Units**	**Number of Defects in Common Areas**	**Total Defects in: Units and Common Areas**	**Number of Defects per Unit**	**Number of Defects per m^2 of Usable Area**
1	A	34	3500	1414	0	1414	41,6	0,4
2	B	141	6682	353	141	494	3,5	0,1
3	C	135	6370	1422	43	1465	10,9	0,2
4	D	82	4031	1417	38	1455	17,7	0,4
5	E	24	1907	759	47	806	33,6	0,4
6	F	67	3579	1824	57	1881	28,1	0,5
7	G	78	4804	258	36	294	3,8	0,1
8	H	108	6047	1321	232	1553	14,4	0,3
	Total	**669**	**36920**	**8768**	**594**	**9362**	Average: **14,0**	Average: **0,25**

The analysis conducted reveals that the average number of defects per unit was 14. However, there were investments where this result was significantly higher or lower than the average, namely 41.6 defects per unit and 3.5 defects per unit, respectively. Furthermore, it was observed that the average number of defects per square meter of usable area was 0.25. In this analysis, the deviations are much smaller, as the lowest number of identified defects per 1 square meter of usable area was 0.1, while the highest was 0.5.

3.4. Quantitative summary of Defect Groups

Table 4 presents a quantitative and percentage summary of defect groups identified in all analyzed buildings. The largest number of defects occurs in areas such as: plaster (22.43%), windows (15.05%), floors (7.57%), and electrical installations (7.12%). Only these four areas of construction work account for over half of all types of defects, as shown in the chart (Figure 1).

Table 4. Percentage Breakdown of Individual Defect Groups

No.	1	2	3
	Defect Group	**Quantity**	**Percentage Share**
1	Plaster	2100	22,43%
2	Windows	1409	15,05%
3	Floor	709	7,57%
4	Electrical Installation	667	7,12%
5	Common Areas	561	5,99%
6	Water and Sewage Installation	518	5,53%
7	Dirt	505	5,39%
8	Doors	490	5,23%
9	Glass Panes	422	4,51%
10	Other	383	4,09%
11	Tiles	305	3,26%
12	Moisture on Building Elements	294	3,14%
13	Balustrade	270	2,88%
14	Facade	259	2,77%
15	Windowsill	139	1,48%
16	Ventilation	137	1,46%
17	Insulation	133	1,42%
18	Roof	61	0,65%
	TOTAL	**9362**	**100,00%**

The extensive database of identified defects, containing over 9300 entries related to completed investments, enables a comprehensive risk analysis. This analysis allows for the identification of factors that impact the quality in construction.

The foundation for ensuring the elimination of as many construction defects as possible, at the stage where it is feasible, involves breaking down the construction process into stages, areas of responsibility, and identifying factors that need to be closely monitored and supervised.

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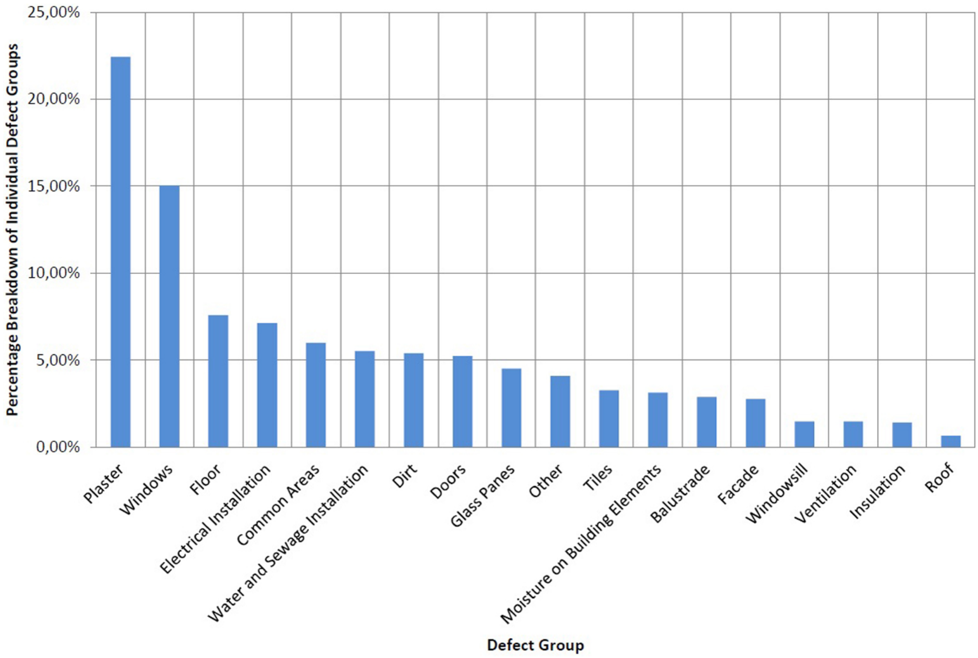

Fig. 1. Percentage Share of Individual Defect Groups

3.5. Analysis of research results

In the course of the research and in the process of preparing the publication, questions and voices in the discussion arose to which the authors of the publication want to address in this chapter.

Due to the very extensive research and a large amount of information, the authors, at the stage of creating the publication, deliberately decided to repeat the basic information regarding the usable area and the number of apartments in Tables 1, 2 and 3, treating this data as key. The percentage of occurrence of individual faults is undoubtedly related to the cost of their repair, however, the authors did not conduct such analyzes at this stage of the research. In the next steps, after quantitative and qualitative analyses, the authors plan to conduct research on the above-mentioned. Connections, correlations and materiality. Based on the authors' many years of engineering practice in the construction of residential buildings and the risk factors associated with them, it can be concluded that inappropriate plastering at a certain level, e.g. 22.43%, does not mean the need to carry out repairs at 22.43% of the original cost. The percentage of defects does not directly reflect the repair costs of the original work. The authors assume that future research and analysis will be carried out to determine the described interconnections.

Currently, there are no results of research conducted on the scale presented in the article, so they cannot be compared with the results of research conducted by other teams. During the publication of the data, detailed questions also appeared, e.g. regarding the types of plasters. In response to these questions, it should be emphasized that in most housing development investments, third-class plaster is the standard. This is the most common description of tolerance and surface quality, and other solutions are rarely used. This is dictated by the price-quality ratio. According to the standard, it is assumed that the surfaces of these plasters should be "even and smooth". These are machine plasters marked as "common". The following are not allowed on plastered surfaces in this category: scratches and mechanical damage, any type of efflorescence, including mold, surface scratches and permanent stains. It should be added that for the purposes of preparing this publication, the authors of the study, due to minor discrepancies in individual elements, omitted minor differences between the 8 analyzed investments, treating them as irrelevant to the purpose of the research.

During the research, questions were also asked about the causes of the type and number of faults. Referring to them, it should be stated that despite the continuous development of construction, the occurrence of defects is one of the main construction problems that require detailed attention. Finding the reason for differences in the number of faults in individual investments requires a deeper analysis. To do this reliably, we must always ask ourselves: Did the problem arise as a result of incorrect work performed by the employee? Was the facility used properly, in accordance with its intended purpose and the principles of periodic inspections? Did the decisions made at the stage of work implementation have an impact on the defect? When looking for answers to these questions, it should be emphasized that there are many factors that generate defects that arise at various stages of construction. Often the cause of the defect is a combination of several factors. The exploration of factors affecting quality is a topic researched by the authors of the study, which resulted in separate publications on this topic [12]. Identification and elimination of sources of problems related to revealed construction defects is an important goal for all entities in the construction process. Engineering knowledge, organizational awareness and consideration of identified causes in the early stages of construction will minimize defect problems. However, it is not possible to completely eliminate them.

Defects were reported by apartment buyers during technical inspections of the premises. During on-site visits, defects were analyzed in terms of their validity. Detected faults were recorded in the database. The following fault locations (attributes) were identified: balustrade, common parts, dirt, roof, door, electrical installation, facade, other, water and sewage installation, windows, insulation, window sill, tiles, floor, glass, plaster, ventilation, moisture on building elements. The publication contains numerical data on defects found in individual buildings, divided into defects located in the premises (8,769 items) and defects located in common areas (594 items).

The prepared material also includes numerical data on the average number of defects per one premises and the average number of defects per square meter of usable area. The analysis shows that the average number of defects per unit was 14. However, there were investments in which this result was much higher or lower than the average, i.e. 41.6 defects/unit and 3.5 faults/unit, respectively. Moreover, it was found that the average number of defects per square meter of usable area was 0.25. In the case of this analysis, the deviations are much smaller, because the smallest number of defects found per 1 m2 of usable area was 0.1, while the largest was 0.5.

The presented research results indicate that there is a need for a deeper analysis of the causes and associated risks that lead to the indicated discrepancies. Further research on the factors affecting the quality of the constructed facilities may provide an answer about the risk of construction defects during the implementation of residential construction investments

4. Conclusions

The article presents a general analysis of the possibility of using procedures for assessing the risk of construction defects in residential construction. The analysis focused on the problems of identifying, quantifying and mitigating risk factors that may influence the occurrence of construction defects. The validity of using risk analysis to improve the quality of construction products is described. In addition, original research on the identification of factors influencing high quality in construction was presented. High quality is achieved by eliminating construction errors. Additionally, based on the collected data on completed construction investments, a database structure was developed, and then a quantitative and objective analysis of defects occurring in selected residential buildings was carried out. Based on the database of identified construction defects, the types of defects most frequently and least frequently occurring in residential premises were determined. The list of fault types is presented in terms of percentage of their share in all identified faults. Based on the calculations and statistical analyses, it was determined which factors were the most important and which were the least important. The research conducted and the analysis of its results allowed conclusions to be drawn regarding the management of the construction company and the investment process. The research and analyzes presented in the article are part of extensive research conducted by the authors of the publication.

References

[1] M. Kowacka, D. Skorupka, A. Bekisz, D. Dudziak Gajowiak, and A. Duchaczek. “Modern management methods in the implementation of construction projects on the example of contingency plans”, *Archives of Civil Engineering*, vol. 69, no. 2, pp. 111–122, 2023, doi: 10.24425/ace.2023.145256.

[2] Ustawa z dnia 27 sierpnia 2009 r. o finansach publicznych. Dz.U. 2009 nr 157 poz. 1240.

[3] A. Dziadosz and A. Kończak, “Review of selected methods of supporting decision-making process in the construction industry”, *Archives of Civil Engineering*, vol. 62, no. 1, pp. 111–126, 2016, doi: 10.1515/ace-2015-0055.

[4] A. Sobotka and A. Radziejowska, “Risk analysis in the realization of buildings in revitalized areas”, *Archives of Civil Engineering*, vol. 65, no. 3, pp. 113–126, 2019, doi: 10.2478/ace-2019-0038.

[5] D. Skorupka, *Method of identifying and assessing the risk of construction projects*. Warszawa: WAT, 2007.

[6] S.T. Regan, ”Risk Management Implementation and Analysis”, *AACE International Transaction of the Annual Meeting*, 2003, pp. 10.1–10.7.

[7] A.H. Willet, *The Economic Theory of Risk Insurance*. University of Pennsylvania Press, 1951.

[8] F.H. Knight, *Risk, Uncertainty and Profit*. University of Boston Press, 1921.

[9] J. Pfeffer, *Insuarance and Economic Theory.* Homewood, Illinois: Irvin Inc., 1956.

[10] T. Kasprowicz, *Inżynieria przedsięwzięć budowlanych.* Warszawa: Instytut Technologii Eksploatacji, 2002.

[11] D. Skorupka, *Innovations in construction projects*. Publishing House of the Wrocław University of Technology, 2019.

[12] B. Hoła and K. Pochybełko “Analiza usterek w wybranych budynkach mieszkalnych”, *Builder Science*, vol. 289, no. 8, pp. 64–67, 2021, doi: 10.5604/01.3001.0015.0419.

Usterki jako czynniki ryzyka w budownictwie mieszkaniowym

Słowa kluczowe: budownictwo, usterki, budownictwo mieszkaniowe, ryzyko

Streszczenie:

W artykule dokonano ogólnej analizy możliwości wykorzystania procedur oceny ryzyka wystąpienia usterek budowlanych w budownictwie mieszkaniowym. W analizie skoncentrowano się na problemach identyfikacji, kwantyfikacji i mitygacji czynników ryzyka mogących mieć wpływ na powstawanie usterek budowlanych. Opisano zasadność stosowania analizy ryzyka w celu podniesienia jakości produktów budowlanych. Ponadto, przedstawiono autorskie badania dotyczące identyfikacji czynników wpływających na wysoką jakość w budownictwie. Wysoka jakość osiągana jest poprzez eliminację błędów budowlanych. Dodatkowo na podstawie zebranych danych o zrealizowanych inwestycjach budowlanych opracowano strukturę bazy danych, a następnie przeprowadzono ilościową i obiektywną analizę usterek występujących w wybranych budynkach mieszkalnych. Na podstawie bazy zidentyfikowanych wad budowlanych określono rodzaje usterek najczęściej i najrzadziej występujących w lokalach mieszkalnych. Zestawienie rodzajów usterek przedstawiono w ujęciu procentowym ich udziału we wszystkich zidentyfikowanych uszkodzeniach. Na podstawie przeprowadzonych obliczeń i analiz statystycznych określono, które czynniki są najważniejsze, a które najmniej istotne. Przeprowadzone badania i analiza ich wyników pozwoliły na wyciągnięcie wniosków dotyczących zarządzania firmą budowlaną i procesem inwestycyjnym. Badania i analizy przedstawione w artykule są częścią rozległych badań prowadzonych przez autorów publikacji.

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