Effective Risk Management in Innovative Projects: A Case Study of the Construction of Energy-efficient, Sustainable Building of the Laboratory of Intelligent Building in Cracow

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Abstract. Many construction projects fail to meet deadlines or they exceed the assumed budget. This scenario is particularly common in the case of innovative projects, in which too late identification of a high risk of delays and exceeding the assumed costs makes a potentially profitable project untenable. A high risk level, far exceeding the level of risk in standard non-innovative projects, is a characteristic feature of the realization phase of innovative projects. This is associated not only with greater complexity of the design and construction phases, but also with the problems with application of new technologies and prototype solutions, lack of qualified personnel with suitable expertise in specialized areas, and with the ability to properly identify the gaps between available and required knowledge and skills. This paper discusses the process of effective risk management in innovative projects on the example of the realization phase of an innovative, energy-efficient and sustainable building of the Laboratory of Intelligent Building in Cracow - DLIM Lab, from the point of view of DORBUD S.A., its general contractor. In this paper, a new approach to risk management process for innovative construction projects is proposed. Risk management process was divided into five stages: gathering information, identification of the important unwanted events, first risk assessment, development and choice of risk reaction strategies, assessment of the residual risk after introducing risk reactions. 18 unwanted events in an innovative construction project were identified. The first risk assessment was carried out using two-parametric risk matrix, in which the probability of unwanted event occurrence and its consequences were analysed. Three levels of risks were defined: tolerable, controlled and uncontrolled. Risk reactions to each defined unwanted event were developed. The following risk reaction types were considered: risk retention, risk reduction, risk transfer and risk elimination. Three-parametric risk matrix was developed to make it possible to assess risk after implementing risk reactions. The possibility of implementing risk management was inversely proportional to the probability of unwanted event occurrence and its contribution to the project outcome. Introducing this risk management strategy allowed to significantly reduce the risk of the innovative construction project. It proved to be an effective tool to reduce risk to an acceptable level. It had a significant contribution to carrying out the project within the assumed time, budget and quality standards.

1. Introduction
Construction industry is characterized by a high percentage of accidents and difficulties in solving the problems encountered during the investment process. It is connected with the dynamic nature of the risk associated with the construction process and its time-dependent nature, changing environmental
conditions (factor associated with an objective assessment of the actual conditions), and the volatility of the perception of the reality by man (factor associated with the interpretation and subjective evaluation). It translates into many overdue realizations, which also proved to be more expensive and did not meet the established quality requirements. For over 20 years 30% of the investment ends in failure to meet the deadlines or exceeding the assumed cost [1]. This scenario is particularly common in the case of innovative projects, in which a too late identification of a high risk of delays and exceeding the assumed costs, makes a potentially profitable project untenable. The characteristic feature of the realization phase of innovative projects is a high degree of risk, far exceeding the level of risk in a typical non-innovative project. It is associated not only with greater complexity of the design and construction phases, but also with problems with the application of new technologies and prototype solutions, lack of qualified personnel with suitable expertise in specialized areas, and with the ability to properly identify the gaps between available and required knowledge and skills. One of the key tasks of the general contractor in the realization phase of this type of projects is an adequate risk management. Effective risk management in innovative construction projects from the planning phase of the project through design, preparation for realization and realization, increases the chances of completion the project in time and to avoid unwanted legal and economic consequences. This paper discusses the process of effective risk management in innovative projects on the example of the realization phase of an innovative, energy-efficient and sustainable building of the Laboratory of Intelligent Building in Cracow - DLJM Lab from the point of view of the general contractor - DORBUD S.A. Kielce. The construction manager was MSc. Igor Cholewicki and the Project Manager MSc. Thomas Celowski. The client was DLJM System Sp. z o.o. from Cracow. The construction of the laboratory has received nearly 10 million PLN funding from the European Regional Development Fund [2]. The architectural design was made by APP Design Studio Architects Artur Wiąk from Cracow.

There are many methods of risk assessment. In [3, 4, 5, 6, 7, 8], various methods of risk assessment, that could be useful in engineering projects were described: matrix methods, check list, What-If, Hazard and Operability Studies, Failure Modes and Effects Analysis, Fault Tree Analysis, Logical Tree Analysis, Cause-Consequence Analysis. In [9, 10], the qualitative and quantitative risk assessment of complex underground construction projects applying Fuzzy Fault Tree Analysis, Ishikava diagrams and expert surveys was presented. In [11], the author described the use of artificial intelligence and computer simulations to predict interference with the equipment on the building site, and the process of risk modelling at the macro level and the construction market level in the realization phase of common construction investment. In [12], the process of risk analysis, using the survey method and the two-parametric matrix in typical construction projects was described. In [13], the benefits and risks associated with “green building projects” were presented. In [14], authors discussed a new method of diagnosing the risk in projects involving the production of an innovative product (Risk Diagnosing Methodology - RDM method), dedicated in particular to companies producing glass parts for the audio-video, and for the lighting industry. In [15, 16, 17], risk management in engineering projects was described. In literature, no studies that describe risk management process in the realization phase of an innovative construction projects were found.

A comprehensive definition of risk from the point of view of the construction project realization phase should be as follows: the risk is the danger of loss, which is understood as an adverse effect on health, environment; the possibility of occurrence of the unwanted event which interferes in achieving the goal; or as not achieving the goal.

2. Challenges connected with the realization phase of the Intelligent Building Laboratory
The construction process of a model laboratory building, in which various R&D works will be carried out, was associated with many challenges. In this model building it was intended to carry out industrial research and development works related to among others: monitoring the technical parameters of the
building shell, production of electricity by photovoltaic prototype blinds and optimization of building automation devices. The task of the building was to recreate the real conditions for the spaces of various purposes. Therefore, the General Contractor DORBUD S.A. was responsible for constructing the building, consisting of multiple test objects: a model hotel reception, a model apartment with a kitchen and a bathroom, a cinema that could meet the stringent requirements of THX certification, conference and lecture rooms, offices, commercial premises and a parking. The floor area of this building was 1200 m². The building consisted of 3 floors above ground and 2 underground. The building was designed and built in low energy standard. Its heat demand is at a level of 30 kWh / (m²·year), which is the lower limit of the heat demand for low-energy buildings. In the building, there will be installed algorithms utilizing artificial intelligence, which will allow better control of the building, saving up to 15% of the energy [2]. The building was presented in figure 1.

The owner specified in the project documentation that the façade shutters should be movable and integrated with the photovoltaics. Such a solution was not available on the market. It was needed to invent a prototyping solution that would meet the owner’s requirements, design a solution, develop the prototype production process, test the solution in experimental conditions, carry out first production and install the prototype, movable, PV shutters on the building site. The feasibility of shutters development was not proved. Their performance during the maintenance phase of the building was not also known. Therefore, the General Contractor had to make decision with limited information available. It was needed to identify technological gaps by indicating gaps between available and required knowledge, skills and experience. Experts in the area of doors, windows and façades were gathered and discussed potential risks connected with a new solution. It was decided to entrust the task to YAWAL S.A., as it was a manufacturer with experience in producing typical PV shutters. Various risk identification methods were applied: risk brainstorm sessions, risk interviews, risk checklists and scenario analysis. It allowed the General Contractor to assess the risk connected with manufacturing, installing and performance of innovative shutters and develop a risk management strategy, in which risk reactions to unwanted events connected with prototype solution would be included.

The General contractor was responsible for installing the following renewable energy sources:

- prototype, movable façade shutters integrated with photovoltaic (BIPV cells - called. Building Integrated Photovoltaics) (figure 2),
- 2 solar collectors,
- 2 heat pumps,
- 2 ground heat exchangers.
- The other solutions providing an intelligent balance of the building included:
  - windows with variable haze, which can vary from transparent to dim thanks to the liquid crystals,
  - recuperation system,
  - rainwater recycling system,
  - integrated Building Management System BMS - a combination of open standards BACnet, LON and KNX.

The realization process was started in July 2014 and completed in December 2015. All the work was carried out in accordance with the assumed schedule of works. The main challenges related to the construction of low-energy, sustainable building included:

- the level of complexity of the project,
- ensuring high quality performance of partitions of the building (low-energy building standard),
- ensuring high quality performance of a cinema hall in the building (standard of THX certification),
- ensuring high quality of the installation of renewable energy sources in the building, including the installation of the prototype of photovoltaic blinds,
the need to make decisions with limited information available (e.g. connected with the possibility of creating innovative PV blinds, not known performance of blinds during the guarantee period),

- the uncertainty associated with the results of planned R & D works on photovoltaic blinds,
- reduced the area of the construction site due to the small area of the plot (707 m2),
- difficulties in carrying out works due to the neighbouring old buildings located 3m from the excavations,
- difficulties in carrying out works due the location directly by a busy street Balicka,
- the need to carry out works in a traffic lane of a busy street Balicka (carrying out drainage and sanitary sewage system under the street Balicka, because in this region the city did not have any sewerage system),
- soil and water conditions making it difficult to perform vertical drilling for ground heat exchanger and sheet piles,
- identified existing underground infrastructure which would interfere with the planned construction,
- the need to incur large financial outlays,
- high intensity of works planned in the schedule.

Figure 1. The Laboratory of Intelligent Building in Cracow [18]

Figure 2. Prototype photovoltaic, movable shutters [19]

3. Risk management process connected with the realization phase of the innovative energy-efficient, intelligent sustainable building

Risk management process of the realization phase of the innovation project was divided into 5 stages:

Step 1: Familiarizing with the project of energy-efficient, intelligent sustainable building and potential problems associated with the realization of innovative projects

In order to identify the potential hazards in innovative project it was needed to gather information about the various construction sites where energy efficient, sustainable and intelligent buildings were built. Identification of potential problems associated with the realization of innovative projects was also supported by the literature review. Various positions describing problems and hazard occurring
during the realization phase in many projects were studied. Moreover, it was needed to analyse the project documentation in detail in order to familiarize with the assumptions in the project documents.

Step 2: Identification of the major unwanted events related to the realization phase of DLJM Lab

Identification of unwanted events was carried out using risk assessment based on Brainstorming Session, risk checklists and Experience-Based Risk Assessment thanks to using experts’ experience in the construction industry, renewable energy and the implementation of the innovations. Risk factors were divided into 6 blocks: design errors, problems with the equipment, problems with the ground conditions, problems with management, problems with the environment and safety, and economic problems. Table 1 presents the identified unwanted events.

Table 1. The identified unwanted events.

| No. | Unwanted event                                                                 |
|-----|--------------------------------------------------------------------------------|
| I   | Design errors                                                                  |
| ue1 | Errors in the architectural design                                             |
| ue2 | Errors in the construction design                                              |
| ue3 | Errors in the installation design                                              |
| II  | Problems with the equipment                                                    |
| ue4 | Problems with availability of the specialized equipment                         |
| ue5 | Equipment failures                                                             |
| III | Problems with the ground conditions                                            |
| ue6 | Unexpected natural subsurface obstacles, unexpected adverse soil and water conditions |
| ue7 | Unexpected man-made subsurface obstacles and elements of the underground infrastructure |
| IV  | Problems with management                                                       |
| ue8 | Problems with the application of new and relatively new technologies and prototype solutions, including those whose feasibility has not been proved yet |
| ue9 | Lack of qualified staff with the proper expertise in the specialized areas      |
| ue10| Unsatisfactory work quality due to the complexity and difficulty of the construction process |
| ue11| Incorrectly estimated completion dates of individual works                      |
| ue12| Delays in the supply of materials                                               |
| V   | Problems with the environment and safety                                        |
| ue13| Accidents on the construction site                                              |
| ue14| Problems with carrying out works due to the space limitations on the construction site |
| ue15| Negative impact on the environment, neighbouring buildings due to generating vibration, noise emission and air pollution |
| VI  | Economic problems                                                              |
| ue16| Incorrect calculation of investment costs (in particular the costs of the innovative elements) |
| ue17| The penalties associated with the failure to deliver an innovative product,     |
|     | elements developed using new and relatively new technologies during the guarantee period |

The analysis also included the risks associated with design errors, because the General Contractor duties also cover verifying the project documentation and errors or difficulties, which can occur during the realization phase. The analysis also included assessment of the risks connected with the innovative building maintenance during the warrantee period, as it has a significant influence on the financial result of the investment.

Step 3: Risk assessment using two-parametric matrix of risk.

For each unwanted event, it is needed to calculate the overall risk \( R(ue) \), based on the two-parametric method of assessing risk:

\[
UE = \{ue1, ue2, ..., ue18\} \\
V_{ue\inUE} R(ue) = P(ue) \cdot C(ue)
\]
where: $ UE \sim \text{set of all identified unwanted events}, \ UE_i \sim \text{i-th unwanted event}, P(ue) \sim \text{the point scale for the probability of occurrence unwanted event, points}, C(ue) \sim \text{the point scale for the consequences connected with unwanted event occurrence}.

In order to assess the probability of the unwanted event occurrence and seriousness of its consequences a group of experts was asked to determine these parameters, using the following point scale:

a) describing the probability of the unwanted event occurrence:
   - 1 point - low probability (L),
   - 2 points - medium probability (M),
   - 3 points - high probability (H),

b) describing the consequences of the events in relation to the size of possible financial losses
   - 1 point - little loss (L) - the financial consequences of $<10\%$ margin,
   - 2 points - medium loss (M) - the financial consequences amounting to $10-30\%$ margin,
   - 3 points - large loss (H) - the financial consequences amounting to $\geq30\%$ margin.

Table 4 presents the identified unwanted events, their probability of occurrence, consequences and risks (columns 1-4).

For the evaluation of the risk addressed to the identified unwanted event the following scale of risk was proposed:
   - tolerable risk – 1-4 points,
   - controlled risk – 5-9 points,
   - unacceptable risk – 10-25 points.

**Step 4: Development and selection of the risk response strategy**

Four types of risk response were considered: risk reduction (CR, ER, CER), risk retention (RET), risk transfer (TRA) and risk avoidance (AV). Risk retention can be divided into its passive and active acceptance. Passive acceptance of risk is connected only with documenting of the risk existence. In this case, the contractors take responsibility for any consequences related to the occurrence of unwanted events. Active acceptance of risk is also connected with documenting the risk existence, but contingency plans are prepared, including scenarios for actions to be taken in the case of the unwanted event occurrence. Risk transfer requires the existence of the party who will be willing to bear the risk. Risk transfer to insurance companies is typical for the risk of very low probability of occurrence and significant consequences. The higher the assessed probability of an unwanted event, the greater the insurance premium. Such risk management is difficult and dangerous. Risk transfer can be applied to the residual risk that remains after the risk reduction.

The proposed approach to risk management is not limited to the fatalistic approach to risk management, but also considers risks in a more proactive manner, through the analysis of the potential risks and the measures to reduce its causes or consequences. Proactive and holistic approach are the basis for the elimination and reduction of risk. Risk avoidance assumes to undertake such actions so that risk was no longer present (e.g. to stop the project, to choose a different design solution). This approach could be applied to risk management both with high probability of occurrence and the very serious consequences, when risk acceptance, reduction and risk transfer are not appropriate at a reasonable cost. Risk reduction involves the removal of one or more causes of risk (CR), one or more consequences of the risks (ER) or removing both the risk causes and consequences (CER). In order to choose the most appropriate method of risk reduction it is needed to check whether the result or the cause is dominant in the considered risks. Table 2 presents the developed risk response strategy for the analysed project.
Table 2. Risk response strategy for the analysed innovative project.

| No. of unwanted event | Risk response strategy |
|-----------------------|------------------------|
| ue1, ue2             | CR - analysis of the project documentation, looking for weaknesses and errors |
| ue3                  | CR - consultation of the project documentation with experts in architectural design, construction, solar installations, heat pumps, ground air heat exchangers, water recycling systems |
|                      | ER - cooperation with a design studio with references from previously completed similar projects |
| ue4                  | ER - assuring providers in the case of emergency |
| ue5                  | CR - carrying out regular and periodic inspections of the equipment, proper maintenance of the equipment |
| ue6                  | ER - contingency plans development in case of encountering unexpected obstacles |
|                      | CR - adapting the technology of the works to adverse ground conditions |
|                      | CR - a review of existing geotechnical documentation, maps, aerial photos, the history of the deposit, a review of the regional geological data and contact with regional geologists |
| ue7                  | CR - Carrying out works with particular caution (in particular due to the fibre optic cables of airports in the vicinity of carried works) |
|                      | CR - applying several methods of underground infrastructure location |
| ue8                  | CR – carrying out the feasibility analysis of an innovative element, identification of the risk factors associated with the manufacturing and maintenance of innovative element, development of the risk remediation measures for the identified risks, preparation of an action plan taking into account the selected risk responses, |
|                      | TRA - risk transfer to the subcontractor, |
|                      | CR - choosing a subcontractor with credentials and experience in similar projects |
| ue9                  | CR - hiring subcontractors and workers with experience, references from similar works |
|                      | CR, ER - development of risk registers with perceived risks and appropriate remediating actions (especially CR, ER) for risks associated with the installation of solar panels, heat pump, ground-air heat exchanger, the installation of water recycling system, certification requirements of THX, installation of smart glasses |
| ue10                 | ER - carrying out quality audits at the different stages of the construction process |
|                      | CR - consultation with experts during carrying out construction works |
| ue11                 | CR - proper development of the schedules by experienced staff, |
|                      | CR - consultation the developed schedule with experts |
| ue12                 | CR - Selection of suppliers in accordance with the developed framework of qualifications |
|                      | CR - selection of certified materials, |
|                      | CR - choice of suppliers with positive experience from previous cooperation, with references |
|                      | ER - the division of large supplies in two parts in order to share the risks |
|                      | ER - preparing a list of alternative suppliers |
|                      | ER - penalties for delays in deliveries included in the contract with the supplier |
| ue13                 | CR – establishment of internal procedures |
|                      | CR – safety training at the building site, familiarizing employees with the identified risks associated with the construction safety, introducing routine safety and health protection plan, |
|                      | CR - coordinator for health and safety constantly present at the building site, |
|                      | CR - occupational health and safety inspector checks at the construction site |
| ue14                 | CR – preparing an appropriate work plan |
| ue15                 | ER - vibration monitoring of adjacent buildings |
|                      | CR – preparing a photographic documentation of existing infrastructure before starting construction works in order to protect against unfounded claims |
| ue16                 | CR - consultation with experts in the field calculation of innovative investment costs |
| ue17                 | TRA - risk transfer to the subcontractor |
| ue18                 | CR- analysis of possible problems related to the functioning of the prototype components, identifying weaknesses before production and improvement, |
|                      | ER - including the innovative elements maintenance costs during the guarantee period in the project budget, |
|                      | TRA-risk transfer to the subcontractor |
Step 5: Risk assessment after the introduction of risk response strategy using three-parametric risk matrix

Table 3. Three-parametric risk matrix.

| Probability | L=2 |
|-------------|-----|
| Consequences | L=1 | M=2 | H=3 |
| 1            | LLL | LML | LHL |
| 2            | 2.00| 4.00| 6.00|
| 2            | LLM | LML | LHM |
| 1            | 1.00| 2.00| 3.00|
| 3            | LLH | LMH | LHH |
| 0.67| 2.00| 2.00|

| Probability | M=4 |
|-------------|-----|
| Consequences | L=1 | M=2 | H=3 |
| 1            | MLL | MML | MHL |
| 2            | 4.00| 8.00| 12.00|
| 2            | MLM | MMM | MHM |
| 1.00| 2.00| 3.00|
| 3            | MLH | MMH | MHH |
| 1.33| 2.67| 4.00|

| Probability | H=6 |
|-------------|-----|
| Consequences | L=1 | M=2 | H=3 |
| 1            | HLL | HML | HHL |
| 2            | 6.00| 12.00| 18.00|
| 2            | HLM | HMM | HHM |
| 3.00| 6.00| 9.00|
| 3            | HLH | HMH | HHH |
| 4.00| 4.00| 6.00|

For each unwanted event the overall risk $R_{residual}$ was calculated using three-parametric risk assessment method:

$$V_{ueue}R_{residual}(ue) = \frac{P(ue) \cdot C(ue)}{N(ue)}$$

(3)

where: $ue, P(ue), C(ue)$ - as it was described in Step 3, $N(ue)$ - the point scale for the possibility of risk reaction for unwanted event, points

In order to assess the probability of the unwanted event occurrence and seriousness of its consequences a group of experts was asked to determine these parameters, using the following point scale:
a) describing the probability of the unwanted event occurrence – as it was described in Step 3,
b) describing the consequences of the events in relation to the size of possible financial losses – as it was described in Step 3,
c) describing the possibility of responding to the risk
   — 1 point – low possibility – it is possible to apply risk retention
   — 2 points – medium possibility – it is possible to apply risk reduction or risk transfer or risk avoidance if risk reduction, retention and risk transfer are not possible, it is possible to reduce the risk twice,
   — 3 points – large possibility – it is possible to apply risk reduction or risk transfer or risk avoidance if risk reduction and retention and risk transfer are not possible, it is possible to reduce the risk three times.
Table 3 presents three-parametric risk matrix developed for the analysed innovative project. Table 4 shows the identified unwanted events, their assessed probability of occurrence, consequences, risk calculated without considering risk management strategy, the possibility of responding to risk and residual risk after introducing risk management strategy.

Table 4. The identified unwanted events, their probability of occurrence, consequences, possibility of responding to risk, residual risk (after introducing risk response reactions).

| No. | P(ue) | C(ue) | R(ue) | N(ue) | R_{residual}(ue) |
|-----|-------|-------|-------|-------|------------------|
| 1   |       |       |       |       |                  |
| 2   | 2.00  | 2.00  | 4.00  | 2.00  | 2.00             |
| 3   | 2.00  | 3.00  | 6.00  | 2.00  | 3.00             |
| 4   | 3.00  | 3.00  | 9.00  | 2.00  | 4.50             |
| 5   | 1.00  | 3.00  | 3.00  | 2.00  | 1.50             |
| 6   | 2.00  | 2.00  | 4.00  | 3.00  | 1.33             |
| 7   | 3.00  | 3.00  | 9.00  | 2.00  | 4.50             |
| 8   | 3.00  | 3.00  | 9.00  | 3.00  | 3.00             |
| 9   | 2.00  | 3.00  | 6.00  | 3.00  | 2.00             |
| 10  | 3.00  | 3.00  | 9.00  | 3.00  | 3.00             |
| 11  | 3.00  | 3.00  | 9.00  | 3.00  | 3.00             |
| 12  | 2.00  | 3.00  | 6.00  | 3.00  | 2.00             |
| 13  | 1.00  | 3.00  | 3.00  | 2.00  | 1.50             |
| 14  | 3.00  | 3.00  | 9.00  | 2.00  | 4.50             |
| 15  | 3.00  | 3.00  | 9.00  | 2.00  | 4.50             |
| 16  | 3.00  | 3.00  | 9.00  | 3.00  | 3.00             |
| 17  | 3.00  | 3.00  | 9.00  | 2.00  | 4.50             |
| 18  | 3.00  | 3.00  | 9.00  | 3.00  | 3.00             |

4. Conclusions
The developed risk management strategy enables to carry out qualitative and quantitative risk assessment of a realization phase in construction projects. The presented methodology allows to take into consideration a specific nature of innovative projects. Introducing an additional, third parameter (possibility of taking risk remediation measures) to the typical two-parametric risk matrix allowed not only to assess the inherent risk of unwanted event occurrence but also consider and asses the possibilities of introducing risk remediation actions and their influence on the residual risk that
remains after applying risk response. The introduction of a risk management strategy allowed to reduce the risk of unwanted events occurrence twice or three times. After the introduction of risk management strategy, the risks of all identified unwanted events occurrence reached an acceptable level. The introduction of a risk management strategy enabled to reduce the overall risks of the project during the realization phase from 128 points to 54.33 points (57.55% of risk reduction). The described risk management proved to be useful, readable and enabled an easy interpretation of the results. It allowed to realize the innovative project successfully, allowing to avoid many serious economic and legal consequences and problems with carrying out works on the construction site.

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