

*The object of this study is the management processes of «sustainable construction». Sustainability is considered through the application of management processes that, in addition to the traditional tasks for construction projects, also outline the tasks of a wider context. Strategies and production practices of «sustainable construction» involve taking into account environmental, social and economic factors that affect a wide range of stakeholders and the overall condition of the built space. In this regard, the issue of applying management processes in the construction industry that ensure proper organizational and technological sustainability of projects is also being updated. This article aims to fill the existing information and methodological gap in the processes of assessing the sustainability of construction project management processes.*

*A correlation method was applied to determine the interdependencies of the characteristics of the use of tools and methods in the processes of managing construction projects with the values of sustainable development 5P (Product, Proses, People, Planet, and Prosperity). Highlighting the characteristics of permanence in project management processes helps to explain the difference in approaches for ensuring the internal sustainability of the construction object and the sustainable management of a construction project.*

*A comprehensive methodology for quantitative assessment of sustainable construction project management in the initiation and planning processes under conditions of uncertainty is proposed. The relative importance of construction project management processes and subcategories of sustainable development of the construction site is taken into account. Basic mathematical models of sustainability assessment have been developed: balanced in all areas of knowledge of construction project management processes at the «Initiation» and «Planning» phases for each category of sustainable development, and integral assessment of sustainability of construction project management processes*

*Keywords: project management, construction project, sustainability, sustainable development, planning processes*

# IMPROVING MODELS FOR SUSTAINABILITY EVALUATION OF CONSTRUCTION PROJECTS IN THE INITIATION AND PLANNING PROCESSES

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## 1. Introduction

Sustainability is defined through the effective use of organizational and production technologies to achieve the Sustainable Development Goals (SDGs) [1]. Taking into account the need for development in sustainability parameters, the construction industry identifies the appropriate correlation with the SDGs [2]. Strategies and production practices of «sustainable construction» involve taking into account all possible environmental, social and economic factors that affect stakeholders and the overall state of the built space. In particular, the construction industry responds to new challenges related to the SDG by introducing new standards: BREEAM (Building Research Establishment Environmental Assessment Method) [3], LEED (Leadership in Energy and Environmental Design) [4], LBC (Living Building Challenge) [5]). The International Organization for Standardization (ISO) has developed sustainability standards for buildings and structures, as well as the performance of relevant engineering works:

– ISO 21929-1. Sustainability in building construction – Sustainability indicators – Part 1: Framework for the development of indicators and a core set of indicators for buildings;

– ISO 15392. Sustainability in buildings and civil engineering works – General principles;

– ISO/TR 21932. Sustainability in buildings and civil engineering works – A review of terminology.

At the same time, construction projects should also be carried out at a higher level of sustainability of all organizational, management and production processes. The triple bottom line of environmental, economic and social efficiency must be considered to achieve operational sustainability. The growing demand for sustainable business processes has led to significant transformations in the project management knowledge system [6]. In particular, the «GPM P5 Global Standard for Sustainable Development in Project Management (GPM P5)» was developed [7]. Assessing the sustainability of project management includes measuring the impact of the project on the external and internal environment. In this context, the issues of a comprehensive study of assessing the sustainability of construction projects from the point of view of project management processes are also updated.

Applying GPM P5 to construction project management is an important task for decision makers. The specifics of the production of the construction «product», its resource intensity, also require more extensive work with the environment of the construction project. The sustainability orientation of the construction project must be represented in the processes, tools, and project actions throughout the entire life cycle.

The initiation and planning phases, which define the basic requirements and necessary measures, are extremely important for assessing the sustainability of construction projects. It is initiation and planning that are keys to turning the SDGs into practical action. However, there is a shortage of tools for assessing sustainability in the early stages of project management, despite the general interest of construction companies in applying sustainability-oriented approaches to the organization of management processes [8]. Actualization of this issue requires further development of new and improvement of existing tools for assessing sustainability-oriented management of construction projects. That is why the subject of this research is relevant.

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## 2. Literature review and problem statement

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Researchers consider project planning as a significant factor contributing to the successful implementation of projects. In [9], it is proposed to evaluate the level of implementation of the planning function in terms of «maturity» of project management, its ability to apply the necessary tools and methods to reduce uncertainty. It is argued that mature planning makes project goals more specific and understandable to the project team. From a sustainability perspective, mature planning is seen as a basis for tracking actual progress, including on the environmental and social sustainable development goals. However, general solutions for maintaining the internal constancy of planning processes are proposed in [9]. The industry specifics of the project are not taken into account.

Most researchers prefer to evaluate project planning from a process perspective. At the same time, they are guided by the PMBOK (Project Management Body of Knowledge) project management standard [10], in which the planning process group makes up more than half of all project processes (24 out of 49). Such studies take into account the project objectives, directly related to the sustainability of the so-called «project triangle according to PMBOK»: time, cost, scope and quality. The research [11] states that sustainable development goals can be achieved by «embedding» sustainable development issues at different levels of the hierarchy of project plans, by «simple implementation of the plan» and «monitoring on a monthly/weekly basis». However, such tools for working with the SDGs during the planning phase lack flexibility.

Decisions on the integration of some SDGs into the project management system are being developed. In [12], a solution was proposed for the sustainable management of construction projects in part of the SDGs: 5 «Gender Equality». It is noted that the gender logical system is effective for the implementation of project stakeholder management processes and the formation of a qualitative context of architectural and planning decisions of construction projects. Sustainable development of project-oriented management as the ability of a management system to apply a gender mainstreaming approach is presented in [13]. A model for assessing the gender maturity of an organization on the platform of the project management maturity model is proposed. The basic principles for creating a gender-oriented project management office are described in [14]. A PMO<sub>G</sub> maturity model is proposed in the context of project management knowledge areas (PMBOK) and gender-sensitive maturity characteristics. However, sustainability-oriented project management requires the development of not only partial solutions, but also integration solutions that offer orientation to all 17 SDGs. In addition, an important research task for the development of sustain-

ability-oriented project management remains taking into account the contextual features of construction project and program management.

The relevant PMBOK tools for evaluating practices for integrating sustainability into project portfolio management are presented in [15]. It is noted that due to the dynamic nature of projects, the project portfolio management system should be quite flexible. This is especially important for managing a portfolio with a large number of construction projects that differ not only in terms of economic indicators, but also environmental and social ones. Traditional project selection tools focus primarily on economic goals, which leads to the loss of benefits that could be obtained by taking into account social and environmental goals. The approach to the selection of construction projects for the portfolio proposed in [15] needs further development, not on the general platform of PMBOK, but on the PMBOK Construction specially developed for the construction industry [16]. Moreover, the analysis of the available literature showed that the content and understanding of sustainability may differ depending on the context (construction, information technology, etc.). The authors of a review and analysis of relevant publications [17] found that 65 % of publications on sustainability in project management are dedicated to a specific industry, most of which (55 %) are related to the construction industry. Also in [17], the impact of sustainability on the processes and practice of project management is analyzed. It is shown that such influence is sensitive at different levels. It is important that there is a need to change the project management paradigm: from tight controllability to flexibility. PMBOK has also been criticized because it identifies internal or external factors of the project environment, but does not identify potential social or environmental interests as influencing factors.

In addition, the assessment of sustainability for different groups of project management processes according to PMBOK (initiation – planning – executing – monitoring and controlling – closing) has not been researched enough, most publications are devoted to the execution process group. In particular, in the study [2] proposes 22 indicators of the sustainability of construction projects at the stage of implementation, which are grouped as environmental and socio-economic. There is a need to further explore sustainability in correlation with all groups of project management processes, with the growing awareness of the need to apply sustainability concepts in project management.

In the study [18], sustainability-oriented project planning was presented on the conceptual basis of strategic management. The author proves that the characteristics of strategic planning can be effectively included in the generalized structure of project management. It is argued that the internal consistency of tools and methods in PMBOK planning process groups can be improved through strategic planning. This, in turn, enables the inclusion of sustainability-oriented processes, since strategic planning is built, in particular, on the basis of the completeness of strategic alternatives and the participation of various stakeholder groups.

Researchers began to increasingly address the issues of sustainability, both as a goal of the project and as a characteristic of the process by which the project is managed. In [19], various options of indicators are proposed for use at different stages of a construction project, and the selection of a set of stability indicators is provided to meet the requirements of different phases of the project. In work [20], 82 sustainability indicators related to the practice of project management in

construction projects are defined. Their classification into economic, environmental and social indicators of sustainability was carried out through semi-structured interviews with construction experts. This research has practical utility as it offers practitioners the opportunity to select the necessary combination of indicators, depending on the sustainability orientation they want to ensure in their projects. In [21], it is stated that usually construction contractors do not have a clear understanding of sustainability, the defining parameter for them is planning productivity and the financial success of the project. Because of this, the authors suggest using the construction productivity factor to convince contractors to implement sustainability mechanisms in the construction project. This study developed a qualitative model for measuring the sustainability indicators of a construction project, taking into account the attraction of contractors to productivity. The model is based on the basic requirements of sustainable development, which are represented by three subsystems (economic, ecological, social), as well as feedback cycles between factors affecting the sustainability and productivity of construction. This model is useful for both practitioners and researchers, illustrating the relationship between performance and sustainability. At the same time, sustainability in the construction project management should be represented by a complex concept, and its development requires systemic thinking.

The paper [22] emphasizes the importance of environmental sustainability indicators for construction projects. The construction industry is considered one of the biggest contributors to climate change due to the consumption of natural resources and the generation of greenhouse gases. The authors note that proper management of construction projects, with a sustainability-oriented decision-making system and subsequent monitoring, can mitigate this problem. In [21], tools are proposed that only partially monitor the sustainability-orientedness of decisions regarding construction projects, namely by three indicators: waste reduction, energy consumption, and carbon emissions. Further development of the research requires expanding the structure of the corresponding indicators.

In [23], the use of the practice of planning engineering construction projects for the integration of sustainable development requirements was investigated. Qualitative methods based on content analysis of interview data of project managers from engineering construction objects were applied. The authors use the concept of «sustainable project planning», which combines the principles of sustainability with management processes (control, response to risks, reaching consensus). A scale that assesses the level of successful project planning taking into account the sustainability and projected success of civil engineering projects in the project life cycle is also proposed. This study focuses on how to integrate sustainability into construction projects from an internal project management perspective. At the same time, factors of the external environment that are important for planning, such as the needs of stakeholders, as well as the managerial task of balancing them, require more thorough research.

Despite the fact that existing studies [9, 11–23] direct attention to the sustainability of construction project management, the vast majority of them consider project planning directly as a tool to support internal sustainability during the project life cycle. The problem of assessing the sustainability of construction projects from the point of view of external sustainability, including achieving the SDGs, remains unexplored.

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### 3. The purpose and objectives of the study

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The purpose of the study is to develop a solution for assessing the sustainability of construction project management on the methodological platform of the project management of the PMBOK Construction [16] and GPM P5 [7] in the context of the «coordinate system» of the SDGs. This will allow construction project managers to provide those who make decisions on the initiation and financing of construction projects (sponsors, customers, developers) with an effective tool to assess the level of sustainability of the applied approaches and methods for the respective project management processes. The proposed decision-making toolkit will allow to initiate and develop construction projects with 5P values (Product, Process, People, Planet, and Prosperity). In the long term, sustainability will increase the energy independence and safety of construction sites, as well as the quality of life and consumption culture of construction project stakeholders.

To achieve this purpose, it is proposed:

- to develop basic mathematical models for quantitative assessment of the sustainability of construction project management in the initiation and planning processes on the methodological platform of PMBOK Construction and GPM P5;
- to propose a methodology for assessing the sustainability of construction project management.

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### 4. The materials and methods of the study

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The object of this study is the management processes of «sustainable construction».

The general methodological basis for this study is the system of construction project management processes defined by PMBOK Construction. For each of the initiation (2) and planning (24) processes, it is recommended to use a certain set of methods and tools. The conceptual basis of the study is also the GPM P5 standard [7], which defines the wider economic, ecological and social context of the project. Application of GPM 5R, together with PMBOK, allows managers to plan project activities to achieve sustainable project management. That is why the study proposes to consider the sustainable planning of a construction project by combining the processes, methods and tools of PMBOK Construction with the principles of sustainable development of GPM P5 (Table. 1).

This study is a scientific attempt to test the hypothesis that there is a specific correlation between the principles and approaches of sustainable development and the effectiveness of construction project management processes from the point of view of environmental friendliness, economy and social orientation (inclusiveness). Greater integration of 5P sustainable development values into management processes is a prerequisite for creating sustainability of the construction object.

Taking into account the general context of the construction project, the categories of sustainable development values of the construction object are proposed:

- P 1: the impact of the product (construction object) implies an increase in the term of operation of the facility through the use of safe materials and inclusive (human-oriented) technical solutions, as well as a decrease in the cost of service and maintenance of the object;
- P 2: the impact of construction project management processes means that project management processes are highly effective, fair to all project stakeholders and focused on achieving sustainable results;

– P 3: social impact. Firstly, it is the creation of decent working conditions, in particular: the creation of safe working conditions, the organization of training and the development of competencies, ensuring diversity and equal opportunities for all members of the project team. Secondly, the ability to interact with society and customers. In addition, it is important to demonstrate respect for human rights, observe the rules of fair competition;

– P 4: environmental impact is related to minimizing physical transportation (travel, deliveries) and maximizing

the use of digital communication technologies. In addition, it is necessary to carefully use energy resources in construction, switch to renewable energy sources and local materials;

– P 5: economical injection. The implementation of a sustainable construction project must be financially successful and cost-effective. To do this, business cases are analyzed with options for estimating current costs, profitability, profits, etc. It is desirable that permanently oriented construction projects receive financial support from investors, government agencies and local governments.

Table 1

Characteristics of the sustainability of construction project management in the initiation and planning processes

Construction project management processes (PMBOK Construction)	Tools & Techniques	Characteristics of sustainability construction project management process
1	2	3
Pre Project/Initiation Phase		
1. 1. Develop Project Charter	1. 1. 1. Expert judgment	– applied to determine methods and means of development of construction, values of elements of sustainable development; – is performed by the sponsor, the customer with the involvement of project stakeholders
	1. 1. 2. Data gathering	Analysis of assumptions and constraints begins with responses to a Request for Proposals (RFP). At the same time, the vision (point of view) of the customer, contractor and every stakeholder participating in the project should be taken into account. For each construction project, it is necessary to collect data on environmental impacts, safety of personnel and the public, as well as safety regulations. Data gathering is carried out by the methods of «brainstorming», «focus groups», «interviewing»
	1. 1. 3. Interpersonal and team skills	Interpersonal and team skills are used for conflict management, facilitation, meeting management. Working in a team focused on achieving the values of sustainable development is based on mutual respect, equal rights and opportunities, fair competition, zero tolerance for corruption, etc.
	1. 1. 4. Meetings	Meetings are held with the participation of key stakeholders of the construction project (including the involvement of the customer, contractor, designer, clients) to determine the project goals, success criteria, key results ..., values of sustainable development (social, environmental, economic)
10. 1. Identify Stakeholders	10. 1. 1. Expert judgment	Expert judgment applied to a comprehensive identification and list of stakeholders (including those with competing goals and expectations that affect the progress of the project in different ways). Expert judgment of stakeholders of a sustainable project is carried out with the involvement of a green manager, BREEAM/LEED/LBC certification experts, as well as taking into account previous experience. In making a decision to move to the «Planning» phase, preference is given to expert evaluation
	10. 1. 2. Data gathering	Data gathering depends on the scale of the project. For example, construction projects financed from state or local budgets involve legally complex data collection procedures (official requests, applications, tenders). Environmental initiatives can be part of regulatory or design requirements (data)
	10. 1. 3. Data analysis	The results of the analysis of stakeholders, their interests, expectations and attitudes towards the project are used to mitigate potential unknown risks. The result of document analysis is an assessment of knowledge, competence of the management team, previous experience («lessons learned») in sustainability-oriented management of construction projects. General data analysis – list of stakeholders with relevant information, definition of role and place in the project, expectations with correlation to SDGs
	10. 1. 4. Data representation	Data representation implemented in the form of «matrix of power/interests of stakeholders to the project» and potential ambiguity regarding the needs and requirements for design and technical solutions of a sustainable construction object
	10. 1. 5. Meetings	Meetings are held regularly with the involvement of all project stakeholders (including beneficiaries, green manager, BREEAM/LEED/LBC certification expert), as well as taking into account the role in the project, responsibilities, level of authority. All meeting participants adhere to a culture of sustainability). Meetings are held using a wide range of online group work tools

1	2	3
Planning Phase		
1. 2. Develop Project Management Plan	1. 2. 1. Expert judgment	Expert judgment is used for: – adaptation of management processes in accordance with the needs of the developer, client, green manager, BREEAM/LEED/LBC certification experts and other stakeholders; – development of technical and management solutions regarding the best way to implement the project and obtain sustainability results/values for all involved parties; – evaluation of the integration of the principles of sustainable development into the environment of the construction project
	1. 2. 2. Data gathering	Similarly to p. 1. 1. 2, p. 10. 1. 2. Particular attention is paid to the collection of data related to safety, quality, protection, ecology, supply of resources. For the development of an integrated construction project management plan, important data are contained in contracts, in particular: stages of delivery; cost/price; requirements for reporting, inspection, reception-handover; import and export rules
	1. 2. 3. Interpersonal and team skills	Similarly to p. 1. 1. 3. Employees may need training in: cultural values of sustainable development; honesty and openness; zero tolerance for corruption; rules of communication with contractors from other countries. It is important that the project management plan includes all team members and reflects the specialized knowledge available to the project manager
	1. 2. 4. Meetings	At the first meeting to discuss the project management plan, it is important to define the roles of each stakeholder (including the green-manager and BREEAM/LEED/LBC certification experts)
2. 1. Plan Scope Management	2. 1. 1. Expert judgment	Expert judgment is used to take into account the requirements of the construction project and the executing organization (owner, contractor, construction manager). In addition, expert evaluation is provided by green-manager and BREEAM/LEED/LBC certification experts
	2. 1. 2. Data analysis	Data analysis includes the analysis of alternatives, in particular, methods and options for engineering, architectural and technical solutions to ensure the stability of the construction site are evaluated. A set of data for project drawings, specifications, contracts is being formed. Tolerances, advantages, quality level of materials and equipment are also determined
	2. 1. 2. Meetings	Meetings are held with key stakeholders of the project (including involving the customer, contractors and subcontractors, green-manager and BREEAM/LEED/LBC certification experts)
2. 2. Collect Requirements	2. 2. 1. Expert judgment	Expert judgment is used to identify and analyze the requirements of stakeholders (including green-manager and BREEAM/LEED/LBC certification experts). The volume and probability of potential claims from the customer, green-manager and BREEAM/LEED/LBC certification experts are determined
	2. 2. 2. Data gathering	Similarly to p. 1. 1. 2., p. 10. 1. 2, p. 1. 2. 2. Construction projects require obtaining official permits for the start of construction and assembly works. As a rule, technical conditions from state inspections (fire safety, labor protection, energy saving, etc.) are required. In addition, a social impact assessment (SIA) of the construction site and an environmental impact assessment (EIA) are performed
	2. 2. 3. Data analysis	Similarly to p. 10. 1. 3, p. 2. 1. 2. The analysis of documents involves the identification of all documented information related to the requirements of design and technical decisions of the construction object. The list of documents may include: regulatory documentation; green construction standards; agreements; requests and offers; knowledge base of best practices of sustainable buildings, etc.
	2. 2. 4. Decision making	Decision making is carried out on the basis of a multi-criteria assessment (including 5P value categories). Among the multitude of subcategories, preference is given to those that ensure the stability of the construction object. The evaluations of green-manager and BREEAM/LEED/LBC certification experts have more weight
	2. 2. 5. Data representation	Data representation is carried out in the form: – Affinity diagrams: stakeholders (including green-managers and BREEAM/LEED/LBC certification experts) identify ideas and combine similar ideas into groups; – Mind mapping: stakeholders (including green-manager and BREEAM/LEED/LBC certification experts) combine all ideas, reflect common and different ones, and then supplement with new ones
	2. 2. 6. Interpersonal and team skills	Similarly to p. 1. 1. 3, p. 1. 2. 3. In addition, customer-oriented methods are used to collect requirements for the construction project, in particular: «Voice of the customer (VOC)», user stories (User stories). Modern construction project management teams use ICT tools (JIRA, Trello, Asana, etc.) to link internal communications
	2. 2. 7. Context diagram	Context diagram reflects how stakeholders (including the customer, designer, contractor, green-manager and BREEAM/LEED/LBC certification experts) will interact to ensure the sustainability of the construction object
	2. 2. 8. Prototypes	Prototypes is implemented by creating working 3D, 4D, ... models of the construction object using information modeling (Building Information Modeling, BIM), allows to obtain a preliminary visualization of the requirements of stakeholders (including green-manager and BREEAM/LEED/LBC certification experts)

Continuation of Table 1

1	2	3
2.3. Define Scope	2.3.1. Expert judgment	Similarly to p. 1.1.1, p. 1.2.1, p. 2.2.1. Preference is given to the assessment of experts who have more experience in the implementation of sustainable construction projects
	2.3.2. Data analysis	Similarly to p. 10.1.3, p. 2.1.2, p. 2.1.3. The analysis of alternatives is used to assess the degree of correlation of the values of sustainable development of the 5Rs in the engineering solutions of the construction object, as well as ways of achieving their sustainability
	2.3.3. Decision making	Similarly to p. 2.2.4
	2.3.4. Interpersonal and team skills	Similarly to p. 1.1.3, p. 1.2.3, p. 2.2.6. The project manager is responsible for timely delivery of technical solutions to the project team and the relevant supply chain team (subcontractor team). Fulfillment of these duties may be part of the contractor's responsibility (for example, under an EPC contract (Engineering, procurement and construction))
	2.3.5. Product analysis	Product analysis can take place several times, in particular at the stages: «sketch design», «technical and economic justification», «project», «working documentation», «working project». To analyze the stability of the construction object, the following methods are used: decomposition of tasks (project actions); assumptions and risk assessment; cost estimation; assessment of values
2.4. Create work breakdown structure, WBS	2.4.1. Expert judgment	Similarly to p. 1.1.1, p. 1.2.1, p. 2.2.1, p. 2.3.1
	2.4.2. Decomposition	It is used to divide the project scope and project deliverables into smaller, more manageable parts. The result of decomposition is Work Breakdown Structures (WBS), Construction Work Packages (CWPs). The WBS and CWPs of the sustainable management of the construction project should include reports on the achievement of the 5P values
3.1. Plan Schedule Management	3.1.1. Expert judgment	Similarly to p. 1.1.1, p. 1.2.1, p. 2.2.1, p. 2.3.1. Expert assessment of the planning of the sustainability of the construction project should be based on knowledge, including the use of special software (for example, Microsoft Project, Project Libre)
	3.1.2. Data analysis	Similarly to p. 10.1.3, p. 2.1.2, p. 2.1.3, p. 2.3.2
	3.1.3. Meetings	Similarly to p. 1.1.4, p. 10.1.5, p. 1.2.4, p. 2.1.2
3.2. Define Activities	3.2.1. Expert judgment	
	3.2.2. Decomposition	
	3.2.3. Rolling wave planning	
	3.2.4. Meetings	
3.3. Sequence Activities	3.3.1. Precedence diagramming method (PDM)	
	3.3.2. Dependency determination and integration	
	3.3.3. Leads and lags	
	3.3.4. Project management information system	
3.4. Estimate Activity Durations	3.4.1. Expert judgment	
	3.4.2. Analogous estimating	
	3.4.3. Parametric estimating	
	3.4.4. Three-point estimating	
	3.4.5. Bottom-up estimating	
	3.4.6. Data analysis	
	3.4.7. Decision making	
	3.4.8. Meetings	
3.5. Develop Schedule	3.5.1. Schedule network analysis	
	3.5.2. Critical path method	
	3.5.3. Resource optimization	
	3.5.4. Data analysis	
	3.5.5. Leads and lags	
	3.5.6. Schedule compression	
	3.5.7. Project management information system	
	3.5.8. Agile release planning	

1	2	3
4. 1. Plan Cost Management	4. 1. 1. Expert judgment	
	4. 1. 2. Data analysis	
	4. 1. 3. Meetings	
4. 2. Estimate Costs	4. 2. 1. Expert judgment	
	4. 2. 2. Analogous estimating	
	4. 2. 3. Parametric estimating	
	4. 2. 4. Bottom-up estimating	
	4. 2. 5. Three-point estimating	
	4. 2. 6. Data analysis	
	4. 2. 7. Project management information system	
	4. 2. 8. Decision making	
4. 3. Determine Budget	4. 3. 1. Expert judgment	
	4. 3. 2. Cost aggregation	
	4. 3. 3. Data analysis	
	4. 3. 4. Historical information review	
	4. 3. 5. Funding limit reconciliation	
	4. 3. 6. Financing	
5. 1. Plan Quality Management	5. 1. 1. Expert judgment	Similarly to p. 1. 1. 1, p. 1. 2. 1, p. 2. 2. 1, p. 2. 3. 1, p. 3. 1. 1. Stakeholders (including the customer, designer, contractor, green-manager and BREEAM/LEED/LBC certification experts) must have experience in quality assurance, control, measurement, and quality improvement, as well as the creation of a quality system for construction objects
	5. 1. 2. Data gathering	Similarly to p. 1. 1. 2., p. 10. 1. 2, p. 1. 2. 2, p. 2. 2. 2
	5. 1. 3. Data analysis	Similarly to p. 10. 1. 3, p. 2. 1. 2, p. 2. 1. 3, p. 2. 3. 2. The analysis of costs and benefits is carried out with the involvement of green-manager and BREEAM/LEED/LBC certification experts
	5. 1. 4. Decision making	
	5. 1. 5. Data representation	Similarly to p. 2. 2. 5. Green-manager and BREEAM/LEED/LBC certification experts develop SIPOC diagrams (Suppliers, Inputs, Process, Outputs, and Customers). Such a logical data model visualizes information flows to achieve the 5P sustainability values
	5. 1. 6. Test and inspection planning	The project team (including green-manager and BREEAM/LEED/LBC certification experts) determine how to test or inspect the construction object to meet the needs and expectations of stakeholders and achieve the 5P sustainability values
	5. 1. 7. Meetings	
6. 1. Plan Resource Management	6. 1. 1. Expert judgment	
	6. 1. 2. Data representation	Similarly to p. 2. 2. 5, p. 5. 1. 5. To document the roles and responsibilities of team members (including green-manager and BREEAM/LEED/LBC certification experts), the following are used: organizational hierarchical structure, hierarchical resource structure, responsibility distribution matrix
	6. 1. 3. Organizational theory	Organizational theory provides orientation to the development of organizational maturity in the sustainable management of construction projects
	6. 1. 4. Meetings	
6. 2. Estimate Activity Resources	6. 2. 1. Expert judgment	
	6. 2. 2. Bottom-up estimating	
	6. 2. 3. Analogous estimating	
	6. 2. 4. Parametric estimating	
	6. 2. 5. Data analysis	
	6. 2. 6. Project management information system	
	6. 2. 7. Meetings	

Continuation of Table 1

1	2	3
7. 1. Plan Communications Management	7. 1. 1. Expert judgment	
	7. 1. 2. Communication requirements analysis	Communication requirements analysis determines the information (internal and external) needs of project stakeholders (including green-manager and BREEAM/LEED/LBC certification experts)
	7. 1. 3. Communication technology	A sustainable construction project management team prefers digital tools for collaboration and information sharing, including: online meetings, electronic document flow, databases, social networks and websites
	7. 1. 4. Communication models	The sustainable management team of a construction project chooses a communication style that takes into account differences in work methods, age, nationality, professional specialty, ethnicity, race or gender
	7. 1. 5. Communication methods	
	7. 1. 6. Interpersonal and team skills	
	7. 1. 7. Data representation	
	7. 1. 8. Meetings	
8. 1. Plan Risk Management	8. 1. 1. Expert judgment	
	8. 1. 2. Data analysis	
	8. 1. 3. Meetings	Meetings take place with the participation of green-managers and BREEAM/LEED/LBC certification experts
8. 2. Identify Risks	8. 2. 1. Expert judgment	
	8. 2. 2. Data analysis	
	8. 2. 3. Interpersonal and team skills	
	8. 2. 4. Prompt lists	Prompt lists are the result of the team’s previous experience of sustainable management of a construction project with models: PESTLE (political, economic, social, technological, legal, environmental), TECOP (technical, environmental, commercial, operational, political), or VUCA (volatility, uncertainty, complexity, ambiguity)
	8. 2. 5. Meetings	
8. 3. Perform Qualitative Risk Analysis	8. 3. 1. Expert judgment	
	8. 3. 2. Data gathering	
	8. 3. 3. Data analysis	
	8. 3. 4. Interpersonal and team skills	
	8. 3. 5. Risk categorization	
	8. 3. 6. Data representation	
	8. 3. 7. Meetings	
8. 4. Perform Quantitative Risk Analysis	8. 4. 1. Expert judgment	
	8. 4. 2. Data gathering	
	8. 4. 3. Interpersonal and team skills	
	8. 4. 4. Representations of uncertainty	
	8. 4. 5. Data analysis	
8. 5. Plan Risk Responses	8. 5. 1. Expert judgment	
	8. 5. 2. Data gathering	
	8. 5. 3. Interpersonal and team skills	
	8. 5. 4. Strategies for threats	
	8. 5. 5. Strategies for opportunities	
	8. 5. 6. Contingent response strategies	
	8. 5. 7. Strategies for overall project risk	
	8. 5. 8. Data analysis	
	8. 5. 9. Decision making	

1	2	3
9. 1. Plan Procurement Management	9. 1. 1. Expert judgment	
	9. 1. 2. Data gathering	
	9. 1. 3. Data analysis	
	9. 1. 4. Source selection analysis	
	9. 1. 5. Meetings	
10. 2. Plan Stakeholder Engagement	10. 2. 1. Expert judgment	Expert judgment is used to determine the level of involvement of each stakeholder (including the customer, designer, contractor, green-manager and BREEAM/LEED/LBC certification experts) at each stage of the construction project
	10. 2. 2. Data analysis	Data analysis can be presented in the form of a «stakeholder participation assessment matrix» (including BREEAM/LEED/LBC certification experts, an expert on gender mainstreaming in construction [24] and others)
	10. 2. 3. Decision making	Decision making takes place with the participation of BREEAM/LEED/LBC certification experts, an expert on gender mainstreaming in construction
	10. 2. 4. Data representation	Data representation in the form of a «stakeholder matrix», green-manager needs matrices, BREEAM/LEED/LBC certification experts and an expert on gender mainstreaming in construction
	10. 2. 5. Meetings	Meetings of stakeholders (including green-manager, BREEAM/LEED/LBC certification experts and, an expert on gender mainstreaming in construction) and the project group are devoted to determining the necessary level of involvement of all stakeholders during the life cycle of a construction project
11. 1. Project HSSE (Healthy, Safety, Security, Environmental) Management Planning	11. 1. 1. Methods for maintaining a healthy site	<ul style="list-style-type: none"> <li>– drug and alcohol screening;</li> <li>– material safety data sheets (MSDS);</li> <li>– globally harmonized system (GHS);</li> <li>– dust control and noise control measures;</li> <li>– onsite medical facilities (includes portable equipment such as an eyewash station, emergency shower, etc.);</li> <li>– fatigue mitigation plans;</li> <li>– work hour limitations;</li> <li>– climate-specific mitigation such as available water, warming huts, etc.;</li> <li>– regular health checkups and hygienic work conditions;</li> <li>– provision of trained first aid personnel (nearby, if not on job site)</li> </ul>
	11. 1. 2. Methods of ensuring job site safety in the construction environment	<ul style="list-style-type: none"> <li>– verification and validation that personal protective equipment (PPE)</li> <li>– pre-site preparation (hazard analysis, permits, site familiarization, and ongoing hazard tagging, etc.);</li> <li>– ongoing training, traffic management;</li> <li>– verification of safeguards;</li> <li>– periodic checking of tools and equipment;</li> <li>– standard operating procedures (SOP);</li> <li>– risk recognition and assessment;</li> <li>– OSHA compliance (Occupational Safety and Health Administration);</li> <li>– onsite safety compliance personnel</li> </ul>
	11. 1. 3. Methods of secure job site	<ul style="list-style-type: none"> <li>– badge- or smartcard-controlled access;</li> <li>– security gates and fencing;</li> <li>– traffic barriers;</li> <li>– security guards;</li> <li>– remote security (cameras, sensors, etc.);</li> <li>– site lighting</li> </ul>
	11. 1. 4. Methods of environmental	<ul style="list-style-type: none"> <li>– recycling/waste management;</li> <li>– hazardous waste handling;</li> <li>– environmental clean-up;</li> <li>– noise monitoring;</li> <li>– acoustic control;</li> <li>– cultural resource planning;</li> <li>– environmental impacts;</li> <li>– site drainage;</li> <li>– dust control;</li> <li>– traffic management;</li> <li>– government permitting requirements</li> </ul>
12. 1. Project Financial Planning	12. 1. 1. Analytical Techniques	
	12. 1. 2. Feasibility Study	
	12. 1. 3 Corporate Finance	

The project management processes of the pre-project phase/initiation phase and the planning phase are a special focus of attention, since it is at the initial stages that the content of the project is formed. During the «execution» phase, fundamental changes in the engineering solutions of construction projects lead to a significant overrun of the budget and a decrease in performance indicators. After all, it is known that the early development of the scope of work creates a starting point for the developer, and the scope and content of design solutions develops along with the creation of requirements for the construction object.

Mathematical modeling tools and tools are also used to test the hypothesis; methods of multi-criteria evaluation and optimization in conditions of varying degrees of certainty of the source information. The application of the GPM P5 sustainable development value focus in the context of the construction project management methodology (PMBOK Construction) allowed to develop a qualitatively new model for assessing the sustainability of construction project management in the initiation and planning processes.

To test the hypothesis, the means and tools of mathematical modeling, methods of multi-criteria evaluation and optimization are also used under conditions of varying degrees of certainty of the initial information. The use of the GPM P5 sustainable development values focus in the context of the construction project management methodology (PMBOK Construction) has made it possible to develop a qualitatively new model for assessing the sustainability of construction project management in the processes of initiation and planning.

The study is based on the experience of the author's participation in the development of decision-making models for construction projects as components of the sustainable development of the city of Kharkiv (Ukraine).

**5. Results of the development of a model for assessing the sustainability of construction project management**

**5.1. Mathematical models of quantitative assessment of the sustainability of construction project management in the initiation and planning processes**

The nature of sustainability orientation of the developer's management can be determined by an integral assessment of the sustainability of construction project management processes. In the context of a project approach, a sustainable construction project management system must demonstrate all the necessary management methods and tools for the initiation and planning of a construction project. Sustainability assessments are carried out using balanced regression relationships (with a zero free term) and include:

– a partial model of balanced assessment for all areas of construction project management knowledge for each process, which has the form:

$$VB_j = \lambda_1 S_{j1} + \lambda_2 S_{j2} + \dots + \lambda_n S_{jn} + \varepsilon_{ij}, \quad j = \overline{1, m}, \quad (1)$$

where  $S_{ji}$  – is an assessment of the sustainability of the  $j$ -th construction project management process of the  $i$ -th area of knowledge,  $j = \overline{1, m}$ ,  $i = \overline{1, n}$ ;  $m$  – is the number of construction project management processes in the «Initiation» and «Planning» phases  $m=28$ ;  $n$  – is the number of categories (subcategories) of 5P sustainable development, which are evaluated;  $VB_j$  – is a balanced assessment of knowledge areas of con-

struction project management for the  $j$ -th process,  $j = \overline{1, m}$ ;  $\lambda_1, \lambda_2, \dots, \lambda_n$  – are non-negative weighting coefficients that satisfy the normalization condition  $\lambda_1 + \lambda_2 + \dots + \lambda_n = 1$ ;  $\varepsilon_{ij}$  – Gaussian white noise with zero mathematical expectation;

– a partial balanced assessment model for all construction project management processes at the «Initiation» and «Planning» phases for each category of sustainable development 5P, which has the form:

$$VB_{di} = \mu_1 S_{1i} + \mu_2 S_{2i} + \dots + \mu_m S_{mi} + \varepsilon_{di}, \quad i = \overline{1, n}, \quad (2)$$

where  $VB_{di}$  – is a balanced evaluation of the sustainability of construction project management in relation to the  $i$ -th category (subcategories) of sustainable development 5P,  $i = \overline{1, n}$ ;  $\mu_1, \mu_2, \dots, \mu_m$  – are non-negative weighting coefficients that satisfy the normalization  $\mu_1 + \mu_2 + \dots + \mu_m = 1$ ;  $\varepsilon_{di}$  – Gaussian white noise with zero mathematical expectation;

– model of integral assessment of sustainability of construction project management processes ( $VB$ ), which can be presented either as a weighted average of balanced scores by knowledge areas for all processes:

$$VB = \mu_1 VB_1 + \mu_2 VB_2 + \dots + \mu_m VB_m + \varepsilon, \quad (3)$$

or as a weighted average of the estimated balanced construction project management processes for all 5P sustainable development categories:

$$VB = \lambda_1 VB_{d1} + \lambda_2 VB_{d2} + \dots + \lambda_n VB_{dn} + \varepsilon, \quad (4)$$

where  $\varepsilon$  – Gaussian white noise with zero mathematical expectation.

Thus, a model has been formed for the integral assessment of  $VB$  sustainability of construction project management processes:

$$VB = \sum_{j=1}^m \sum_{i=1}^n \mu_j \lambda_i S_{ji} + \varepsilon. \quad (5)$$

Mathematical relations (3) and (4) result in the equation:

$$\begin{aligned} \mu_1 VB_1 + \mu_2 VB_2 + \dots + \mu_m VB_m &= \\ = \lambda_1 VB_{d1} + \lambda_2 VB_{d2} + \dots + \lambda_n VB_{dn}, \end{aligned} \quad (6)$$

which allows to control the results of calculating the optimal values of the weighting factors  $\lambda_1, \lambda_2, \dots, \lambda_n$  and  $\mu_1, \mu_2, \dots, \mu_m$ .

In problems where there are no statistical characteristics of the variables describing the object, the method of least squares (LSM) is used for parametric identification. It is necessary to take into account the following complications: firstly, the set of models (1), (2), (5) is linear in areas of knowledge and in project management processes, but non-linear in general in terms of the evaluated parameters. Such a situation requires the use of iterative computational procedures. Secondly, in order to obtain reasonable regression estimates, it is necessary that the volume of observations exceeds the number of weighting coefficients by several times. On the other hand, the size of the diagnostic matrix of an individual object does not meet this condition. Thirdly, the rows and columns of the matrix are characterized by a high level of multicollinearity. Therefore, the potential numerical instability of computational procedures is traced. In order to overcome the latter difficulties, it is proposed to use a priori estimates and regularization of the optimality criterion.

Taking into account the subject area of the assessment task, let's accept restrictions on the weighting coefficients:

$$\begin{aligned} \lambda_i &\geq 0, \quad i = \overline{1, n}; \quad \mu_j \geq 0, \\ j &= \overline{1, m}; \quad \sum_{i=1}^n \lambda_i = 1; \quad \sum_{j=1}^m \mu_j = 1. \end{aligned} \quad (7)$$

Taking into account the peculiarities of the diagnostic matrix and the identification problem in general, the calculation of optimal estimates of the weighting coefficients is carried out using the weighted LSM. At the same time, restrictions are taken into account and regularization is applied (to ensure the stability of computer calculations and reflect the presence of a priori ideas about the values of the coefficients). The optimality criterion to be minimized is the function:

$$\begin{aligned} f &= \alpha_1 \sum_{j=1}^m \left( \sum_{i=1}^n \lambda_i S_{ji} - VB_j^{(e)} \right)^2 + \\ &+ \alpha_2 \sum_{i=1}^n \left( \sum_{j=1}^m \mu_j S_{ji} - VB_{di}^{(e)} \right)^2 + \\ &+ \alpha_c \left( \sum_{j=1}^m \sum_{i=1}^n \mu_j \lambda_i S_{ji} - VB^{(e)} \right)^2 - \\ &- \chi \sum_{j=1}^m (\mu_j + \mu_j^{(a)})^2 + \chi \sum_{i=1}^n (\lambda_i - \lambda_i^{(a)})^2, \end{aligned} \quad (8)$$

where  $\alpha_1, \alpha_2, \alpha_c$  – are the integral weights of real observations of  $VB_j^{(e)}, VB_{di}^{(e)}, VB^{(e)}$  of the corresponding sustainability indicators of construction project management processes;  $\lambda_i^{(a)}$  and  $\mu_j^{(a)}$  – a priori estimates of the corresponding weight coefficients;  $\chi$  – a positive regulation parameter,  $i = \overline{1, n}; j = \overline{1, m}$ .

The choice of values  $\alpha_1, \alpha_2, \alpha_c, \lambda_i^{(a)}, \mu_j^{(a)}, \chi$  allows to take into account additional information about the quality of control measurements and expert data processing, experience in assessing the sustainability of construction projects, as well as the complexity of formalizing the opinion of experts. When the estimates  $\lambda_i^{(a)}$  and  $\mu_j^{(a)}$  are unknown, then is accepted a priori  $\lambda_i^{(a)} = 0, \mu_j^{(a)} = 0$ , which corresponds to the norm restriction of the optimal values of the weighting coefficients according to criterion (8). The degree of stabilization of the optimal estimates of the weighting coefficients is determined by the value of the regulation parameter  $\chi$ , a priori  $\chi = 0.001$  is accepted. The selection of the ratio between the values of the weighting elements  $\alpha_1, \alpha_2, \alpha_c$  allows to adjust the relative degree of minimization of the corresponding deviations. Taking into account the scale of the values under consideration and volumetric data, the following is assumed a priori:  $\alpha_1 = 1, \alpha_2 = 1, \alpha_c = 1 (m+n \sim 40)$ .

The specificity of the set of models (1), (2), (5) and the structure of the conditional minimization problem (7), (8) allows splitting the iterative process of parametric identification into separate components. At the first stage, reduced problems of a much smaller size are solved, parallelism of calculations is allowed. At the same time, the corresponding models are linear in parameters, and the objective functions are quadratic, therefore they have a single unconditional global minimum. Also, at the first stage, the selection of the initial approximation around the compatible conditional extremum is ensured. The admissible input initial estimates of the weighting factors can be taken as normal (minimum according to the norm) solutions of the constraints-equations from (7), which gives  $\lambda_i = 1/n, \mu_j = 1/m$ . Next, based on

the initial values of the weighting coefficients, their refined estimates are found as solutions to two parallel quadratic programming problems  $Q_1$  and  $Q_2$ :

$$\begin{aligned} Q_1: f_{Q1} &= \alpha_1 \sum_{j=1}^m \left( \sum_{i=1}^n \lambda_i S_{ji} - VB_j^{(e)} \right)^2 + \\ &+ \chi \sum_{i=1}^n (\lambda_i - \lambda_i^{(a)})^2 \rightarrow \min, \end{aligned} \quad (9)$$

with restrictions:  $\lambda_i \geq 0, i = \overline{1, n}; \sum_{i=1}^n \lambda_i = 1;$

$$\begin{aligned} Q_2: f_{Q2} &= \alpha_2 \sum_{i=1}^n \left( \sum_{j=1}^m \mu_j S_{ji} - VB_{di}^{(e)} \right)^2 + \\ &+ \chi \sum_{j=1}^m (\mu_j - \mu_j^{(a)})^2 \rightarrow \min, \end{aligned} \quad (10)$$

with restrictions:  $\mu_j \geq 0, j = \overline{1, m}; \sum_{j=1}^m \mu_j = 1$ , where the objective functions  $f_{Q1}$  and  $f_{Q2}$  – are separated  $\lambda_1, \lambda_2, \dots, \lambda_n$  and  $\mu_1, \mu_2, \dots, \mu_m$  components of criterion (8), in which  $\lambda_c = 0$  is set and the corresponding balance ratios (7) are taken into account.

At the second stage, the results of preliminary calculations are reconciled and a comprehensive correction of the set of parameter values of the models as a whole takes place. Relying on the directly independent preliminary estimates of the weighting coefficients as initial, their agreement and final optimization is carried out as a result of solving the general problem for the conditional extremum (7), (8). Control of calculations of optimal values of weighting coefficients is carried out by checking equality (6).

To implement computational procedures of parametric identification, the freely distributed Scilab software environment is used [25]. The obtained LSM estimates of the weighting coefficients will serve as an information base for further expert research.

## 5.2. Development of a methodology for quantitative assessment of the sustainability of construction project management

Development of a methodology for quantitative assessment of the sustainability of construction project management  $\lambda_1, \lambda_2, \dots, \lambda_n$  (Table 2) and the subcategories of the sustainable development of the construction object  $\mu_1, \mu_2, \dots, \mu_m$  (Table 3) by expert means. At the same time, a decisive role is given to an expert in the field of green construction (green manager). He/she carries out an adjusted generalization of their corresponding numerical estimates, obtained by the methods of parametric identification of sustainability balance models according to the criterion of the minimum sum of squares of the deviations of the model values of the sustainability of management processes from the real ones.

An example of quantitative assessments of sustainability of construction project management processes is given in Table 4. A continuous scale  $[-1; 1]$  with reference markers:

- «1» – the construction project management process fully ensures the achievement of the value (category) of sustainable development;
- «0» – the construction project management process does not involve achieving the value (category) of sustainable development;
- «-1» – the construction project management process negatively affects the value (category) of sustainable development.

Table 2

An example of weighting coefficients of management processes in ensuring the sustainability of a construction object

Construction Project Management Knowledge Areas	Construction project management processes in the «Initiation» and «Planning» phase (PMBOK, PMBOK Construction)		Weight coefficient, λ
1. Project integration management	1. 1. Development of the Project Charter	1	0.05
	1. 2. Development of a project management plan	2	0.05
2. Project scope management	2. 1. Project scope management planning	3	0.045
	2. 2. Collection of requirements	4	0.035
	2. 3. Determining of project scope	5	0.035
	2. 4. Creating a hierarchical structure of works	6	0.03
3. Project schedule management	3. 1. Planning project schedule	7	0.035
	3. 2. Determining of operations/project actions	8	0.03
	3. 3. Sequence of operations/project actions	9	0.03
	3. 4. Evaluation of the duration of operations/project activities	10	0.03
	3. 5. Project schedule development	11	0.03
4. Project cost management	4. 1. Project cost management planning	12	0.035
	4. 2. Estimating of project cost	13	0.03
	4. 3. Defining the project budget	14	0.03
5. Project quality management	5. 1 Plan quality management	15	0.04
6. Project resource management	6. 1. Plan resource management	16	0.04
	6. 2. Estimate activity resources	17	0.03
7. Project communications management	7. 1. Plan communications management	18	0.035
8. Project risk management	8. 1. Plan risk management	19	0.040
	8. 2. Identify risks	20	0.035
	8. 3. Perform qualitative risk analysis	21	0.030
	8. 4. Perform quantitative risk analysis	22	0.030
	8. 5. Plan risk responses	23	0.035
9. Project Procurement Management	9. 1. Plan Procurement Management	24	0.04
10. Project Stakeholder Management	10. 1. Identify Stakeholders	25	0.035
	10. 2. Plan Stakeholder Engagement	26	0.035
11. Project Health, Safety, Security, and Environment (HSSE) Management	11. 1. Project HSSE Management Planning	27	0.05
12. Project Financial Management	12. 1. Project Financial Planning	28	0.03
Σ			1.0

Table 3

An example of weighting factors for categories of sustainable development P5

Categories of sustainable development P5	Subcategories of sustainable development of the construction object	Weighting coefficient, μ
P 1. Impact of the product (construction object)	P 1. 1. The term of operation of the construction object	0.06
	P 1. 2. Operational maintenance of the construction object	0.07
P 2. The impact of construction project management processes	P 2. 1. Effectiveness of project processes	0.05
	P 2. 2. Efficiency of project processes	0.07
	P 2. 3. Fairness of project processes	0.06
P 3. Social impact	P 3. 1. Labor practices and decent work	0.07
	P 3. 2. Society and customers	0.07
	P 3. 3. Human rights	0.06
	P 3. 4. Ethical behavior	0.06
P 4. Environmental impact	P 4. 1. Transport	0.05
	P 4. 2. Energy	0.08
	P 4. 3. Land, air, and water	0.06
	P 4. 4. Consumption	0.06
P 5. Economic impact	P 5. 1. Business case analysis	0.07
	P 5. 2. Business agility	0.06
	P 5. 3. Economic stimulation	0.05
Σ		1,00

An example of assessing the sustainability of construction project management processes according to the 5P categories of sustainable development

Construction project management process number	Categories (subcategories) of sustainability															
	P 1. Impact of the product (construction object)		P 2. The impact of construction project management processes			P 3. Social impact				P 4. Environmental impact				P 5. Economic impact		
	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	1	1	1	0	0	0	0	1	1	1	1	1	1	1	0.5	0.5
2	0.8	1	0.9	1	1	0.9	1	0	0	0	0.5	0.5	0.5	0.5	-0.8	-0.5
3	1	1	1	0	0	0	0	-1	-0.7	-0.5	1	1	1	1	1	1
4	-1	-0.3	-0.7	-0.5	-0.4	-0.5	-0.3	0	0	0.5	0.5	0.5	0.5	-0.5	-1	-0.3
5	-1	-0.4	-0.5	0	0.5	0.4	0.5	-1	-1	-1	-0.7	-0.7	-0.5	-1	0	0
6	0.5	0.8	0.5	0.9	0.7	0.6	0.8	0.75	0.5	0.5	0.75	0.75	0.75	0.6	0.5	0.8
7	0.7	0	0.8	0	0	0	0	1	0.5	0.5	0.5	0.5	0.5	0.5	0	0
8	1	1	1	0	0	1	1	0	0	0	0	0	0	0	1	1
9	0.3	0.3	0.3	0	0	0	0	0	0	0	0	0	0	0	0.3	0.3
10	-1	-0.8	-1	-0.6	-0.7	-1	-1	1	1	1	1	1	1	1	-0.8	-0.5
11	0.5	0.5	0.5	0	0	0	0	1	1	1	1	1	1	1	0.5	0.5
12	-0.9	0	-0.9	0	0	0	0	1	1	1	1	1	1	1	-0.9	0
13	0.4	0.5	0.4	0.9	0.6	0.5	0.9	1	1	1	1	1	1	1	0.4	0.5
14	-1	-0.3	-0.7	0.3	0.2	0.5	0.5	-0.4	-0.5	-0.2	-0.2	0.7	0.8	0.6	-1	-0.3
15	-1	-1	-1	0	0	0	0	-1	-1	-1	0	-0.5	0	0	-1	-1
16	0.5	0.5	0.5	0.7	0.7	0.7	0.8	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.5
17	-0.3	0.7	-0.2	0.8	0.8	0.8	0.9	1	1	1	1	1	1	1	-0.3	0.5
18	1	1	1	1	1	1	1	0.5	0.5	1	1	1	1	1	1	1
19	1	1	1	1	1	1	1	1	1	1	1	1	1	1	-0.5	-0.5
20	0	0	0	0	0	0	0	1	1	1	1	1	1	1	0	0
21	-1	-1	-1	-1	-1	0	-1	0	0	0	0	0	0	0	-1	-1
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0.7	0	0.7	0	0	0	0	0.7	0.5	0.7	0.7	0.7	0.7	0.7	0.7	0
24	1	0	0	0	0	0	0	1	0	0	0	0	0	1	1	0
25	0.6	0.9	0.7	0.9	0.3	0.5	0.9	1	0.8	0.8	0.8	0.8	0.8	0.69	0.6	0.9
26	0.8	0	0	0	0	0	0	0.5	0	0	0	0	0	0.8	0.8	1
27	0.9	1	1	1	1	0.9	1	0	0	1	1	0	0	0.9	0.9	1
28	0	0	0	0	0	-0.5	0	0	0	0	1	0	-0.5	0	0	0

Next, using (1)–(10), the values are calculated:

- a balanced assessment of all areas of construction project management knowledge for each process ( $VB_j$ );
- a balanced across all construction project management processes at the «Initiation» and «Planning» phases for each category of sustainable development 5P ( $VB_{ai}$ );
- integral assessment of sustainability of construction project management processes ( $VB$ ).

These assessments can help in a detailed analysis of the sustainability elements of the management processes of the construction project under investigation. Visualization of balanced assessments for all management processes for each subcategory of sustainable development of the construction object in the form of a profile (Fig. 1) helps to see the weak points in achieving the 5P values. In particular, the example of the construction project under consideration is maximally oriented towards the implementation of ecological solutions. Instead, business solutions are not efficient enough and need improvement.

The diagram of the balanced assessment of sustainability for all 5P categories (Fig. 2) visualizes the degree of effectiveness of the application of project management tools and methods to ensure the sustainability of the construction object. Thus, in the investigated project, the stability of the construction object is reduced by the processes numbered: 2, 3, 4, 5, 10, 12, 14, 15, 17, 19, 21 and 28. Assessing the degree of negative impact, they need to be revised and improved sustainability processes: collection of requirements (process 4), determination of project content (process 5), assessment of the duration of operations (process 10), determination of the project budget (process 14), planning of project quality management (process 15), and qualitative analysis of project risks (process 21). In addition, the tools and methods of quantitative analysis of the project's risks (process 22) need to be improved, since during the evaluation it was not established that it is oriented towards achieving the values (categories) of sustainable development.

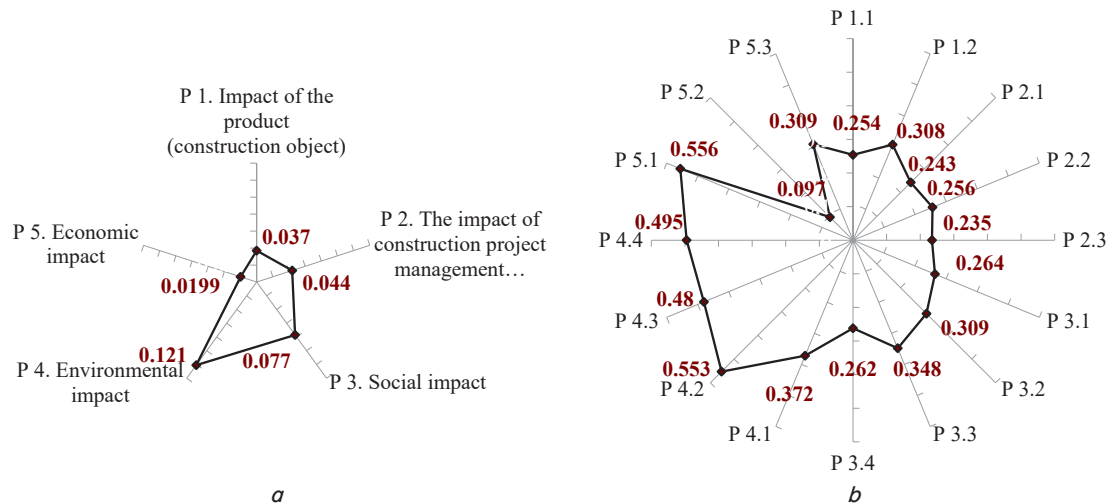


Fig. 1. Examples of a profilogram of balanced assessments for all management processes to ensure the sustainability of a construction object: *a* – profilograms of balanced assessments of sustainability for all management processes for each 5R category; *b* – profilogram of balanced assessments of sustainability for all management processes for each subcategory of 5P

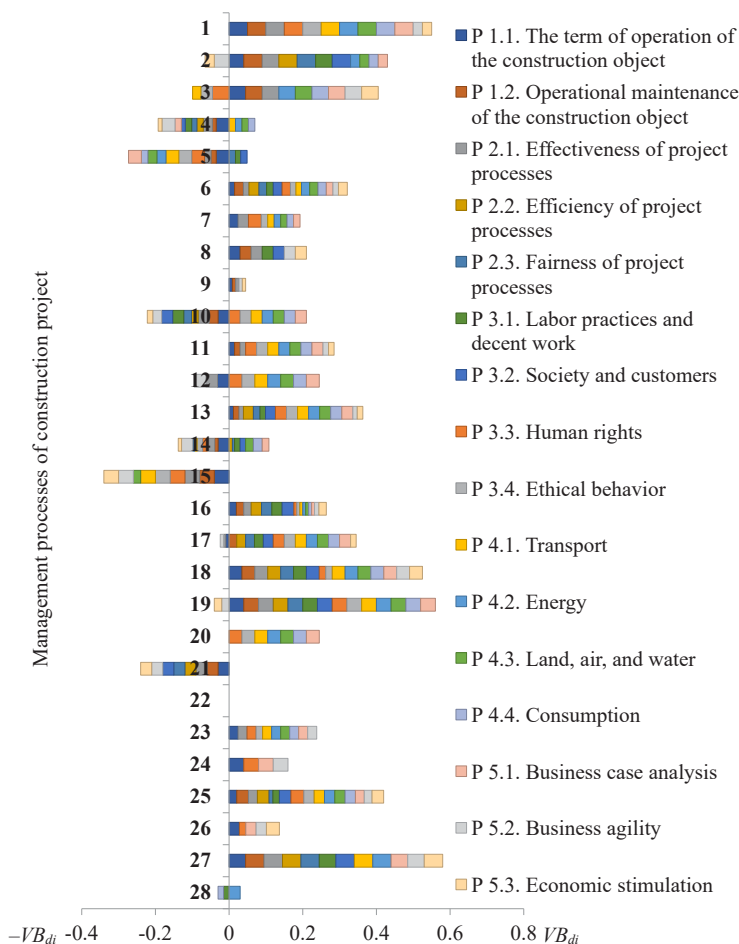


Fig. 2. An example of a diagram of a balanced assessment of sustainability by all categories (subcategories) of 5P for each construction project management process

In general, the integral assessment of the sustainability of the construction project management (which was considered as an example) was  $VB=0,337$ . Given the parameters of the weighting coefficients (Tables 2, 3), the maximum limit value

of the integrated stability estimate is  $VB^{(max)}=1.02$ , and the minimum value is  $VB^{(min)}=-1.02$ .

### 6. Discussion of the results of modeling the assessment of the sustainability of construction project management

The developed method of quantitative assessment of the sustainability of construction project management should become an important tool for making decisions about the start of construction of the object. Initiation and planning processes (defined by PMBOK Construction, PMBOK) become the focus of attention, because the foundations for key technical decisions of the construction object are laid in the initial phases of the project. To assess sustainable development, the 5P categories of sustainable development were used: Product, Process, People, Planet, Prosperity (defined by GPM P5). Taking into account the characteristics of the sustainability of construction project management in the initiation and planning processes (Table 1) in combination with the weighting factors of the management processes in ensuring the sustainability of the construction object (Table 2) and the categories of sustainable development 5R (Table 3) allows obtaining a quantitative assessment of sustainable management orientation. A continuous scale is used for evaluation  $[-1; 1]$ . The normalization of the values of the weighting coefficients of the management processes in ensuring the stability of the construction object ( $\lambda_n$ ) will depend on the number of processes accepted for implementation. Thus, in PMBOK Construction [16] two processes ( $n=2$ ) are defined in the «Initiation» phase, and twenty-four in the «Planning» phase ( $n=24$ ).

The level of sustainability of project management will determine the procedure for normalizing the values of the weighting coefficients of the importance of the categories of sustainable development P5 ( $\mu_m$ ). To assess the sustainability

of construction project management, five categories (impact of the product of the project/construction object, impact of construction project management processes, social impact, environmental impact, economic impact) and sixteen sub-categories ( $m=16$ ). will be applied. The introduction of the weight coefficient of sustainable development categories  $\mu$  will be applied. The introduction of the weight coefficient of sustainable development categories.

Such an author's development opens the possibility to assess the sustainability of construction project management processes. And the application of mathematical tools (1)–(10) allows to formalize decision-making in conditions of varying degrees of certainty of the initial information. The proposed mathematical apparatus is basic, it can be supplemented and developed in accordance with the conditions and specifics of a separate construction project and (or) program.

The correct use of the proposed approach requires the expert to have developed competences in SDGs and the specifics of their implementation in construction projects. The expert carries out his own research of pre-project decisions, forms a «personal vision (personal point of view)» regarding the effectiveness of these decisions in ensuring the stability of the construction object as «input data» in the form of tables of the accepted form. During the filling of tabular forms by the expert, omissions and/or errors in the cells are possible (intentional or accidental), as well as violations of the rules of ethics (predominance of subjectivity over objectivity). Such a situation will lead to the fact that at the «output» we will receive individual numerical values of criterion evaluations and weighting coefficients outside their agreed ranges. The proposed method of quantitative assessment of the sustainability of project management allows timely detection of inconsistencies and their elimination. Also, during the control of input data of computational procedures, technical errors may be detected that require elimination.

The developed tools for assessing the sustainability of construction project management processes are an important tool for improving and developing the construction project management system in the perspective of the SDGs. The use of the developed analytical tools will be useful in the design activities of construction companies, developers, investors, as well as capital construction departments of local governments that carry out construction projects and programs.

At the same time, the author's approach needs further scientific and practical development in the direction of working with specific data. Analytical reports on implemented projects of new construction, reconstruction, restoration of buildings in Lodz city (Poland) should form the empirical base of further research. This experience of sustainability-oriented management of construction projects can be useful for infrastructure restoration programs in Ukraine. The consistent application of the fuzzy logic apparatus, as well as the development of an appropriate software product, can serve as a promising direction for relevant scientific research.

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## 7. Conclusions

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1. Basic mathematical models for quantitative assessment of the sustainability of construction project management have been developed, in particular:

- a partial model of balanced assessment for all areas of construction project management knowledge for each process ( $VB_j$ );
- a partial balanced assessment model for all construction project management processes at the «Initiation» and

«Planning» phases for each category of sustainable development 5P ( $VB_{di}$ );

- model of integral assessment of sustainability of construction project management processes ( $VB$ ).

The proposed models are formed in the interdependence of three variables:

- the level of influence of management processes on ensuring the sustainability of the construction object;
- the level of importance of achieving the values of sustainable development 5P (Product, Proses, People, Planet, Prosperity);
- assessment of construction project management methods and tools to ensure the achievement of sustainable development according to the specified parameters.

This approach makes it possible to form a comprehensive assessment of the sustainability of construction project management processes in accordance with GPM P5 and PMBOK Construction, as well as a qualitative context of architectural and technical solutions of construction projects.

2. A comprehensive methodology for quantitative assessment of sustainable construction project management in the initiation and planning processes under conditions of uncertainty is proposed. The methodology was developed using the apparatus of fuzzy mathematics and takes into account the relative importance of construction project management processes and subcategories of sustainable development of the construction object. The application of this technique involves the following steps:

- determination of process weighting coefficients ( $\lambda_1, \lambda_2, \dots, \lambda_m$ ) and subcategories of sustainable development of the construction object ( $\mu_1, \mu_2, \dots, \mu_m$ ) by expert way;
- quantitative assessment of sustainability of construction project management processes using a continuous scale  $[-1; 1]$ ;
- calculation of sustainability values of construction management processes ( $VB_j, VB_{di}, VB$ );
- to present the results of a quantitative assessment of the sustainable management of a construction project in a graphical form (profile charts and diagrams).

The larger the scale of a construction project or program, the more visible are the effects of sustainable project management. In general, the application of the proposed models and methods for assessing the sustainability of construction project management processes brings the construction industry to a higher level of environmental culture and social responsibility. The use of evaluation tools will allow decision makers to evaluate pre-project solutions (feasibility studies) and the organizational potential of the developer company in the context of sustainability in the 5P categories. Such an assessment is important for making a decision on financing for the start of construction work.

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## Conflict of interest

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The author declares that he has no conflict of interest in relation to this study, including financial, personal, authorship or other, which could affect the study and its results presented in this article.

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## References

1. Claro, P. B. de O., Esteves, N. R. (2021). Sustainability-oriented strategy and Sustainable Development Goals. *Marketing Intelligence & Planning*, 39 (4), 613–630. doi: <https://doi.org/10.1108/mip-08-2020-0365>
2. Rajabi, S., El-Sayegh, S., Romdhane, L. (2022). Identification and assessment of sustainability performance indicators for construction projects. *Environmental and Sustainability Indicators*, 15, 100193. doi: <https://doi.org/10.1016/j.indic.2022.100193>
3. BREEAM International New Construction. Version 6.0 (2021). BRE Global Ltd. Available at: <https://files.bregroup.com/breem/technicalmanuals/sd/international-new-construction-version-6/>
4. LEED v4.1 building design and construction: Getting started guide for beta participants (2022). Washington: U.S. Green Building Council, 300.
5. Living building challenge 4.0: a visionary path to a regenerative future (2019). Seattle: Living Future Institute, 84.
6. Gontar, B., Gontar, Z., Sikora-Fernandez, D. (2018). Strategiczne zarządzanie projektami transformacji inteligentnych miast. Łódzkiego. doi: <https://doi.org/10.18778/8142-621-3>
7. The GPM P5TM Standard for Sustainability in Project Management (2019). GPM Global. Version 2.0. Available at: <https://mosaicprojects.com.au/PDF-Gen/The-GPM-P5-Standard-for-Sustainability-in-Project-Management-v2.0.pdf>
8. Fesenko, T., Minaev, D. (2014). Costomer focus in the project communications management (on the example of house building). *Eastern-European Journal of Enterprise Technologies*, 5 (3 (71)), 4–10. doi: <https://doi.org/10.15587/1729-4061.2014.28032>
9. Kerzner, H. (2022). *Project management: A Systems Approach to Planning, Scheduling, and Controlling*. Wiley, 880. Available at: <https://www.wiley.com/en-us/Project+Management%3A+A+Systems+Approach+to+Planning%2C+Scheduling%2C+and+Controlling%2C+13th+Edition-p-9781119805373>
10. A Guide to the project management body of knowledge (PMBOK® Guide): Sixth Edition (2017). Project Management Institute, 756.
11. Kivilä, J., Martinsuo, M., Vuorinen, L. (2017). Sustainable project management through project control in infrastructure projects. *International Journal of Project Management*, 35 (6), 1167–1183. doi: <https://doi.org/10.1016/j.ijproman.2017.02.009>
12. Fesenko, T., Shakhov, A., Fesenko, G., Bibik, N., Tupchenko, V. (2018). Modeling of customeroriented construction project management using the gender logic systems. *Eastern-European Journal of Enterprise Technologies*, 1 (3 (91)), 50–59. doi: <https://doi.org/10.15587/1729-4061.2018.123124>
13. Fesenko, T., Fesenko, G. (2017). Developing gender maturity models of project and program management system. *Eastern-European Journal of Enterprise Technologies*, 1 (3 (85)), 46–55. doi: <https://doi.org/10.15587/1729-4061.2017.28031>
14. Fesenko, T., Shakhov, A., Fesenko, G. (2017). Modeling of maturity of gender-oriented project management office. *Eastern-European Journal of Enterprise Technologies*, 5 (3 (89)), 30–38. doi: <https://doi.org/10.15587/1729-4061.2017.110286>
15. Siew, R. Y. J. (2015). Integrating sustainability into construction project portfolio management. *KSCE Journal of Civil Engineering*, 20 (1), 101–108. doi: <https://doi.org/10.1007/s12205-015-0520-z>
16. A Guide to the project management body of knowledge Construction (PMBOK® Guide) (2016). Project Management Institute, 489.
17. Silvius, A. J. G., Schipper, R. P. J. (2014). Sustainability in project management: A literature review and impact analysis. *Social Business*, 4 (1), 63–96. doi: <https://doi.org/10.1362/204440814x13948909253866>
18. Papke-Shields, K. E., Boyer-Wright, K. M. (2017). Strategic planning characteristics applied to project management. *International Journal of Project Management*, 35 (2), 169–179. doi: <https://doi.org/10.1016/j.ijproman.2016.10.015>
19. Yu, W., Cheng, S., Ho, W., Chang, Y. (2018). Measuring the Sustainability of Construction Projects throughout Their Lifecycle: A Taiwan Lesson. *Sustainability*, 10 (5), 1523. doi: <https://doi.org/10.3390/su10051523>
20. Stanitsas, M., Kirytopoulos, K., Leopoulos, V. (2021). Integrating sustainability indicators into project management: The case of construction industry. *Journal of Cleaner Production*, 279, 123774. doi: <https://doi.org/10.1016/j.jclepro.2020.123774>
21. Dabirian, S., Khaznadi, M., Taheriattar, R. (2017). Qualitative Modeling of Sustainability Performance in Construction Projects Considering Productivity Approach. *International Journal of Civil Engineering*, 15 (8), 1143–1158. doi: <https://doi.org/10.1007/s40999-017-0241-4>
22. Al-Tekreeti, M. S., Beheiry, S. M., Ahmed, V. (2022). Commitment Indicators for Tracking Sustainable Design Decisions in Construction Projects. *Sustainability*, 14 (10), 6205. doi: <https://doi.org/10.3390/su14106205>
23. Yu, M., Zhu, F., Yang, X., Wang, L., Sun, X. (2018). Integrating Sustainability into Construction Engineering Projects: Perspective of Sustainable Project Planning. *Sustainability*, 10 (3), 784. doi: <https://doi.org/10.3390/su10030784>
24. Fesenko, T., Fesenko, G., Bibik, N. (2017). The safe city: developing of GIS tools for gender-oriented monitoring (on the example of Kharkiv city, Ukraine). *Eastern-European Journal of Enterprise Technologies*, 3 (2 (87)), 25–33. doi: <https://doi.org/10.15587/1729-4061.2017.103054>
25. Campbell, S. L., Chancellor, J.-P., Nikoukhah, R. (2010). Modeling and Simulation in Scilab. *Modeling and Simulation in Scilab/Scicos with ScicosLab 4.4*, 73–106. doi: [https://doi.org/10.1007/978-1-4419-5527-2\\_3](https://doi.org/10.1007/978-1-4419-5527-2_3)