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A New Direction of Professional Activity of Consulting Engineers in the Construction Industry

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Abstract: Today, the professional activities of consulting engineers need new functions based on a research-based approach to the design, construction and operation of sophisticated construction projects. The authors introduce new terms and use the concept of technology platforms to present a research-driven platform for consulting engineers. This platform is a complex system that has three constituent subsystems, including "Processes", the "Database of work items" and "Participants". Formalized interaction between the platform constituents is based on a tree of goals. The implementation of actions, focused on each goal, allowed (1) clustering the requirements applicable to the new type of consulting engineers; (2) developing an algorithm that underlies the database of work items to be performed by new consulting engineers; (3) developing the principle of automated selection of work items; (4) making a graphical representation of activities, performed by consulting engineers in the form of a BPMN diagram. The platform is a concept for a novel approach to the activities of consulting engineers, who will contribute their experience and use the research-driven approach to ensure the reliability and safety of sophisticated construction projects.

Keywords: consulting engineer; engineering services; consulting companies; platform; tree of goals; sophisticated construction projects; research-driven approach; FIDIC

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1. Introduction

1.1. Features of Implementation of Sophisticated Construction Projects

Due to urban population growth, the development of urban spaces [1] is an inevitable consequence of globalization. Adaptation to relevant present-day demands from society, business communities and fundraising efforts is the main driving force that affects the rapid development of cities [2] and brings urban planning activities to a new level.

An increase in urban areas and spaces is a method of reforming crowded and overcrowded urban environments. The vertical planning of urban spaces [3]—in other words, the construction of high, super-high and mega-high buildings—has become a strong trend in the development and optimization of urban spaces around the world [4]. The Council on Tall Buildings and Urban Habitat (CTBUH), dealing with issues of high-rise construction, made a list of the 100 tallest buildings in the world. The heights of these buildings range from 828 m to 333.1 m, and most of them are multifunctional: they accommodate offices, hotels, residences, stores, cinemas and parking lots. The CTBUH keeps records of the 100 tallest buildings in the world, whose heights range from 330 m to 1000 m.

Since the 2000s, high-rise construction has become a popular method of planning urban spaces in the Russian Federation. However, if we refer to the statistics of completed high-rise projects in Russia (Moscow) and in China (Hong Kong, Figures 1 and 2), the number is much smaller in Russia.

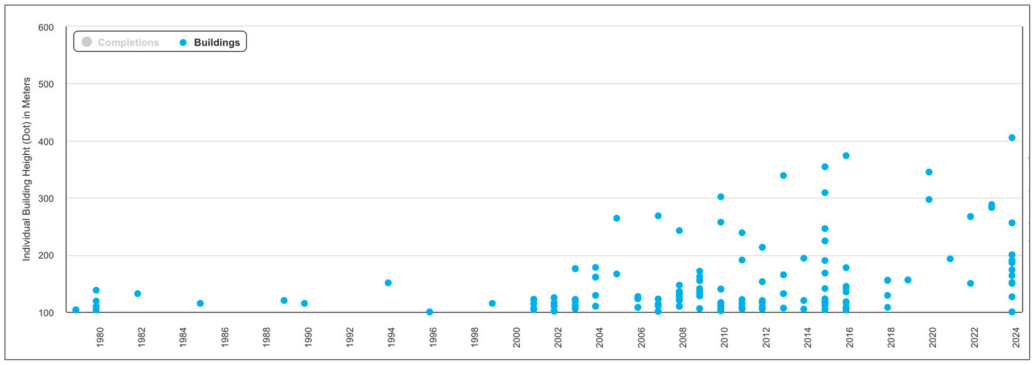

Figure 1. Completed construction projects that are over 100 m high (Moscow, Russian Federation). Data provided by the Council on Tall Buildings and Urban Habitat (CTBUH).

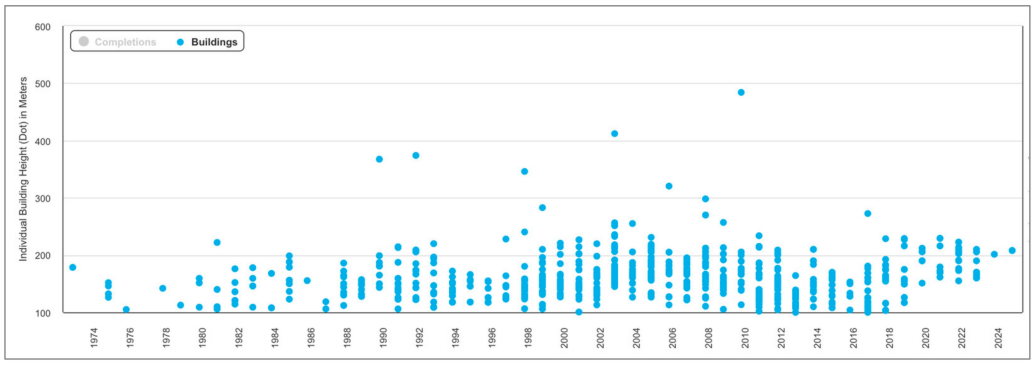

Figure 2. Completed construction projects that are over 100 m high (Hong Kong, China). Data provided by the Council on Tall Buildings and Urban Habitat (CTBUH).

An alternative method towards sustainable urban development is the rational integrated development of underground spaces [5]. It is difficult to overestimate the role of underground construction, as it is one of the most important factors of urbanization [6]. Underground facilities can easily fit into existing urban architectural ensembles, thereby solving problems of infrastructure and improving the living conditions for urban residents [7]. In Europe, one of the deepest parking lots is located in Leiden (The Netherlands). Its depth is about 22 m, which corresponds to the size of a seven-story building. In China, Hangzhou, an automatic 12-level parking lot was built at a depth of about 40 m. It can accommodate 200 cars.

Subterranean public buildings include the building of the Civil Engineering Department of the University of Minnesota, which has seven underground floors; the Sydney Opera House, the substructure of which is 37 m deep; the State Academic Bolshoi Theater of Russia, which has a rehearsal room at a depth of 20 m; and Okhotny Ryad shopping center in Moscow (Russia). It is a seven-level underground shopping facility that is 38 m deep.

The construction of such facilities is frequently implemented using unprecedented design solutions, new materials that have no standard or design strength and deformation characteristics; new design methods, as well as pre-fabrication and construction requirements [8–13]; and new construction methods and techniques. In this study, structures having such characteristics will be addressed as "sophisticated construction facilities", and works [14,15] focus on the difficulties arising during their construction.

The most important task in respect of a sophisticated construction facility is to ensure the reliability and safety of its construction and operation. Reliability and safety assurance is undoubtedly relevant for all construction facilities. However, this issue requires particular attention during the construction of sophisticated facilities due to the considerable social, economic and environmental consequences of their collapse. For example, statistical data on collapsed standard buildings in Russia in 2017–2018, issued by the Urban Centre for Examination, show that:

1. Fifty-three percent of collapses resulted from violations (including the failure to meet deadlines) during the operation of buildings and structures;
2. Thirty-two percent of collapses were caused by a failure to comply with the construction and installation technology;
3. Nine percent of collapses were caused by defective and low-quality construction materials;
4. Six percent of collapses were caused by errors in structural design.

Many recent collapses of buildings and structures had dramatic consequences despite the absence of any design features dealing with their height or depth [16]. Hence, any collapse-related damage is both tragic and enormous, especially if the design and construction of collapsed buildings and structures has new non-standard design solutions, materials and novel technologies of construction and installation, or the collapsed building had unique height, span or depth parameters.

Research projects are aimed at studying various features of design and construction. Such projects were launched to learn more about wind loads and vortex resonance [17,18], basic structural and construction systems [19], the involvement of information modeling technologies and advanced construction methods and techniques [20], as well as novel materials and products [21].

1.2. The Application of Activities Conducted by the International Federation of Consulting Engineers in the Context of This Study

The quality of sophisticated construction projects and their safety during operation can be ensured by attracting specialists and scientists from other countries, companies and universities. Their experience, qualification, previous research undertakings and professional skills serve as the criteria of professionalism. However, their participation means either getting a new participant involved in the construction process or extending the functionality of an existing one and developing a set of basic principles and processes for this purpose.

Here, the authors focus on the international approach to managing investment and construction projects that ensures distinct roles and transparent interaction. This approach is the ideology and concept of the activities conducted by the International Federation of Consulting Engineers (FIDIC). The FIDIC is the global representative body of national associations of consulting engineers, representing over one million professional engineers and 40,000 firms from more than 100 countries. Within this federation, consulting engineers meet current challenges that accompany investment and construction project management, reconcile the interests of clients and contractors and assess and share risks using the standards and contract templates based on the partnership model of relationships.

By taking advantage of FIDIC methodology, we can develop a strategy and introduce an additional and completely new function to the professional activity of consulting engineers and firms that is capable of providing support in the process of implementation of sophisticated construction projects by combining research and consulting-based approaches, which could merge the experience and knowledge of specialists in the course of solving complex problems of engineering and construction to control the design and implementation of sophisticated projects.

1.3. Consulting Engineers Applying a Research-Based Approach

In this study, the research-based approach that will be used by consulting engineers encompasses the following set of functions, whose mission is to confirm the proper application of various technologies, construction methods and solutions during the implementation of sophisticated construction projects:

- Research and practical application of earlier findings in the field of construction in case of questions or controversial issues arising in the process of implementing sophisticated construction projects;

- Critical evaluation and interpretation of existing research in the context of new proposed design and technical solutions for the implementation of sophisticated construction projects;
- Use of personal experience and the experience of colleagues in the course of professional activities;
- Scientific analysis of proposed solutions and ideas and selection of the most optimal ones (for example, studying the applicability of methods for excavating a pit in constrained conditions of construction with the least impact on surrounding buildings);
- Use of the most recent achievements of science and technology in the field of analysis and processing of results of calculations in the design and construction, as well as monitoring, conducting and analyzing laboratory tests and their results.

All of the above features of the research-based approach reduce the cost of making corrections to avoid potentially irreversible consequences of wrong decisions and errors at any stage of the lifecycle of sophisticated construction projects.

The trend towards the widespread involvement of technical consultants has converted the engineering consulting industry into a core component of the development and transfer of engineering knowledge [22–24]. Drees & Sommer is the company providing such services. Its services are based on many years of experience coupled with a comprehensive approach to any issues emerging in the course of the scheduling, design, construction and operation of various projects. CHI Consulting Engineers (CHI) offers independent verification and expert services in bridge construction, encompassing all phases of design and construction support.

This type of activity is often conducted by research universities (Moscow State University of Civil Engineering (National Research University)) and centers for research ("JSC Research Center of Construction") in Moscow. Hence, research is conducted by "specialized organizations" having qualified and experienced researchers and other personnel, machinery and software.

We can also argue that the activity to be conducted by consulting engineers will be "an alternative opinion" needed to solve complex design, engineering and construction problems. For example, if the customer needs to verify the correctness and accuracy of design solutions proposed by the design companies or if the project has various complicating aspects mentioned earlier in the text, the customer can contact such an organization, which will make an independent structural analysis using alternative certified software tools and provide the results. Alternatively, consulting engineers can perform the engineering and geotechnical monitoring during the construction of such facilities, especially in the conditions of dense urban development or in proximity to facilities of historical and cultural significance, to summarize and analyze the monitoring results and compare them with the projections. In their works, A.A. Lapidus [25], D.V. Topchiy [26], P.G. Ermeev [27], A.M. Belostotsky [28], M.I. Farfel [29] and I.I. Vedyakov [30,31] investigate various components of the need for such an activity, which is called "scientific and technical support" in the Russian Federation. These authors also study its role in the implementation of unique facilities, cases of solving complex problems and issues arising at different stages of the lifecycle of sophisticated construction projects.

The main task of consulting engineers, using a research-based approach in their work, will be to perform a set of research, development and innovation-focused activities at various stages of the lifecycle of buildings and structures, if the design documentation has non-standard complex engineering solutions, materials, structures and technologies. Global practice assumes that consulting engineers are obliged (1) to be unbiased and (2) not to serve the interests of the customer but (3) to be in contractual relations with the customer. However, when the customer builds a sophisticated facility, whose characteristics will be implemented for the first time, the customer will need a team of professional consulting engineers, who will contribute their knowledge, experience and research potential to confirm the validity of the customer's decisions and serve his interests.

1.4. Necessary Tasks to Create a New Structure of Consulting Engineers

This study should accomplish the following tasks to create a new conception of consulting engineers applying a research-based approach in their activities:

- Development of guidelines that could serve as regulations for this type of activity (Task 1);
- Development of unambiguous approaches and work selection principles for consulting engineers to use when dealing with different characteristics of sophisticated construction facilities (Task 2);
- Introduction of unified comprehensive requirements applied to consulting engineers and companies (Task 3).

To accomplish these tasks, the authors of this article consider a new activity to be conducted by consulting engineers; it is a holistic set of interrelated structural elements. This approach could be implemented by applying the concept of technology platforms. The platform has many key advantages, as it can increase the value of end products and services by scaling business models and component-wise implementation of its offerings [32–37].

At present, a technology platform is a system capable of streamlining the interaction between various participants (business entities, universities and independent experts) to solve complex research and engineering problems. It also includes the arrangement of engineering, information and intellectual assets in the digital environment [32,33]. The mission of a technology platform is to act as a communication platform supporting the interaction of various technologies. Several research projects [38,39] prove the applicability of the platform-centered approach to the construction industry, but now there is little research and practice-oriented information about the use of platforms to upgrade the construction industry. Works [40–44] contain the principles of technological platforms that are important for the goals and objectives of this study.

The activities of consulting engineers can also be presented as a complex system, and its generation follows the basic principles of systems, such as integrity, hierarchy, structurization, multiplicity and systematicity. Therefore, to better understand the essence of this system, it is decomposed into subsystems, presented in Section 2. They solve the three tasks set in the Introduction section. These tasks are aimed at creating a new conception of consulting engineers in the construction industry.

The interaction between platform elements is based on the tree of goals that contemplates the consecutive decomposition of goals of each platform element and their further study.

The authors also apply the process approach to ensure the collaboration of all elements of the platform for consulting engineers. For this purpose, BPMN 2.0 (Business Process Model and Notation) was selected. BPMN 2.0 is a method of making flow charts that demonstrates business process stages from beginning to end. BPMN flow charts clearly demonstrate the sequence of work-related activities and information flows needed to implement the process. Therefore, they are the key management tools [45]. The application of this approach was addressed in a number of research papers focused on construction processes [46,47]. This approach was considered a reliable instrument for developing mechanisms and sets of work items for stakeholders.

The development of a technology platform for consulting engineers, using a research-based approach, allowed accomplishing the goals set in the research projects and developing a unified approach to the involvement and activities conducted by new consulting engineers engaged in the construction of projects featuring complex, non-standard and unique design solutions and various new construction materials and technologies.

2. Materials and Methods

2.1. FIDIC Methodology as the Basis for a New Conception of Consulting Engineers

The authors apply the FIDIC's (International Federation of Consulting Engineers, federation) ideology as the basis for a new conception of consulting engineers, who could use a research-based approach to sophisticated construction projects. The authors draw

attention to the White Book of the FIDIC (a contract for engineering services), which is applied to contracts made between a client (a customer) and a consultant (an engineer) for the pre-project documentation development, feasibility study preparation, construction control and project management.

However, the above areas of knowledge and the White Book approach to consulting services lack a research-based approach to consulting activities performed at various stages of the lifecycle of sophisticated construction projects.

On the basis of the above, the authors propose reconsidering the role of consulting services by adding a new type of activity, which encompasses not only construction-related consulting services but a new complex approach to issues of engineering surveys and design and construction of sophisticated facilities, taking into account their engineering characteristics, materials and aspects of the construction process's arrangement.

The authors use the White Book as the template of a contract between the customer and the consultant. This template summarizes the general aspects of consultants' activities and proposes new types of activities to be conducted by consulting engineers using the research-based approach (Table 1).

Table 1. Activities to be conducted by (1) consulting engineers within the framework of FIDIC and (2) the new proposed conception of consulting engineers taking advantage of a research-based approach.

Consulting Engineers' Activities Conducted within the Framework of FIDIC	Activities to Be Conducted Using the Proposed Conception of Consulting Engineers Taking Advantage of a Research-Based Approach
The engineer acts for and on behalf of the customer when supervising the activities of the contractor.	The new role of consulting engineers is to apply a research-based approach that justifies solutions towards the implementation of complex construction projects by the participants in the construction process at various stages of the lifecycle of a construction facility.
The engineer sends all agreed upon notices to the contractor within the framework of the contract.	The opinion, issued by consulting engineers, is an "alternative opinion".
The engineer identifies changes to be made.	Consulting engineers conduct a set of activities to ensure work safety, quality and efficiency at various stages of the lifecycle of sophisticated facilities in respect of each participant in the construction process.
The engineer issues payment requests payable by the customer.	Acting within the scope of their services, consulting engineers make recommendations that are not a "call for immediate action"; rather, they serve as the evaluation of the work performed and the maneuver allowing project participants to make adjustments along the way.
	Consulting engineers interact with other participants in a sophisticated construction project only via the customer.

The authors have identified the following practical goals of consulting engineers taking advantage of the research-based approach:

- At the pre-project stage: researching the most optimal and expedient solutions for the structural system of the facility, taking into account its architectural conception, surveying purpose and program approval;
- At the stage of engineering surveying: ensuring the reliability and validity of all types of surveys;
- At the stage of design: controlling the design quality, assessing the reliability and validity of approaches to project design (in terms of structural, management and engineering solutions);
- At the stage of construction: ensuring the facility's compliance with the approved design documentation and detailed design documentation, quality control, safety and reliability of the work performed.

Hence, consulting engineers can obtain a new consulting-related function based on the research-based approach to the implementation of a sophisticated construction project, if consulting engineers are participants in the construction process, or if they can join it later.

2.2. Applying the Platform Approach to Create a New Scope of Activities to Be Conducted by Consulting Engineers and the Definition of the Main Term of the Research

To build the "platform for consulting engineers using a research-based approach in the construction industry", it was necessary to identify the main subsystems this platform can consist of. To accomplish this, the authors of the article identified three main subsystems, presented in Table 2. These subsystems were formed on the basis of the tasks aimed at creating a new line of activity for consulting engineers in construction.

Table 2. Correspondence between the tasks set in the study and the subsystems of the platform for consulting engineers using a research-based approach.

№	Task	Subsystem
Task 1	Developing management aspects of activities of consulting engineers using a research-based approach, which would act as regulations.	Processes
Task 2	Developing unambiguous approaches and work selection principles to be applied by consulting engineers to different characteristics of sophisticated construction facilities.	Database of work items
Task 3	Setting comprehensive uniform requirements for consulting engineers and companies.	Participants

Participants are consulting engineers who meet certain requirements applied to the new type of activity. It is important to emphasize that this subsystem has a list of consulting engineers, engineering consulting companies, institutes of consulting engineers and requirements for consulting engineers. In this article, the "Participants" subsystem deals with the requirements for consulting engineers using a research-based approach.

Hence, the three main subsystems of the platform are identified. They are "Processes", the "Database of work items" and "Participants". Table 3 shows the functions of each subsystem.

Table 3. Functions of the subsystems of the platform for consulting engineers using a research-based approach.

Subsystem	Subsystem Functions
Processes	Building relationships between the customer and consulting engineers in terms of activities of consulting engineers using a research-based approach.
	Conveying the processes that are underway during the provision of research-based consulting services.
	Conveying the variability of decisions made in the course of research-based consulting services provision.
	Acting as the regulations governing the provision of research-based consulting services.
Database of work items	Listing the work items to be completed during the provision of research-based consulting services, taking into account the characteristics, features and implementation phases of a sophisticated construction project.
	Automatically selecting the types of activities by applying the pre-set characteristics of a construction project.
Participants	Listing the requirements for consulting engineers using a research-based approach.

Figure 3 shows the visual representation of the platform.

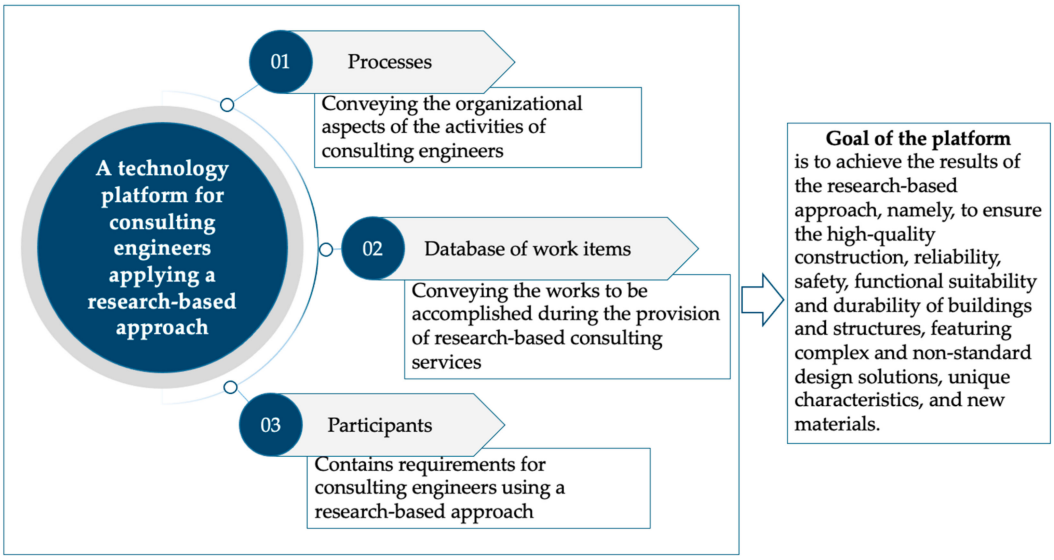

Figure 3. A visual representation of the platform.

Therefore, we can develop a definition for the core notion of this study: a platform for consulting engineers, using a research-based approach, that involves new types of activities conducted by consulting engineers. These types of activities are based on the interaction between the customer and consulting engineers in the process of implementing certain processes using the database of work items that can justify the validity of solutions during the implementation of sophisticated construction projects.

The application of the platform-based approach to the activities of consulting engineers allowed for creating a conceptually new, unified and structured space for consulting engineers, who can perform their work within the framework of a research-based approach to the construction of sophisticated facilities.

2.3. Formalizing the Interaction between Platform Elements Based on the Tree of Goals

According to several studies [48,49], one can use the method of a tree of goals [50] to formalize the interaction between the platform elements, which are its subsystems. This method is applied to the platform for consulting engineers as a hierarchical structure that has the main goal at the top level, tasks at the next level and the scope of solutions at the bottom level (Figure 4).

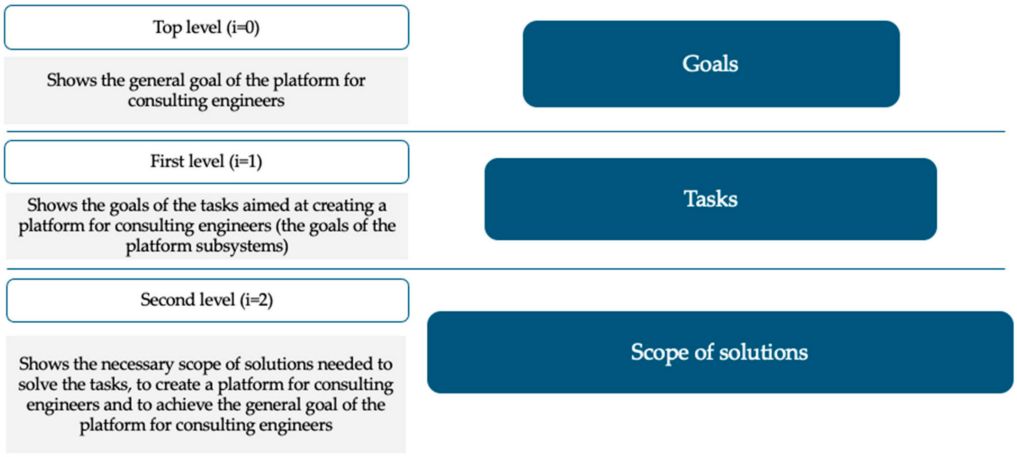

Figure 4. The tree of goals of the platform for consulting engineers using a research-based approach.

Whenever a tree of goals is developed, goals are broken down into levels, and this is the way they are simplified, clarified and refined.

The tree of goals has one top "G^0". It characterizes the general goal of the platform for consulting engineers and is located at the top level (i = 0). Then, the top-level goal is broken down into the first-level goals (i = 1) of the platform for consulting engineers "G^1_{01}, G^1_{02}, G^1_{03}", which are, in turn, broken down into the second-level goals (i = 2) "G^2_{011}, G^2_{012}, G^2_{013}, . . . , G^2_{021}, G^2_{022}, G^2_{023}, . . . , G^2_{031}, G^2_{032}, G^2_{033}, . . . ".

The goals of the platform under study are listed in Table 4.

Table 4. Goals of the platform for consulting engineers using a research-based approach.

Level in a Tree of Goals	Goals	Solutions Aimed at Accomplishing the Goal
i = 0	G^0 is achieving the result of activities conducted by consulting engineers using a research-based approach.	G_{01} is developing work performance procedures for consulting engineers using a research-based approach.
		$^{G1}{}_{02}$ is developing the principle of automated selection of work items to be performed by consulting engineers, taking into account the characteristics of a construction facility.
		G^1_{03} is setting the principal requirements for consulting engineers and companies using a research-based approach.
i = 1	G^1_{01} is developing work performance procedures to be complied with by consulting engineers using a research-based approach.	G^2_{011} is outlining principal actions towards developing services provision procedures to be complied with by consulting engineers and the customer.
		G^2_{012} is selecting a single engineering consulting company for the entire period of implementation of a sophisticated construction project.
		G^2_{013} is consecutive work performance by consulting engineers at each stage of the lifecycle of a sophisticated construction project.
		G^2_{014} is applying the process approach to managing the activities of consulting engineers using a research-based approach.
	G^1_{02} is developing the principle of automated selection of work items, taking into account the characteristics of a construction facility.	G^2_{021} is making a database of work items on the basis of the engineering documentation, research and experience in the implementation of sophisticated construction projects featuring complex, non-standard and unique design solutions, new materials, structures and technologies.
		G^2_{022} is introducing general parameters for selecting the list of works performed by consulting engineers.
		G^2_{023} is introducing special parameters for selecting the necessary list of works performed by consulting engineers in terms of different characteristics of construction facilities.
		G^2_{024} is developing the principle underlying the selection of work items performed by consulting engineers.
	G^1_{03} is setting requirements for consulting engineers and companies using a research-based approach.	G^2_{031} is the experience of consulting engineers in performing a similar type of work in the course of implementing construction projects that involve complex, unique and non-standard designs and solutions, new materials, structures and technologies.
		G^2_{032} is the availability of the license needed to perform licensed work (engineering surveys, design, construction) for the relevant category of construction projects.
		G^2_{033} is the availability of required instruments and testing facilities.
		G^2_{034} is the availability of software packages needed to make calculations and process the results obtained by consulting engineers.
		G^2_{035} is the availability of consulting engineers who are holders of degrees in engineering sciences.
		G^2_{036} is the availability of consulting engineers, specializing in engineering surveys, design and construction.
		G^2_{037} is the average 5-year construction experience of consulting engineers.
		G^2_{038} is the availability of consulting engineers, who hold academic degrees of the Candidate of Engineering Sciences or the Doctor of Engineering Sciences.

The authors emphasize that first-level goals (i = 1) belong to the subsystems within the platform, while second-level goals (i = 2) are within the scope of solutions tied to each first-level goal that takes into account the need to solve the tasks set in Section 1.

Figure 5 shows the goal tree matrix of the platform for consulting engineers using a research-based approach.

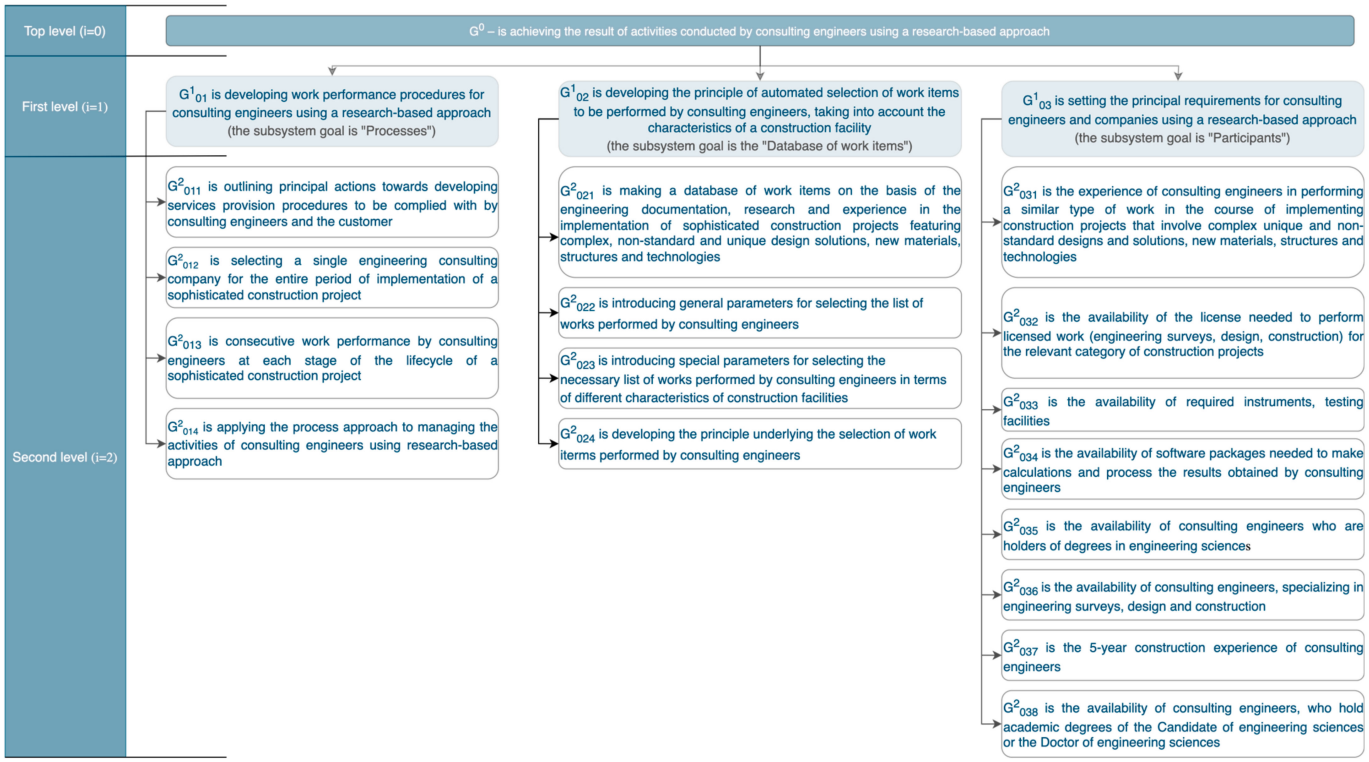

Figure 5. Goal tree matrix of the platform for consulting engineers using a research-based approach.

In Section 3, the authors deeply analyze each of the subsystems of the investigated platform, their goals and the scope of solutions needed to accomplish these goals.

3. Results

This section discusses how these subsystems can be used to select engineering consulting companies and specialists. It also addresses the formation of a database of work, performed by consulting engineers, and selection of the work items themselves, as well as the flow chart of work performance procedures for consulting engineers using a research-based approach.

3.1. The "Participants" Subsystem of the Platform for Consulting Engineers Using a Research-Based Approach in the Construction Industry

The first-level goal of the "Participants" subsystem in the goal tree of the platform for the new activities of consulting engineers using a research-based approach is G^1_{03} or setting requirements for consulting engineers and companies using a research-based approach. This goal is set to solve Task 3 in Section 1.4., namely, "to set consistent and exhaustive requirements for consulting engineers and companies, that perform these types of work". Therefore, the scope of solutions (second-level goals) was defined by the authors on the basis of the research-based analysis of a list of comprehensive requirements for consulting engineers in the construction industry. It is also noteworthy that this goal conveys functions of the "Participants" subsystem, presented in Table 3.

Table 5 has a description of the scope of solutions focused on accomplishing goal G^1_{03}.

Table 5. Description of the scope of solutions focused on accomplishing goal G^1_{03}.

Scope of Solutions for G^1_{03}	Description of the Scope of Solutions for G^1_{03}
G^2_{031} is the experience of consulting engineers in performing a similar type of work in the course of implementing construction projects that involve complex, unique and non-standard designs and solutions, new materials, structures and technologies.	Due to the implementation of complex, non-standard and unique design solutions and use of new materials, structures and technologies, consulting engineers need relevant experience in the implementation of sophisticated construction projects with similar characteristics.
G^2_{032} is the availability of a license authorizing a person or a company to perform licensed types of work (engineering surveying, design, construction) within a relevant category of construction projects.	Companies and consulting engineers must be properly licensed to perform certain types of work (engineering surveying, design, construction). The license authorizes them to provide certain services, make engineering surveys, prepare design documentation and build construction facilities.
G^2_{033} is the availability of required instruments and testing facilities.	Companies and consulting engineers need instruments and testing facilities to independently test materials and structures.
G^2_{034} is the availability of software packages to make calculations and process the results obtained by consulting engineers.	Companies and consulting engineers must have access to various advanced software packages to process their measurements, make calculations and track their evolution over time.
G^2_{035} is the availability of consulting engineers holding degrees in engineering sciences.	Consulting engineers are required to hold degrees in engineering sciences.
G^2_{036} is the availability of consulting engineers specializing in engineering surveys, design and construction.	Consulting engineers need to have the necessary qualification confirming their ability to perform work in the field of engineering surveys, design and construction.
G^2_{037} is the average 5-year construction experience of consulting engineers.	It conveys the average experience of consulting engineers in the field of construction; it is needed to make conclusions about the expertise of each specialist.
G^2_{038} is the availability of consulting engineers holding academic degrees of the Candidate of Engineering Sciences or the Doctor of Engineering Sciences.	Companies and consulting engineers need specialists with academic degrees (1) to take advantage of their opinions on various complex issues or (2) to contribute their research findings to construction projects.

These requirements, applied to the new conception and work of consulting engineers using a research-based approach, serve as the checklist for engineering consulting companies and specialists to be invited into sophisticated construction projects. These requirements address various aspects of consulting engineering activities. For example, the requirement that deals with the "availability of required instruments and testing facilities" and "the availability of software packages needed to make calculations and process the results obtained by consulting engineers" conveys the need for consulting engineers to perform structural analysis and laboratory testing of materials and compare their results with those obtained by the design companies.

The process approach, including the BPMN 2.0 business process modeling notation, was applied in Figure 6 to design the process of selecting an engineering consulting company, taking into account its compliance with the requirements developed for such companies:

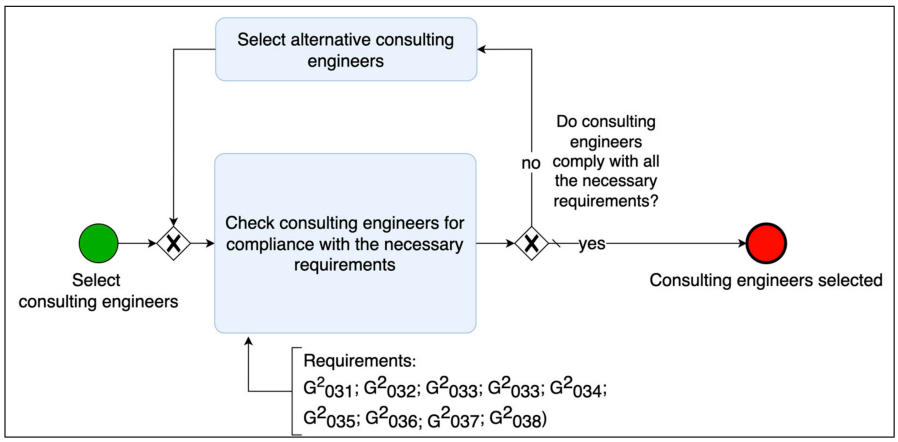

Figure 6. The process of selecting consulting engineers.

3.2. The "Database of Work Items" Subsystem of the Platform for Consulting Engineers Using a Research-Based Approach in the Construction Industry

The first-level goal of the "Database of work items" subsystem in the tree of platform goals is G^1_{02}, namely, the development of the principle of automated selection of works, taking into account the characteristics of a construction facility. This goal was set to solve Task 2 in Section 1.4., namely, "to develop unambiguous approaches and principles of work selection by consulting engineers in respect of different characteristics of sophisticated construction facilities". Hence, the scope of solutions (second-level goals) encompassed a set of actions aimed at making a database of work items, performed by consulting engineers, and computerizing their selection. This goal conveys the functions of the "Database of work items" subsystem presented in Table 3.

Table 6 has a description of the scope of solutions for the accomplishment of goal G^1_{02}.

Table 6. Scope of solutions needed to accomplish goal G^1_{02}.

Scope of Solutions for G^1_{02}	Description of Scope of Solutions for G^1_{02}
G^2_{021} is the generation of a database of work items performed by consulting engineers who study the engineering documentation, perform research and contribute their expertise to the implementation of sophisticated construction projects that feature complex, non-standard and unique design solutions, new materials, structures and technologies.	Generation of a unified database of work items, performed by consulting engineers who study the engineering documentation and invest their research findings and experience at each project stage. It will allow making a customized list of work items to be performed by consulting engineers, taking into account the specific parameters of a sophisticated construction facility.
G^2_{022} is introducing general parameters for selecting the list of works performed by consulting engineers.	General parameters will allow making a list of principal work items extracted from the list of general work items performed by consulting engineers. General parameters will serve as the basis for the selection of work items having pre-set general parameters. General parameters may include: • Aspects complicating the facility construction; • Stages of the work performance by consulting engineers; • The built-up area to be affected by a new construction project; • A cultural heritage building adjacent to a new construction project (or a construction project will share the site with a cultural heritage building).
G^2_{023} is the introduction of special parameters for selecting a list of work items to be performed by consulting engineers in respect of different characteristics of construction facilities.	Special parameters allow making a list of work items corresponding to the features of a sophisticated construction facility and some of its principal characteristics.Special parameters may include: • Category of complexity of engineering and geological conditions; • Geotechnical category of the facility; • Seismicity of the construction site; • Intensity of the environmental impact; • Features (methods) of construction; • Type of the foundation; • Type of structural elements.
G^2_{024} is the development of the principle underlying the selection of work performed by consulting engineers.	It will be an unambiguous and universal approach to making a list of work items to be performed by consulting engineers using a research-based approach.

The authors propose a step-by-step algorithm for the generation of a consolidated database of items of work to be performed by consulting engineers (Figure 7). This algorithm is based on the earlier study performed by the authors [51], and it is tailored to the needs of this project.

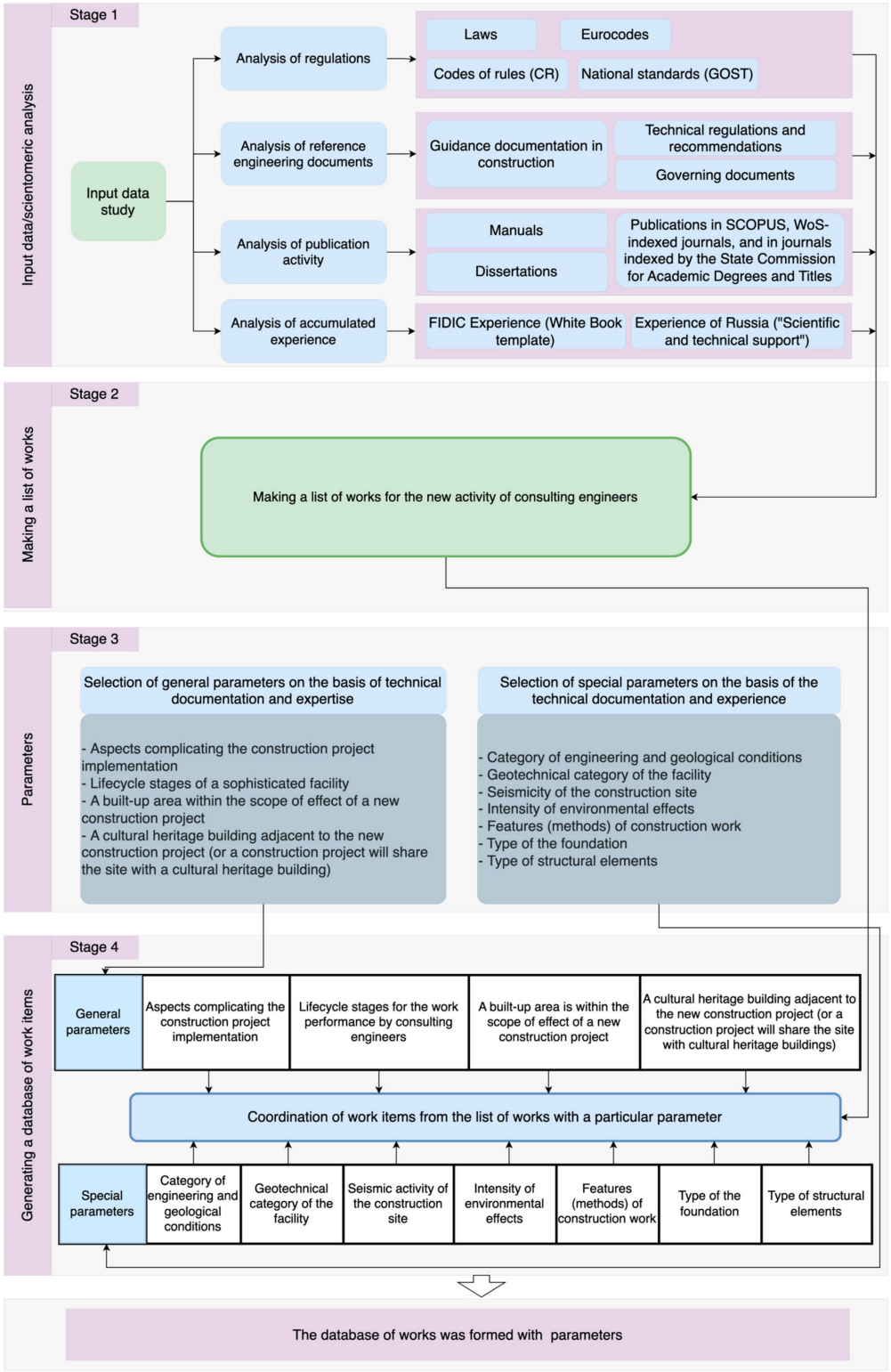

Figure 7. The algorithm for generating a consolidated database of work items performed by consulting engineers.

Figure 8 shows the principle of automated selection of work items performed by consulting engineers, taking into account general and special parameters of a construction facility. This procedure needs software to be developed.

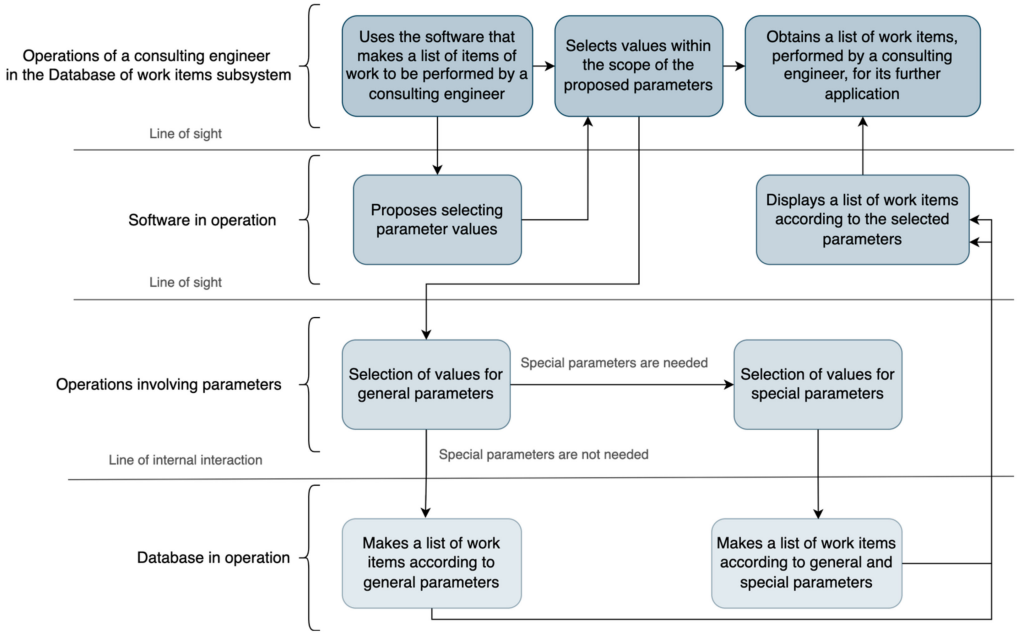

Figure 8. The principle of automated selection of work items, performed by consulting engineers using a research-based approach, taking into account general and special parameters of a sophisticated construction facility.

As was mentioned earlier, consulting engineers conduct certain research, development and innovation-focused activities at various stages of the lifecycle of buildings and structures, whose design documentation contains non-standard and complex engineering solutions, materials, structures and technologies.

Table 7 has a general list of work items that can be performed by the new type of consulting engineers at the stages of engineering surveys, design and construction.

Table 7. The general list of research undertakings, performed by consulting engineers at the stages of engineering surveying, design and construction.

	Engineering Surveying
1	Development of recommendations concerning the request for proposal and the program of engineering surveys.
2	Evaluation and analysis of engineering surveying materials.
3	Evaluation of geological risks.
4	Experiments and research undertakings focused on the design of bases, foundations and substructures.
	Design
1	Independent development of computational models using alternative certified software packages; comparative analysis of computational models and results.
1.1	Identification of compliance/incompliance of design solutions with the requirements of applicable design regulations and standards.
1.2	Verification of design models used in the design process (independent computations to be made using two independently developed software tools; the first computation is to be made by the general designer, and the second one is to be made by the corporate entity in charge of consulting engineers).
1.3	Verification of design solutions which are beyond the scope of regulatory documents.
1.4	Local verification of design solutions and analyses of the most critical structural elements.

Table 7. *Cont.*

	Engineering Surveying
2	Testing new structures, nodes and joints used in the construction of buildings; interpretation of test results.
3	Adjustment of the snow load distribution over the roofs of buildings and structures.
4	Using model-based wind tunnel tests to revise values of aerodynamic coefficients.
5	Development of non-standard methods of computation and analysis in the course of design of bases, foundations and substructures.
6	Forecasting the condition of bases and foundations of the designed facility, taking into account all potential types of effects.
7	Potential geotechnical effect of construction on the surrounding development, geological conditions and the environment.
8	Identification of potential scenarios of emergency situations in respect of foundations, bases and substructures.
9	Development of process regulations for special types of work.
10	Geotechnical examination.
11	Consolidated 3D analysis of the "base—foundation—structure" system needed to develop a design solution for the foundation.
	Construction
1	Engineering and geotechnical monitoring.
2	Consolidation and analysis of the results of engineering monitoring during the construction of buildings.
3	Consolidation and analysis of all types of geotechnical monitoring results; their comparison with the projections.
4	Immediate development of recommendations or proposals for the adjustment of design solutions in the furtherance of findings of engineering and geotechnical monitoring in the case of deviations from the projections.
5	Quality control of construction and erection works at each project stage.
5.1	Analysis and approval of construction procedures, welding work arrangements and regulations for certain types of works (bolted connections, reinforcing and concreting works, non-destructive testing of concrete strength, etc.).
5.2	Analyses of structures in case of any deviations from the design solutions and/or regulations governing the mounting and manufacturing of structures (or issuance of recommendations concerning this analysis).
5.3	Proof testing of materials, connections and fasteners.
5.4	Development of recommendations on the random quality control of materials, connections and fasteners.
5.5	Development of supplementary requirements for the acceptance of the finished structures in the absence of any information in the regulations governing the erection and manufacturing of these structures.
5.6	Selective incoming quality control of materials and constructions at the construction site.
5.7	Quality control of the production of prefab structural elements and fasteners at manufacturing enterprises.
5.8	Other actions that, if implemented, ensure the safe construction and operation of a building.

3.3. The "Processes" Subsystem of the Platform for Consulting Engineers Using a Research-Based Approach in the Construction Industry

The goal of the first level of the "Processes" subsystem in the tree of goals is G^1_{01}, or the development of work performance procedures for consulting engineers using a research-based approach. This goal was set to solve Task 1 in Section 1.4., namely, "to develop work performance procedures for consulting engineers using a research-based approach, for these procedures to serve as regulations". Therefore, the scope of solutions (second-level goals) encompassed a set of actions focused on developing unified work performance procedures for consulting engineers using a research-based approach. This goal conveys the functions of the "Processes" subsystem listed in Table 3.

Table 8 has a description of the scope of solutions focused on accomplishing goal G^1_{01}.

Table 8. Description of the scope of solutions focused on accomplishing goal G^1_{01}.

Scope of Solutions for G^1_{01}	Description of the Scope of Solutions for G^1_{01}
G^2_{011} is the identification of principal actions focused on arranging the provision of engineering consulting services by consulting engineers and the customer.	Principal actions focused on the arrangement of services provision by consulting engineers are: • Development by the customer of the request for proposal of services of consulting engineers (it has a consolidated list of research undertakings to be performed by consulting engineers); • Selection of consulting engineers by the customer (subject to compliance with the requirements listed in p. 3.3); • Execution of an agreement between the customer and consulting engineers; • Identification of the scope of work to be performed by consulting engineers (using p. 3.4 of the "Database of work items" subsystem, project-related permits and technical documentation provided by the customer); • Work performance by consulting engineers (according to a certain schedule provided in the contract and the request for proposal); • Consulting engineers issue progress reports on the project implementation and decision-making recommendations to the customer.
G^2_{012} is the selection of a single engineering consulting entity for the entire period of implementation of a sophisticated construction facility.	• No need to select consulting engineers at each stage of work; • No time is wasted by each newly selected company or consulting engineers on reading initial approvals/results of engineering surveys/design documentation.
G^2_{013} is consecutive work performance by consulting engineers at each stage of the lifecycle of a sophisticated construction facility.	Timely identification and control of all emerging deficiencies and errors at each stage of the lifecycle, followed by the correction and prevention of unfavorable outcomes at the further stages in the lifecycle of a sophisticated construction facility.
G^2_{014} is the application of the process approach to the management of activities conducted by consulting engineers using a research-based approach.	Identification and description of an unambiguous approach to the development of work performance procedures to be complied with by consulting engineers in the course of conducting a new type of activities in the construction industry.

The scope of solutions was applied to make a graphical model using the BPMN 2.0 business process management notation. The model is provided in Figure 9, and it focuses on accomplishing the goal of the "Processes" subsystem (G^1_{01}). It is a graphical representation of the regulations governing work performance by consulting engineers using a research-based approach. Subject to (1) the integration of the "Database of work items" subsystem into the model, (2) the application of the principle of automated selection of the work to be performed by consulting engineers (Figure 8), as well as (3) "The process of selecting consulting engineers" contingent on the compliance with the pre-set requirements applied to such organizations (Table 5, Figure 6), this model allows accomplishing the general goal of the platform for consulting engineers using the research-based approach (G^0); namely, it ensures the high performance of consulting engineers using a research-based approach in terms of the quality of construction work, reliability, safety, operational suitability and durability of buildings and structures featuring complex structural solutions, unique characteristics and advanced materials.

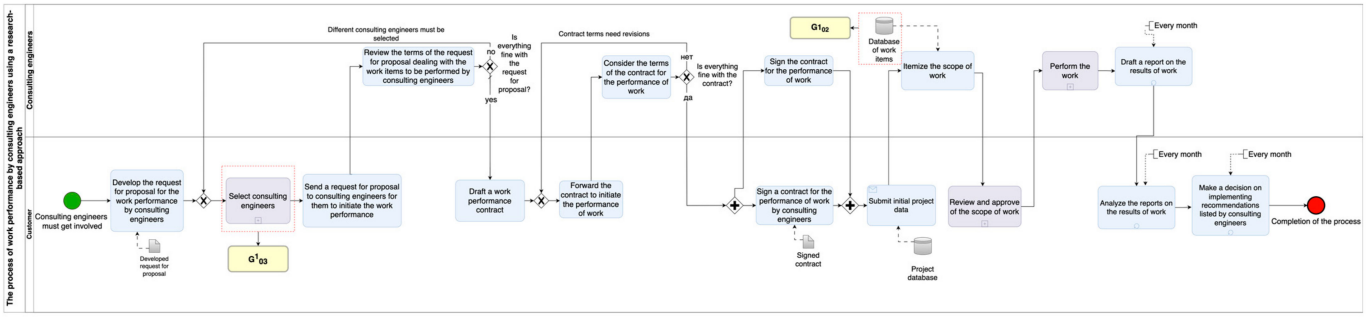

Figure 9. The flow chart of work performance procedures for consulting engineers using a research-based approach.

The process presented in Figure 9 conveys the attainment of all scopes of solutions in the "Processes" subsystem and the development of work performance procedures for consulting engineers using a research-based approach, and it also conveys the incorporation of the "Database of work items" and "Participants" subsystems, which are marked with corresponding goals.

4. Discussion

The role and standing of consulting engineers in the construction industry are becoming more and more important, the same as the number of tasks that they accomplish. Consulting engineers are often responsible for (1) managing the process of construction as a whole and (2) supervising its budgets. Furthermore, engineers can assume responsibility for any section of the project. However, the implementation of daring and unique design ideas, invested in sophisticated construction facilities, requires a new area of activity, which will stem from a research-based approach. Consulting engineers will be able to justify their recommendations and verify their calculations, concerns, monitoring sessions and many other items of work that they perform (refer to Table 7 for examples) from the standpoint of science. Hence, the authors of this study present a conceptually new type of activity to be conducted by consulting engineers and propose a consolidated professional platform for consulting engineers using a research-based approach in their work.

Towards this end, the authors take advantage of the concept of technology platforms to study the activities of consulting engineers as a holistic set of interrelated structural elements and introduce a new term of "the platform for consulting engineers, using a research-based approach in the construction industry".

The main subsystems of the platform were identified in the furtherance of the tasks of the study. They are "Processes", the "Database of work items" and "Participants". The tree of goals was used to set the general goal of the platform and its first-level goals and the scope of solutions (second-level goals) for each first-level goal that will solve the tasks set in the study.

Hence, a list of eight requirements (Table 5) to be met by consulting engineers and companies was made for the "Participants" subsystem. This is an important step on the way towards the platform construction, since the activity of consulting engineers using a research-based approach is proposed for the first time, and the requirements applied to these specialists have never been developed before. The practical application of these requirements will not only allow selecting highly qualified consulting engineers who accomplish their tasks in time, but it will also reduce the time spent on their selection. This subsystem can undergo further studies to determine the maximum and minimum requirements applicable to the development of some kind of a consolidated pattern of assessment of any consulting engineer who would like to provide consulting services.

The algorithm (Figure 7) of the database generation and the principle of automated selection of work items (Figure 8) are proposed for the "Database of work items" subsystem. The authors believe that the items of work contributed to this database will be related to academic research projects in terms of the construction of unique and sophisticated

facilities, as well as the most recent experience of experts from such countries as China and UAE. The automated selection of work items allows identifying the scope of work to be performed by consulting engineers. The great potential of this subsystem is that it can be constantly updated to remain popular not only with consulting engineers but also with customers willing to obtain an idea of the composition and amount of work to be performed. Further research can focus on the software development to computerize the principle of selecting the work performed by consulting engineers.

As far as the practical application is concerned, this approach can be implemented using the proposed BPMN diagram, which is a flow chart of the process of arranging the activities of a consulting engineer (Figure 9). This flow chart, made in the form of a BPMN diagram, reflects the step-by-step arrangement of activities of a consulting engineer (taking into account the development of the request for proposal for the work performance by consulting engineers, the contract for the performance of consulting services, the identification of the items of work to be performed by consulting engineers and other assignments). Moreover, in G^1_{02} and G^1_{03} (yellow boxes in Figure 9), this flow chart lists the criteria for selecting consulting engineers (G^1_{03}), the use of the "Database of work items" performed by consulting engineers and their automated selection (G^1_{02}). It turns out that this flow chart is an efficient practical tool needed to organize this new activity, including the choice of consulting engineers and the choice of work performed by them.

The authors identified one peculiar correlation between (1) designing a platform for consulting engineers using a research-based approach in their activities, focused on the implementation of sophisticated construction projects based on the process approach, (2) business process modeling notation BPMN 2.0 and (3) continuous process development model PDCA. The Deming cycle is at the heart of business process management ideas. Any process can take advantage of the data available in the project environment. Any process can be simulated and converted into an executable form. Hence, it is a closed loop. Therefore, one can obtain a closed loop by applying the Deming cycle to the platform for consulting engineers using a research-based approach, which means continuous potential improvement of the process and the platform itself (Figure 10):

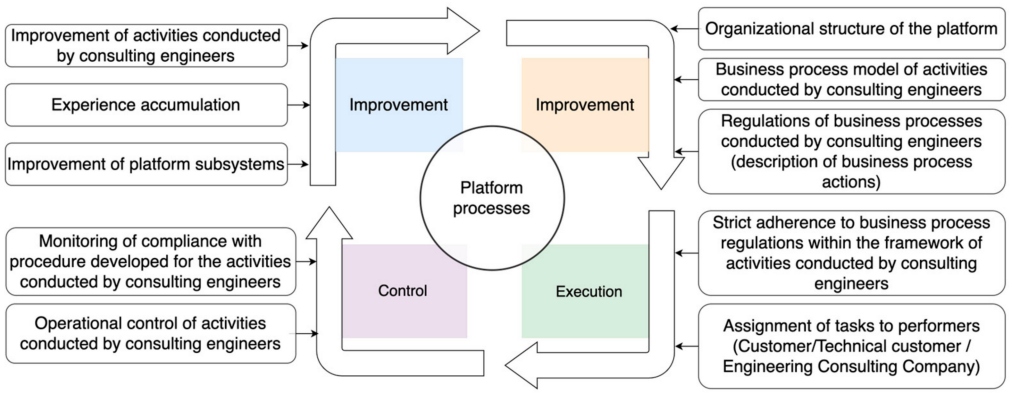

Figure 10. The Deming cycle applied to the platform.

5. Conclusions

A supplementary research-based process is required for the successful implementation of construction projects featuring sophisticated and non-standard design solutions, unique characteristics, new materials, structures and technologies. The analysis carried out in this study shows the need to generate a new type of activity inherent in consulting engineers and consisting in using a research-based approach in the process of providing consulting services to ensure the reliable and safe design, construction and operation of sophisticated construction facilities.

The authors (1) made a platform for activities conducted by consulting engineers using a research-based approach as the concept and the basis for developing this branch of the

construction industry and (2) identified the tasks to be solved to develop a unified and logical structure of this activity.

Having developed the concept of the platform for consulting engineers, the authors consider this activity as a complex system that has subsystems defined in the study: "Processes", the "Database of work items" and "Participants".

In compliance with the tree of goals method, higher-level goals (top level: i = 0; first level: i = 1) are decomposed into the scope of solutions (second level: i = 2) for each respective subsystem of the platform.

As a result, the following conclusions can be made for the "Participants" subsystem of the platform for consulting engineers using a research-based approach:

1. Eight requirements are identified for the selection of consulting engineers who will perform a set of work items of the research nature;
2. The practical application of these requirements will allow selecting highly qualified consulting engineers;
3. The practical application of these requirements will accelerate the process of selecting consulting engineers.

As for the "Database of work items" subsystem of the platform:

1. The algorithm for generating a unified database of research assignments to be performed by consulting engineers was developed;
2. The principle of automated selection of research undertakings to be implemented by consulting engineers was developed;
3. A general list of research assignments to be performed by consulting engineers is proposed.

The platform has the following benefits thanks to the "Processes" subsystem:

1. A graphical model (BPMN process) of arrangement and provision of consulting services by consulting engineers using a research-based approach was developed; this model can serve as the regulations;
2. The process of providing this type of consulting service should be considered in the context of the entire lifecycle of a sophisticated construction facility.

Without, at least, one of the devised subsystems, the platform operation will not generate sufficient results and synergies not only in terms of the result of the activity of consulting engineers using a research-based approach but also in terms of the time needed to implement the work performance procedures applicable to this activity and hence the construction project term.

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