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Case of an Airport Expansion Construction Project

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Incorporating Project Complexities in Risk Assessment: Case of an Airport Expansion Construction Project

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Abstract: In today's construction projects, which are getting more complex as a consequence of especially technical, organizational, and external aspects, complexities are considered a major source of risks. Moreover, risks may turn to complexity-creating elements and propagate additional risks through a bidirectional interaction. Complex construction projects, typically large-scale dynamic endeavors, require the realization of a high number of interdependent tasks through the consumption of various resources such as time, money, labor, and materials. In such projects, while complexities are usually assumed to be given or embedded, due to the subjective and dynamic characteristics of complexities, a tailored approach is required in order to manage them holistically without ignoring their interactions with risks. In this context, the aim of this study is to propose a practical approach that could be utilized to incorporate project complexities in the risk assessment of complex construction projects. The proposed approach entails the integrated usage of risk registers, risk breakdown structures, and complexity-incorporated risk-influence diagrams along with the utilization of a previously developed complexity assessment framework. The underlying basic assumption was that the complexities could directly or indirectly trigger risks, while the risks in turn affect the project objectives. The implementation of the approach in the case of an airport expansion construction project showed that linking the risks to project objectives starting from complexities based on this assumption is possible. In this way, it was shown that multidimensional cause-effect relationships between the complexities and risks, among the risks themselves, and the impact of this interaction on project objectives could be detected and diagrammatically evaluated. Furthermore, it was observed that incorporating complexities in the earlier stages of a project would lead to improvement in the assessment of risks. Considering the results of the case study, the proposed approach has the potential to contribute to improved risk management. **DOI: 10.1061/(ASCE)ME.1943-5479.0001099.**

Introduction

Complex construction projects, typically large-scale dynamic endeavors, require the realization of a high number of interdependent tasks through the consumption of various resources such as time, money, labor, and materials. Common characteristics of such engineering projects are requiring long durations, containing multiple technical disciplines, involving high numbers of stakeholders, and including high complexity levels (Ahn et al. 2017). Investigations frequently point to the low success rates of the completion of these projects in planned time and cost along with the shortcomings in terms of scope and quality (Chapman 2016). One of the reasons for failure in projects in general is the increasing complexity (Baccarini 1996; Vidal and Marle 2008; Hertogh and Westerveld 2010; Braglia and Frosolini 2014; Chapman 2016; Rad et al. 2017) and its underestimation (Bosch-Rekveldt et al. 2011). In this respect, understanding and addressing the effects of complexities will help achieve success in complex construction projects (Dao et al. 2017; Luo et al. 2017a, b; Ma and Fu 2020).

Complexities are considered potential sources of risk in large-scale (mega) construction projects (Erol et al. 2020). However, the other way around may be also true according to Bosch-Rekveldt et al. (2011). Risks may turn to complexity-creating elements and propagate additional risks through a bidirectional interaction. In other words, complexities and risks can relocate in the cause-effect dilemma and trigger each other mutually. Furthermore, risk propagation is considered a challenge along with a high level of uncertainty in large-scale complex projects (Chen et al. 2022). While complexities are usually assumed to be given or embedded in such projects, due to the subjective and dynamic characteristics of complexities, a tailored approach is required in order to manage them holistically without ignoring their interactions with risks. In this regard, along with interactions between risks, complexities in projects should be identified and interactions between complexities and risks should also be taken into account in risk assessment.

Complexities and risks were shown to be not independent of each other (Ackermann et al. 2007; Zhang and Fan 2014; Thomé et al. 2016), and one way of controlling the risks in a complex construction project is to first identify the complexities, then explore the risk-complexity interactions, and accordingly analyze the risks and finally determine risk response measures. A study by

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Cooke-Davies (2011) shows that complexity is the most significant aspect affecting risk management. The interdependency between complexities and risks appeared to cause critical problems in projects (Vidal et al. 2011). Although several researchers have proposed different ways of supporting risk management, there is still a clear gap between practice and theory (Taroun 2014). The lack of integration of complexity and risk leads to unrealistic risk assessments and the formulation of inadequate management strategies (Erol et al. 2020). Therefore, the rise in the complexity of projects represents an opportunity as well as a need for a new approach to risk management (Grey 2014). An evolving perception of project complexity and related risks suggests linking the complexities to risks (San Cristóbal et al. 2018; Hartono 2018).

In this respect, complexities need not be ignored and taken into account in the risk assessment process of risk management due to the combined effect of complexities and risks on project objectives and success. The issue of how complexities can be incorporated into risk assessment in a practical way constitutes the main problem of this study. The main stakeholders that will benefit from a possible solution to this problem typically would be the owner, the contractor(s), other responsible parties, and in turn the end-users of a project whose common desire is the completion of the project with success. Around this context, the aim of this study is to propose a practical approach that could be utilized to incorporate project complexities in the risk assessment of complex construction projects. In this regard, first, the paper presents a summary of the review conducted of the relevant literature to clarify the relationship between risk and complexity, disclose the effect of complexity on project risk management, and touch upon the approaches previously proposed to incorporate the risk-complexity interaction into risk management. Next, complexity and risk assessment processes were handled in conjunction, and a complexity-incorporated risk assessment approach, the complexity-based risk assessment method (CBRAM), was proposed based on the integrated usage of a number of conventional risk assessment tools and methods such as risk registers, risk breakdown structures, and risk-influence diagrams along with the utilization of a previously developed complexity assessment framework called the technical-organizational-external (TOE) framework (Bosch-Rekveldt et al. 2011). Finally, CBRAM was implemented in a case of an airport expansion construction project, and the results of the application and potential contributions of the proposed approach are discussed.

Project Complexity, Risk-Complexity Relationship, and Risk Management

Project complexity has been investigated in the literature, resulting in many different definitions of the complexity concept. Still, there is a lack of consensus on how to conceptualize project complexity (Vidal and Marle 2008; Qureshi and Kang 2015; Padalkar and Gopinath 2016; San Cristóbal et al. 2018). In the early days, complex systems were considered as characterized by a large number of interrelated components (Simon 1962). This idea was followed by the systems theory of Waldrop (1993), which characterizes a complex system as the interaction between various actors within a technical or physical environment.

In general, it is difficult to define project complexity with a high consensus. The reason for this is that complexity is an evolving, subjective, overarching, and abstract concept that can change considerably over time (Hartono 2018). Geraldi et al. (2011) categorize the project complexity mainly in terms of structural complexity (attributable to size, variety, and interdependence), uncertainty (related to situations not known or not certain), dynamics (refers to changes in projects), pace or speed (refers to the rate at which a project is delivered), and sociopolitical complexity (related to combined social and political factors). Baccarini (1996) highlights uncertainty, sociopolitical complexity, and structural complexity as the main components of complexity. Furthermore, Baccarini (1996, p. 202) proposed a notable description for complexity: "Project complexity consists of many varied interrelated parts and can be operationalized in terms of differentiation and interdependency." This systematic approach has become the basis later on for others like Vidal and Marle (2008), Vidal et al. (2011), Poveda-Bautista et al. (2018), and Hartono (2018). Sterman (1992) identified five features of dynamic project complexity as multiple interdependent components, performance dynamics over time, multiple feedback processes, nonlinear relationships, and the existence of hard and soft data. Still, every project manager or practitioner might have his/her own perception of the complexity of a project, as the practitioners perceive the environment and reality through a filter that depends on their own representations, mental models, personal experiences, and personal culture (Jaafari 2001).

The TOE framework (Bosch-Rekveldt 2011), which is utilized in this study, enables to identify various aspects of projects that contribute to the complexity, particularly, with regard to where the

Table 1. Complexities identified by the TOE framework (adopted from Bosch-Rekveldt 2011)

Technical complexity (17 elements)	Organizational complexity (17 elements)	External complexity (13 elements)
High number of project goals	High project schedule drive	Level of competition
Non-alignment of project goals	Lack of resource & skill availability	Instability of project environment
Unclarity of project goals	Lack of experience with parties involved	Company internal strategic pressure
Uncertainties in scope	Lack of Health, Safety, Security & Environment (HSSE) awareness	Lack of experience in the country
Strict quality requirements	Interfaces between different disciplines	Remoteness of location
Project duration	Number of financial sources	Interference with existing site
Size in Capital Expenditure (CapEx)	Number of contracts	Required local content
Number of locations	Type of contract	Lack of company internal support
Newness of technology (worldwide)	Number of different nationalities	Political influence
Lack of experience with technology	Number of different languages	Dependencies on external stakeholders
High number of tasks	Presence of Joint Venture (JV) partner	Variety of external stakeholders' perspectives
High variety of tasks	Involvement of different time zones	Number of external stakeholders
Dependencies between tasks	Size of project team	External risks
Uncertainty in methods	Incompatibility between different project management methods/tools	—
Involvement of different technical disciplines	Lack of trust in project team	—
Conflicting norms and standards	Lack of trust in contractor	—
Technical risks	Organizational risks	—

complexity is foreseeable in the project. The framework, which is shown in Table 1 in the form of a simplified list of complexity elements, considers the TOE risks among the sources of project complexity along with some other specific risks such as "uncertainties in scope" and "strict quality requirements," and by doing so, it reflects the natural interdependence inherent between risks and complexities. In other words, a sharp distinction between complexities and risks as to which one is the result and which one is the source does not exist in the TOE framework. On the contrary, it is assumed that as the size and scope of projects alongside the inherent variety, interrelatedness, and differentiation increase, the complexity creating the effect of the factors such as project duration, unclarity of goals, uncertainties in scope, and strict quality requirements (which are also considered among the commonly encountered risk factors) escalate, and therefore such risk factors are proposed to be handled also as the complexity elements. A similar view exists in the studies of Ackermann et al. (2007), Perminova et al. (2008), Geraldi et al. (2011), Fang and Marle (2012), and Williams (2017). Detailed explanations of the complexity elements of the TOE framework and how they may contribute to overall project complexity can be found in Bosch-Rekveldt (2011) and Bosch-Rekveldt et al. (2011). For instance, "project duration" turns to a complexity element according to the TOE framework as the size and scope of a project expand along with changes in project characteristics attributable to complex projects. With a similar approach, Yang et al. (2021) introduced the concept of complex project risks and provided a list in this context that represents the vague relationship between complexity and risk factors.

Every project is unique and performed under uncertain conditions, hence requiring risk management. The main activities or processes of risk management have been defined as risk management planning, risk identification, risk analysis (qualitative and quantitative), risk response planning, and risk controlling according to the PMBOK (PMI 2021). The risk is defined as "an uncertain event or condition that, if it occurs, has an effect on at least one project objective such as time, cost, scope or quality. A risk may have one or more causes and, if it occurs, one or more impacts." (Hillson 2002, p. 11). In practice, project risks are typically characterized by the product of the likelihood of their occurrence and the impact in which the impact indicates the effect and consequences of an event on the project objectives (Nicholas and Steyn 2017). The combination of likelihood and impact enables a project manager to decide which risks to accept or mitigate and which risks to avoid or transfer. The mechanism of risk occurrence can be modeled as shown in Fig. 1 in the form of a cause-event-effect structure (Raz and Hillson 2005; Bakker and de Kleijn 2014). A project risk is usually considered a threat but can equally well be an opportunity.

Project complexities may trigger risk events or contribute to the causes of risks (Bosch-Rekveldt et al. 2011) when the cause-event-effect structure of Fig. 1 is considered. The increasing complexity of projects (e.g., number of interfaces in a project) results in more interactions and dynamics, which contributes to project risks (Bakker and de Kleijn 2014). Emblemsvåg (2020) considers complexity as an inherent property of real-life projects that leads to risks. Thus, better integration of the relationship between complexities and risks can help to improve risk management (Ackermann et al. 2007). In this regard, Ackermann et al. (2007, 2014) supported the idea of risk mapping and demonstrated that the information of a risk map is valuable to identify the likely effects of the complex environment of projects. Thomé et al. (2016) introduced a framework that combined uncertainty and the indirect impact of the perceived complexity on risk management. Later, the concept of influence mapping is followed by Williams (2017). Qazi et al. (2016) proposed a new process to manage project complexity together with risk management, namely, the project complexity and risk management (ProCrim) process. This process helps capture the interdependency between project complexity, complexity-induced risks, and project objectives based on the expected utility theory and Bayesian belief networks (Qazi et al. 2016).

In this regard, interdependences between project complexities and risks (Bosch-Rekveldt et al. 2011; Qazi et al. 2016; Emblemsvåg 2020) as well as among the risks (Nasirzadeh et al. 2008; Siraj and Fayek 2021) have been investigated to an extent in the literature, and the earlier developed methods are essential to understand the influence of complexity on project risk management based on these interdependencies. However, there is still a need for a practical approach that enables incorporating complexities in risk assessment, detecting the cause-effect relationships between complexities and risks as well as between the risks, and opening the way to take improved risk response actions. Therefore, this study focuses on the potential cause-effect relationships between complexities and risks along with their combined effect on project objectives in order to propose a practical and integrated approach for the incorporation of complexities into risk assessment, named the CBRAM.

Risk-Complexity Interrelationship and Complexity-Based Risk Assessment Method

On the basis of the reviewed literature, two essential insights into the interdependency between complexity elements and risk factors were observed. Based on this, in CBRAM, two types of relationships were assumed to exist between the complexities and risks. First, complexities might create risks. These risks were called the risks directly induced by the complexities. Second, this first group of risks occurring from the complexities might influence the project objectives through the additional risks they propagate. This second group of risks were named the risks indirectly induced by the complexities. Based on this two-sided risk propagation, it was assumed that complexities may trigger a causal effect for risks, while the risks influence the project objectives. However, the distinction between complexities and risks was not established with sharp lines in this study based on the consideration that risks may also be the source of complexities as the size and scope as well as the variety, interdependence, and differentiation among the project components

Fig. 1. Cause-event-effect structure of risk. (Data from Raz and Hillson 2005.)

increase. In other words, complexity and risk can change place in the cause-effect dilemma and trigger each other mutually. In parallel to this argument, the TOE framework utilized in CBRAM as a complexity assessment tool contains also a number of complexity elements that are generally encountered as risk factors (see Table 1).

Difficulties may be encountered in handling complexities when using traditional risk management methods or tools such as risk registers and risk breakdown structures (RBS). For instance, risk registers, which are used to record, prioritize, and follow up the captured risks, when used alone fail to reflect the complexity effect on risks alongside their insufficiency in revealing the interactions between risks. Risk registers handle risks one by one, independently from each other. This emerges as a problem in complex construction projects. In practice, the cumulative effect of risks might be more than the sum of their individual influences based on the interactions between risks as well as between risks and complexities. Therefore, ignoring the potential cause-effect mechanisms or relationships between complexities and risks as well as the interactions among the risks during the risk assessment process would give way to incomplete and misleading conclusions in responding to risks and their prioritization.

Within the context of the presented arguments, the CBRAM was developed by combining the TOE framework (as the complexity assessment tool), risk registers (as the tool for registering, prioritizing, and following up the risks), RBSs (as the tool for categorization, hierarchization and causality breakdown of risks), and complexity/risk-influence diagrams (as the tool for visually setting up the cause-effect network between complexities and risks through *complexity-risk-project objective* chains). The insufficiency of risk registers in setting the link between complexities and risks was balanced by utilizing the RBSs (a generic RBS example is shown in Fig. 2) in combination with the complexity/risk-influence diagrams (an example complexity/risk-influence diagram is illustrated in Fig. 3). Besides, the TOE framework provided CBRAM the ability to identify the project complexities related to the project objective(s) handled. By this integrative approach, CBRAM gains the capability of setting up the cause-effect network between complexities and risks based on the potential *complexity-risk-project objective chains* predicted to occur. The complexity/risk-influence diagram given as an example in Fig. 3 was developed by considering three complexity elements (use of innovative technology, different nationalities, and instability project environment) and two project objectives (schedule and budget) alongside a number of risk factors (induced from complexities directly or indirectly as depicted in the legend) that were predicted to be effective on the project handled. Details of how such diagrams are constituted and the underlying logic are explained in the application of CBRAM in the upcoming section.

The application process of CBRAM is explained below step by step and illustrated in Fig. 4.

Step 1: The process starts with providing an awareness of the complexities of a project. For detecting the complexities of a project and creating a complexity footprint, the TOE framework is

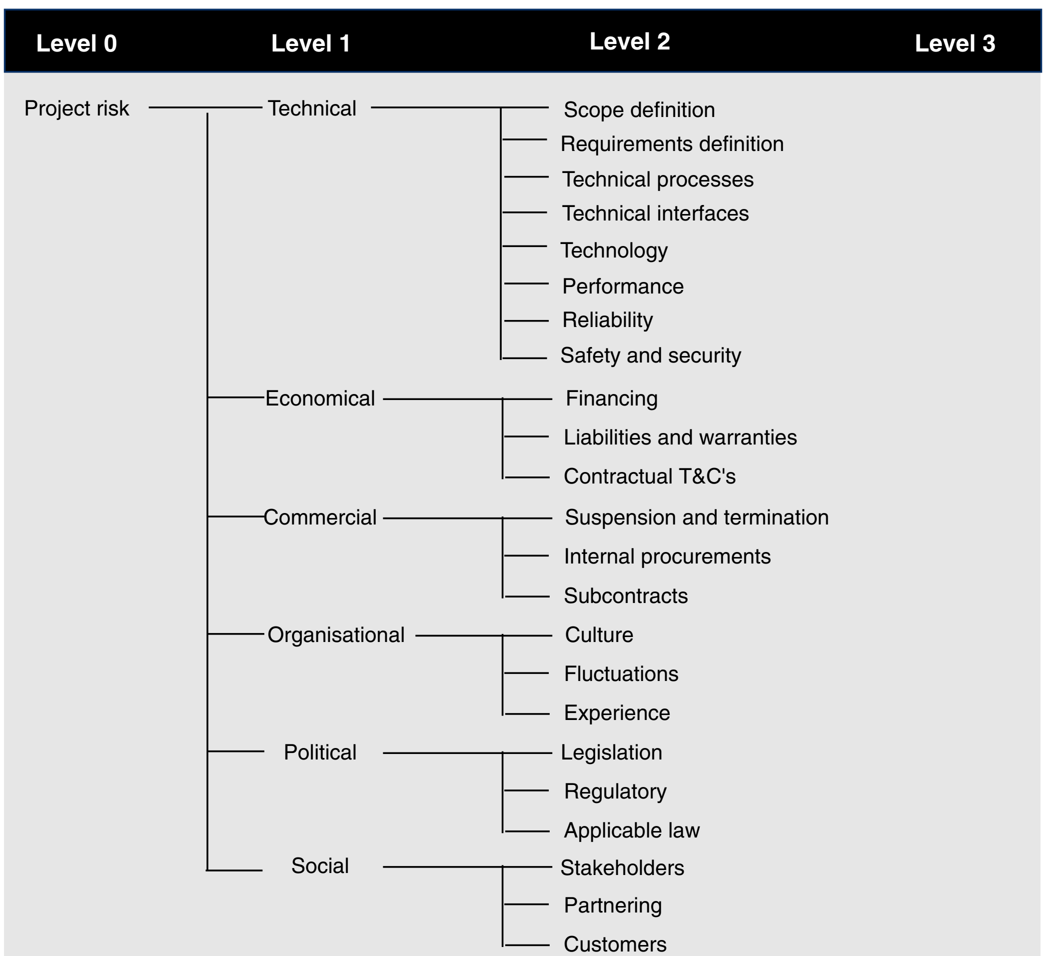

Fig. 2. Example generic RBS. (Data from Hillson 2003.)

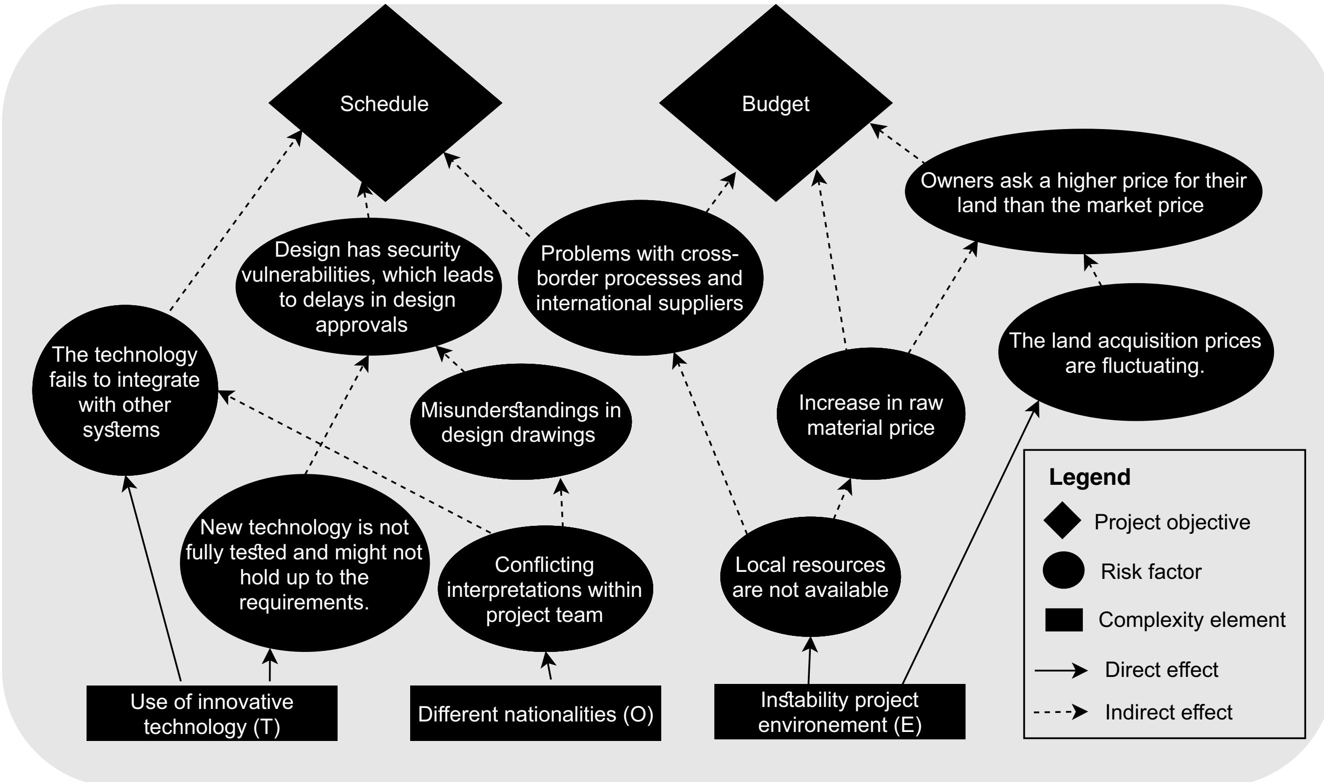

Fig. 3. Example complexity/risk-influence diagram.

utilized. A complexity footprint is created by the practitioners involved in a project by scoring the complexity elements involved in the TOE framework (see Table 1).

Step 2: Once the complexities of a project are determined on average in terms of the perspectives of the practitioners attended to the scoring process, in Step 2, the CBRAM focuses on categorization, hierarchization, and causality breakdown of risks. Risks may have multiple causes and multiple effects as well as different cause-effect dependencies depending on the complexities. Thus, instead of reacting to each individual cause-event-effect relationship with only one single risk response, one risk response could target multiple risks. Or, each cause-effect relationship may require more than one single risk response depending on how the risk in question spreads out over different complexities. In order to bring a solution to the above-mentioned limitation inherent with the risk registers, the CBRAM utilizes combined usage of the risk register with the RBS. The RBS reorganizes the risk register from higher to lower levels of detail in a hierarchical form by relating lower-level risks to higher-level risks (see Fig. 2). In doing so, the RBS enables to decompose risks into subcategories and record generic risks that occur frequently (Hillson 2002, 2003). The use of an RBS in combination with a risk register increases the level of detail of the identified risks. The lower-level risks that need further investigation form the focal point of the risk register. On the other hand, the higher-level risks allow making appropriate connections between the risks and complexities. Thus, the information needed with regard to the relationships between complexities and risks is obtained at the higher levels of RBSs.

Redeveloping the RBS for every new project would be impractical. Therefore, the use of a generic RBS for a specific industry, sector, or type of project is proposed. The generic RBS enables to record common risks, which occur frequently, based on previous experiences and lessons learned. Furthermore, the generic RBS can be customized by adding specific characteristics unique to the project handled. In practice, this means that while the generic RBS aims to reveal the risks that frequently occur, the customized RBS aims to provide specific insights into the effects of the risks in a particular project by the incorporation of risk registers into the generic RBS. Through the customized RBS, one can observe the predicted risks of a project at different detail levels and disclose the sources of the risks based on the relevant complexities as described in Step 3.

Step 3: Finally, the CBRAM benefits from the complexity/risk-influence diagrams to set up the cause-effect network between complexities and risks (which are identified in Steps 1 and 2, respectively) through *complexity-risk-project objective* chains (see Figs. 4 and 5). The idea of using complexity/risk-influence diagrams is conceived to encourage thinking about the way in which risks can be traced back to their original source, i.e., the complexities. These diagrams in combination with the customized RBSs enable the realization of the cause-effect search needed for tracing the causalities between the risks and complexities as well as the interactions between the risks. Eventually, the risks can be linked to one or more causes or one cause can be linked to one or multiple risks. This creates a network of interrelated complexities and risks. In this way, CBRAM captures the risks directly or indirectly induced by complexities through tracing risks toward the complexities. Furthermore, CBRAM evaluates the impacts of risks on the project objectives through tracking risks toward the objectives along the *complexity-risk-project objective* chains that generate the complexity/risk-influence diagrams. In a way, CBRAM places the *source-event-effect* model of risk structure illustrated in Fig. 1 over the *complexity (source) —risk (event)—project objective* structure and constitutes a network of risks, complexities, and project objectives. Ultimately, CBRAM strengthens the risk assessment process through the incorporation of the complexity assessment. In this way, CBRAM is expected to improve project risk management

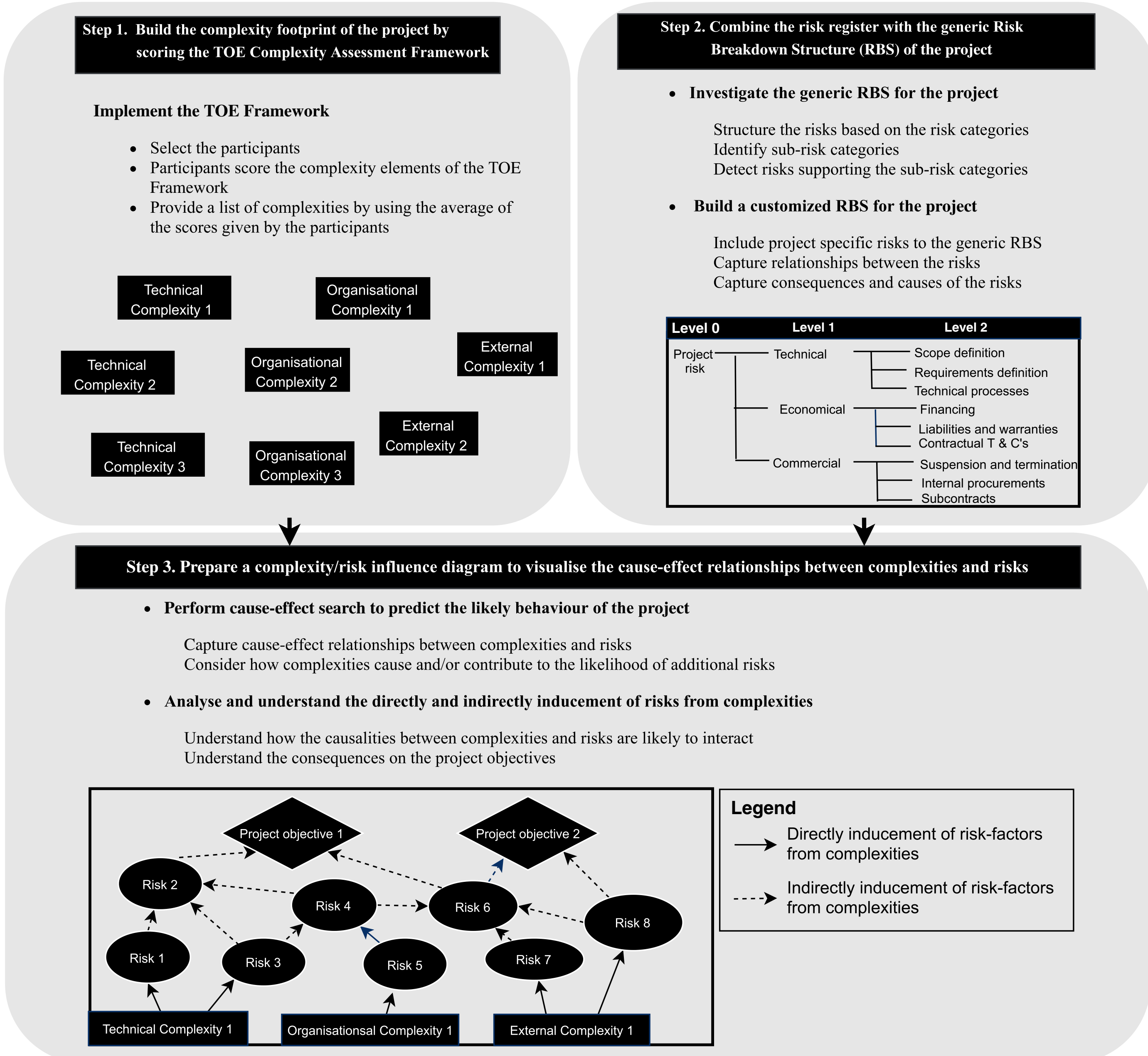

Fig. 4. Stepwise illustration of the CBRAM process.

by paving the way to improved risk analysis and risk response measures, which is a requirement for success in complex projects. However, the details of the procedure to be followed depend on the dynamics of each project, whereas the general steps would be as described up to here to keep the practicality aimed for by CBRAM.

Application of CBRAM in the Case of an Airport Expansion Construction Project

CBRAM was applied to an airport terminal expansion construction project realized in Germany. The airport has been in service for more than 80 years, and it is one of the biggest hubs in Europe in terms of passenger and freight transport. Furthermore, it is one of the biggest infrastructure facilities in its region and stretches an enormous land area. However, the airport has exceeded its designed capacity. Therefore, the total capacity of the terminal is increased with three additional piers. Since the estimated cost of the project is approximately 2 billion euros, it can be considered a large-scale as well as a complex construction project when the scope, duration, and other challenging factors are considered alongside. The company, which is responsible for the operation of the airport, is the *owner* of the project. Besides the *main contractor*, who is responsible for the overall construction of the project, a *consultant company* is also involved as the procurement coordinator and project planner under a project management contract from the initiation phase starting in the early 2000s to the completion expected more than two decades later.

The application of CBRAM on the airport terminal expansion project was conducted within the consultant company. The construction phase is composed of two separate parts procured under a design & build contract. The first part consists of the construction of the main terminal building with departure and arrival levels, the

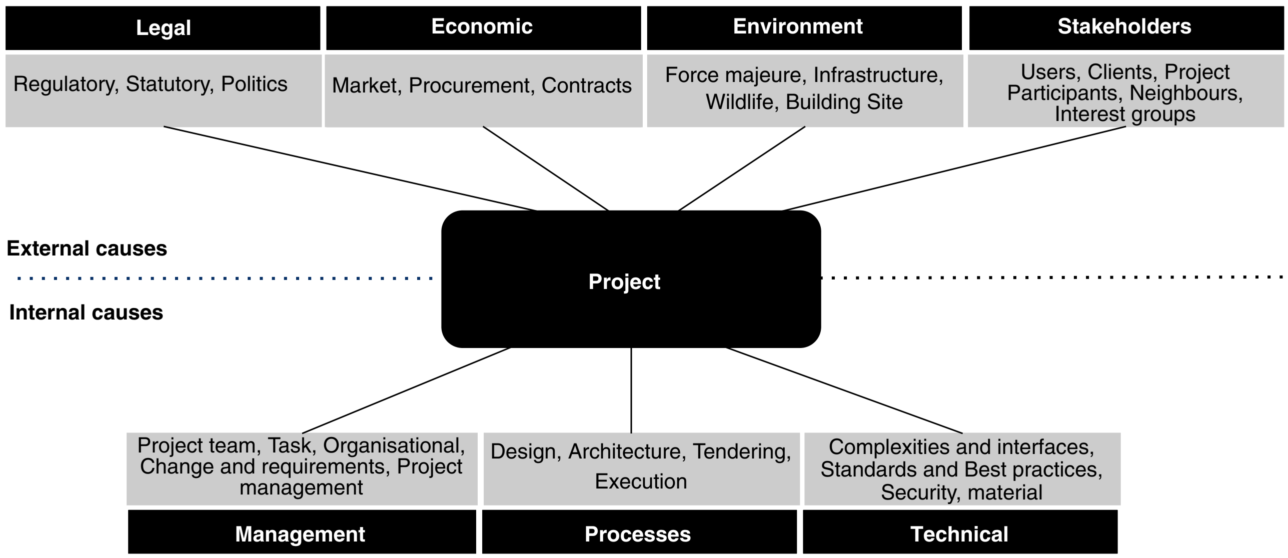

Fig. 5. Risk categories used by the Consultant Company.

lounges fitting to a passenger volume of 14 million travelers, the automated baggage systems, and two piers. The starting date of the operations for this part is currently projected for 2023. The completion of the second part, i.e., the construction of the third pier is expected in 2025.

In this case study, CBRAM was applied by only considering the complexities and risks affecting the schedule, progress, and timely completion of the project rather than those influencing other project aspects like the costs and quality. In other words, only one single project objective was handled at a time for the sake of simplifying the application. In line with the CBRAM process illustrated in Fig. 4, first, in Step 1, a group of experts from the consultant company who have worked on the airport terminal expansion project were asked to score the complexity elements in the TOE framework (see Table 1) by focusing only on the schedule and progress. The experts were selected based on their background and years of experience in the field of complex construction projects. Based on the average years of experience of the experts, which was around 20 years, it was assumed that the respondents had considerable experience in this field. First, a number of qualitative response options were provided to the experts in the form of a 5-point Likert scale ranging from very effective, effective, average, ineffective to very ineffective and having values of 5, 4, 3, 2, and 1, respectively. Then, the qualitative responses given by the experts were quantified and the averages were taken to find the complexity elements having the highest score. In this study, the top-10 complexities were taken into account. These complexity elements were assumed to constitute the complexity footprint of the project and therefore they were processed in the CBRAM application. The complexity elements in question are given below with brief explanations:

- *Strict quality requirements (Technical Complexity):* Challenges arose due to special approval procedures and quality requirements required to be implemented.
- *Project duration (Technical Complexity):* The preparation of the detailed designs and execution plans started in 2001 and were completed at the end of 2017. The completion of the construction is expected at the end of 2023. As a result of such a long project duration, it has not been possible to directly implement the previously prepared designs and plans due to the changes occurring over time in the legal provisions and framework conditions.
- *High number of tasks (Technical Complexity):* The number of tasks in a project of this scale is quite high.
- *High project schedule drive (Organizational Complexity):* Since every misalignment or delay would have had an effect on later activities, all the execution work was needed to be done within the agreed time spans. For instance, since the design value for the flight operation had been incorrectly implemented in the detailed design during the preconstruction stage, the construction could only be started after all the design drawings had been revised.
- *Lack of resource and skills availability (Organizational Complexity)*: In a project of this size, several problems arose as a result of the availability as well as the prices of raw materials and also the engineering market.
- *Interfaces between different disciplines (Organizational Complexity):* With the high number of stakeholders involved in the project, several interface gaps occurred. For instance, some problems arose due to insufficient coordination, especially during the course of working on the technical systems and structural units.
- *Size of project team (Organizational Complexity):* The whole control of the execution in terms of quality, deadlines, costs, and teamwork was outsourced. In this way, the project has been executed under a single design-build contract. As a result, around 500 individual subcontracts were awarded to small and middle-sized construction companies by the consultant company (the procurement coordinator).
- *Interference with existing site (External Complexity):* The construction inevitably would have affected the air traffic flow and also the other modes of transport in the vicinity. Thus, all the plans were required to be assessed by the state transport authority as well as the municipality. Besides, being positioned directly within the area of a large airport, the space for the construction site is very limited. This situation resulted in additional infrastructural work to incorporate the new terminal control mechanism into an already existing location without influencing the rest of the airport.
- *Political instability (External Complexity)*: Due to severe insecurities caused by such a big project, politics meddled with the project and several decisions that led to a shift in the overall schedule had to be taken.
- *Dependencies on external stakeholders (External Complexity)*: The external stakeholders that were anticipated upfront included

the municipality, politicians, the people living nearby the airport, the businesses that were affected by the construction works, and the contractors hired for the construction works. With so many participants, a lot of negotiations and tender rounds have been necessary as of the starting date. Apart from the effect on air traffic flow, nuisances of the construction work, and interventions in the public space of the airport itself, the access roads in the neighborhood were also affected. This caused implications for neighboring entrepreneurs and inhabitants.

The risk register of the project has been regularly updated by the consultant company throughout the design and construction phases. Based on the latest updated risk register and the previous risk registers, the risks were categorized as follows:

- *Foreseen Risks:* Foreseen Risks are the risks that were identified during the design phase and therefore entered into the risk register before the construction phase.
- *Unforeseen Risks:* Unforeseen Risks are the risks that could not be identified during the design phase but are the risks detected and added to the risk register during the construction phase.

In Step 2, a generic RBS was generated specifically for this project based on the risk management plan of the consultant company. Second, a customized RBS was built by incorporating the foreseen risks and unforeseen risks, which are extracted from the risk register, into the generic RBS. Risk categories used by the consultant company are shown in Fig. 5. The customized RBS is given in Fig. 6 for the external and internal project risks. The hierarchical breakdown of risks through the customized RBS provided the opportunity of categorizing the risks transferred from the risk register at different detail levels. The risks filtered from the risk register were represented by short titles and in a consolidated form in the customized RBS, compatible with the characteristic structure of the generic RBS, whereas the long descriptions and lower breakdowns were used later in complexity/risk-influence diagrams.

In Step 3, complexity/risk-influence diagrams were built by connecting the foreseen and unforeseen risks to the complexities identified in Step 1 through a cause-effect search. The hierarchical structure of the customized RBS in different detail levels in Fig. 6 was utilized during this task to set up the connections between the complexities and risks. The risk categories in Fig. 5 were utilized not only as the higher-level risk categories within the customized RBS but also became helpful in catching the clues about which complexity is interrelated with which risks, and this information was used in building the complexity/risk-influence diagrams. In other words, the similarities between the categories of complexities used in the TOE framework (see Table 1) and the risk categories used by the consultant company (see Fig. 5), which are also utilized in RBS (see Fig. 6), helped set up the appropriate links between the complexities and risks identified in Steps 1 and 2, respectively. The purpose was to understand which causalities exist between the complexities and risks.

For instance, the *internal project risk-technical-material-quantity-availability* path of the RBS in Fig. 6 was connected to the complexity *unavailability of sufficient resources & skills* in the complexity/risk-influence diagram of Fig. 7. Furthermore, the risks spreading from this complexity toward the handled project objective were determined based on the relevant risk(s) located on the customized RBS with taking into account the cause-effect relationships in between the risks. In other words, the causal links between risks and complexities, as well as the distribution of risks from complexities to project objectives, were determined by using the hierarchical structure of RBS, which is ordered from the top to the bottom with increasing levels of detail.

As shown in Fig. 7, the causal chains between the complexities and risks were illustrated through the use of arrows, which represent "Complexity A causes, exacerbates, or promotes Risk B" as an example. This first group involves the risks directly induced by the complexities. Next, the risks (foreseen and unforeseen) were connected to each other through the search for what would make this happen and what if this happens. This second group of risks constitutes the risks indirectly induced by the complexities. Then, arrows were drawn from the risks in these two groups toward the items relevant to the project objective handled, i.e., schedule, progress, and timely completion of the project. Finally, the cause-effect network between the complexities and risks composed of *complexity-risk-project objective* chains was built, and a part of which is given in Fig. 7.

Fig. 8 illustrates an example *complexity-risk-project objective* chain from the built complexity/risk-influence diagrams. The logic behind this chain is: as a result of strict quality requirements, special infrastructure requests by the airlines (such as the closed gates and additional technology to handle the process) occurred which resulted in changes in the airline mix (larger aircraft) due to the changes in the International Civil Aviation Organization (ICAO) guidelines requested by the airlines which in turn led to a significant deviation from the approved planning status due to internal requirements. The risk *special infrastructure requests by the airlines,* which is a risk foreseen during the design phase, and the risk *changes in the airline mix*, which is a risk unforeseen during the design phase but valid during the construction phase, have been shown differently in Fig. 8 for the sake of distinction.

One of the complexity/risk-influence diagrams built for different groups of complexities out of the ten complexities identified in Step 1 based on the logic illustrated in Fig. 8 was previously given in Fig. 7. The foreseen and unforeseen risks are indicated differently in this figure, which points out a distinguishing finding. The cause-effect interdependencies among the foreseen and unforeseen risks obtained along the *complexity-risk-project objective* chains in Fig. 7 indicate that the process of linking the risks to project objectives should be performed starting from the complexities at the initial project phases. In this way, the opportunity of identifying beforehand the risks directly or indirectly stemming from the complexities but being effective during the construction phase would increase.

Discussion of Results

The application of CBRAM on the airport terminal expansion project provided complexity/risk-influence diagrams or networks (one of which is given in Fig. 7) composed of *complexity-risk-project objective* chains (see Fig. 8 for an individual example) built based on the typical causalities observed between the complexities and risks. In the assessment of project risks, such a network provides additional contribution with respect to the separate usage of risk registers and RBSs (see Fig. 2). Through the established network, the risks regularly updated in the risk register by the consultant company and which were transferred to the RBS (see Fig. 6) were sourced backward to the complexities that directly or indirectly induced risks and also linked forward to the project objective handled. In other words, the complexity assessment realized by the usage of the TOE framework and the customized RBS built by using the risk register of the consultant company helped to compose the complexity/risk-influence diagrams. These diagrams were built upon the *source-event-effect* model of the risk structure in Fig. 1 in the form of *complexity (source)-risk (event)-project objective (effect)* structure. Using this approach, the interactions between complexities and risks as well as the interactions between risks in the risk register were disclosed, and the links between the risks and the

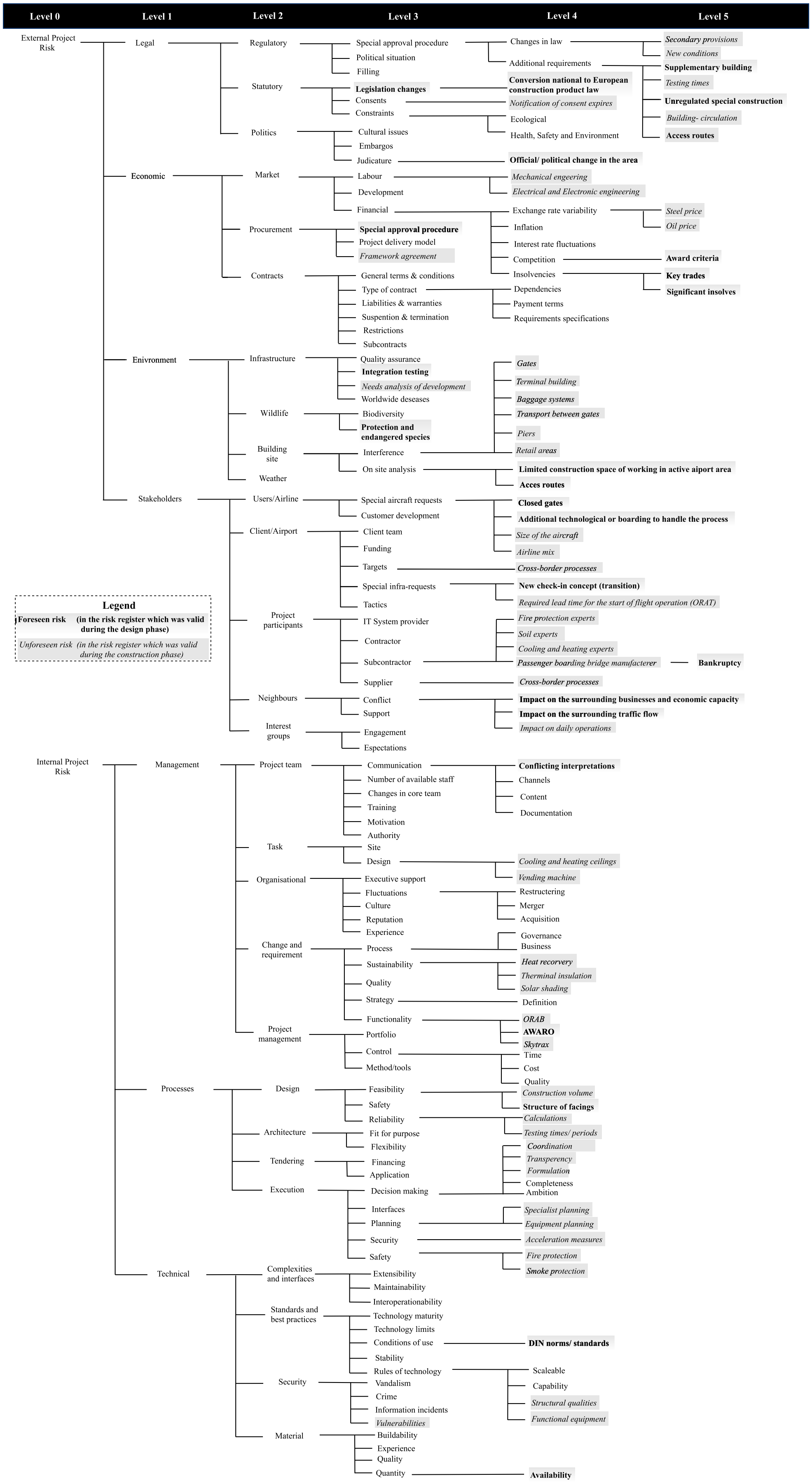

Fig. 6. Customized RBS for the external and internal risks of the terminal expansion project.

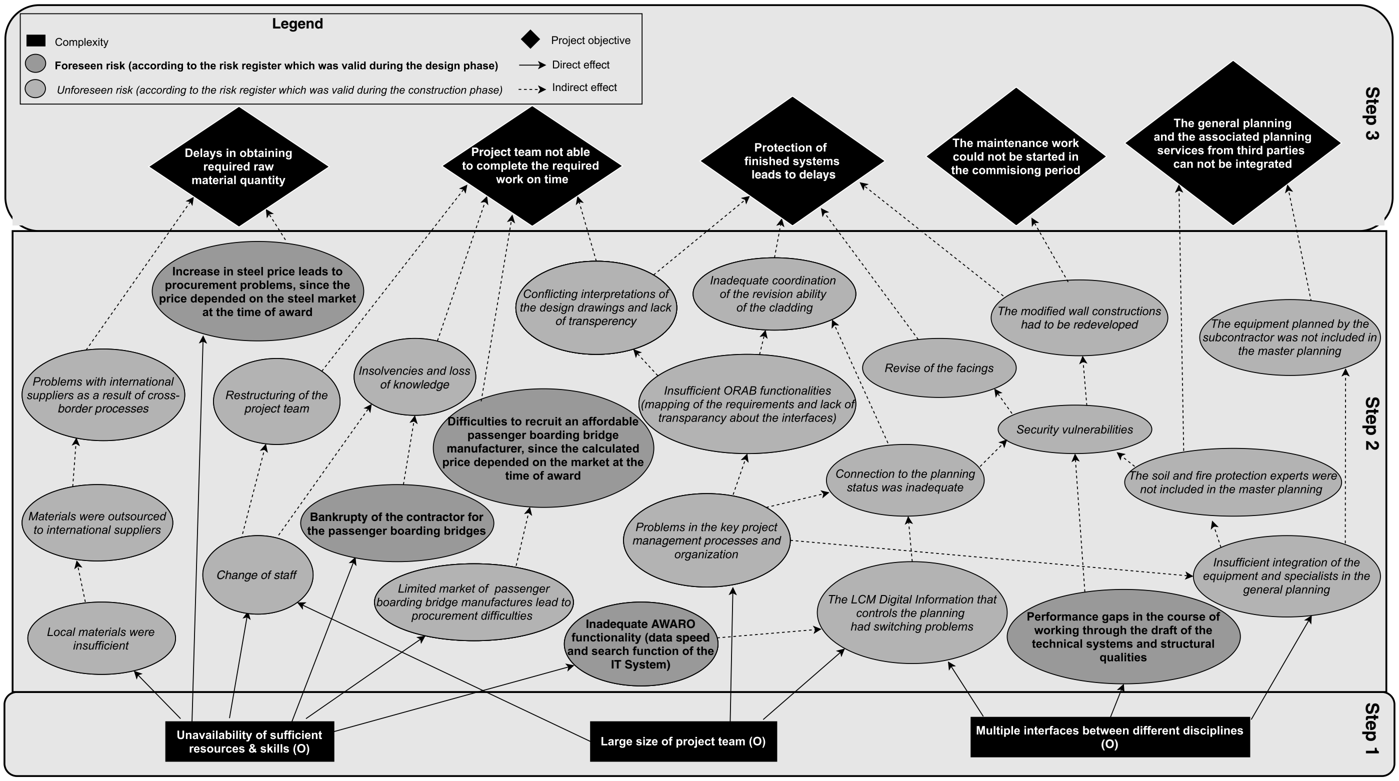

Fig. 7. Risk-influence diagram of the terminal expansion project in terms of the organizational complexities "unavailability of sufficient resources & skills," "(large) size of project team," and "(multiple) interfaces between different disciplines."

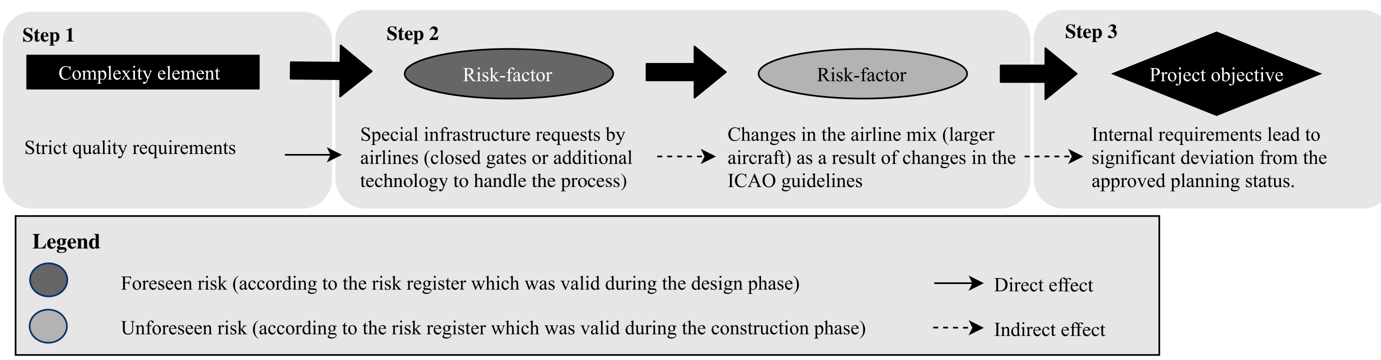

Fig. 8. Example "complexity-risk-project objective" chain.

project objective handled in this application were figured out. This information would provide awareness of the risk-complexity and risk-risk interactions, which in turn help control the risks more effectively, and help improve the risk response actions by increasing the accuracy of prioritization of the risks based on an improved risk analysis. For instance, the effect *project team not able to complete the required work on time* in Fig. 7 is found to be impacted by five different chains dispersing from two different complexities. Furthermore, some of the risks on these *complexity-risk-project objective* chains are risks that could not be foreseen before the construction phase but occurred later during the construction phase. In case CBRAM had been used earlier during the design phase, it would have been more likely to assign higher occurrence probability x impact values to the relevant risks, and accordingly, this would have changed the strength of the risk response actions taken to control the risk of delay that might occur as a result of the risks in question.

The results of this CBRAM application suggest the added strength to the risk identification process if CBRAM would be used in the early project stages. To clarify; in case the foreseen risks dominate on complexity/risk-influence diagrams, this means that most of the risks were anticipated before they actually occurred. In contrast, if the unforeseen risks dominate, it means that most of the risks were not anticipated in advance, but included in the risk register after they occurred during the construction phase. For instance, the complexity/risk-influence diagram in Fig. 7 contains more unforeseen risks than foreseen risks, which is a situation depicting the latter case. This was also observed in the other complexity/risk-influence diagrams obtained. This observation shows the value of linking the risks to project objectives starting from the complexities as early as possible in projects. For instance, as shown in Fig. 7, delays on schedule have occurred due to the delays in obtaining the required amount of raw materials and this situation had not been registered as a risk during the design phase based on the assumption that local suppliers would be sufficient in this respect. Furthermore, because of having to source the required materials from the international market, the delay risk due to cross-border procedures and related paper-works indirectly emerged. Eventually, the directly and indirectly induced risks constituting the *complexity-risk-project objective* chain of this specific example could be linked to the complexity unavailability of sufficient resources & skills.

It is possible to compare the differences against the case in which the CBRAM is not applied through a detailed examination of other *complexity-risk-project objective* chains set out in Fig. 7. As an example, the chain;

> large size of project team (*complexity*)—problems in the key project management processes and organization (*unforeseen risk*)—insufficient integration of the equipment and specialists in the general planning (*unforeseen risk*)—the soil and fire protection experts not included in the master plan (*unforeseen risk*)—the general planning and associated planning services from third parties cannot be integrated (*the situation representing the handled project objective*)

consists of three different interrelated risks that were not foreseen during the design phase where CBRAM was not applied but occurred later during the construction phase. It could have been more likely to detect these unforeseen risks based on the complexities *large size of project team* and *multiple interfaces between different disciplines*, which could have been identified and included in the risk assessment process in case CBRAM is used. Without generalizing, the observation of such cases during the current CBRAM application is considered an indicator of the potential value of CBRAM.

The following complexity-risk-project objective chain example is given in Fig. 7, which includes this time a foreseen risk rather than an unforeseen risk, unlike the previous example. Such chains, which were observed also in other complexity/risk-influence diagrams obtained, could be considered as an indication of CBRAM's potential in contributing to risk assessment when applied upfront, once more as an ungeneralized argument. In other words, it would be more likely to detect such risks in case CBRAM is utilized exante.

> unavailability of sufficient resources & skills (*complexity*)—increase in steel price leads to procurement problems, since the price depended on the steel market at the time of award (*foreseen risk*)—delays in obtaining required raw material quantity (*the situation representing the handled project objective*)

Although the current application is an expost one where the CBRAM is implemented on the data belonging to the construction phase, the findings strengthen the suggestion that in case the CBRAM had been used earlier during the design phase, some unforeseen risks occurring during the construction phase possibly could have been foreseen beforehand. Furthermore, as discussed, some of the complexity-risk-project objective chains containing foreseen risks and taking place on the complexity/risk-influence diagrams obtained in this expost application show CBRAM's potential in case it is applied exante. However, CBRAM's potential in this regard needs further research that will be based on its exante application during the early risk identification at the preconstruction phase of projects. In addition, CBRAM's contribution to improving the risk analysis stage of risk management needs to be explored. CBRAM carries the potential of strengthening the whole risk management process from the identification of risks to the determination of risk response measures. In this regard, future research, to be carried out exante at different project phases, should investigate the value of CBRAM from this perspective on a larger scale.

Not all of the risks that occurred in practice might have been caused by only the 10 complexity elements included in this application. Some other complexities also may have influenced the occurrence of some of the risks, and some risks may be insufficiently identified. Therefore, the task of exploring the complexities and predicting the risks gains importance and needs to be realized in a proper manner for the effective implementation of CBRAM.

The application of CBRAM on the terminal expansion project only focuses on the project objective schedule, progress, and timely completion of the project. This objective was represented by different situations in this application. For instance, delays in obtaining raw material quantity and delays occurring in the protection of finished systems are among these situations for the complexity/risk-influence diagram of Fig. 7. In case multiple objectives are processed through CBRAM, it can be expected that some of the risks would exhibit a combined and more intensive effect on the project success. On the other hand, the opposite might also occur due to possible conflicts between objectives. Such effects, which would evolve from handling multiobjectives concurrently, need to be handled in future research and taken into account during the implementation of the CBRAM.

Conclusions and Recommendations

This case study proposes a practical and integrated approach for the incorporation of project complexities into risk assessment and presents the application of this approach to an airport expansion project. This approach, named the CBRAM, would help practitioners realistically assess the project risks without ignoring the complexities and constitute a bridge between theory and practice. The need for finding solutions to the global problem of low success rates in complex construction projects is frequently mentioned. The growing size and complexity with the increasing uncertainties recently have been the leading cause of failure in such projects. This study can be considered a step toward the solution to this problem. It is proposed to assess the risks through the incorporation of project complexities during the implementation of risk management due to the combined effect of complexities and risks on project success in complex construction projects. Ignoring the potential cause-effect relationships between the complexities and risks as well as between the risks may be the cause of an insufficient understanding of project risks.

First, a summary of the review conducted on the relevant literature was presented to clarify the relationship between risk and complexity, disclose the effect of complexity on project risk management, and touch upon the approaches previously proposed to incorporate the risk-complexity interaction into risk management. Next, complexity and risk assessment processes were handled in conjunction, and the CBRAM was proposed based on the integrated usage of a number of conventional risk assessment tools and methods such as risk registers, RBSs, and risk-influence diagrams along with the utilization of a previously developed complexity assessment framework called the TOE framework. Finally, CBRAM was implemented in a case of an airport expansion construction project, and the results of the application and potential contributions of the proposed approach are discussed.

On the basis of the reviewed literature, two essential insights into the interdependency between complexity elements and risk factors were observed. Based on this, in CBRAM, two types of relationships were assumed to exist between the complexities and risks. Firstly, complexities might create risks. These risks were called the risks directly induced by the complexities. Second, this first group of risks occurring from the complexities might influence the project objectives through the additional risks they propagate. This second group of risks were named the risks indirectly induced by the complexities. Based on this two-sided risk propagation, it was assumed that complexities may trigger a causal effect for risks, while the risks influence the project objectives. However, the distinction between complexities and risks was not established with sharp lines in this study based on the consideration that risks may also be the source of complexities as the size and scope as well as the variety, interdependence, and differentiation among project components increase. In other words, complexity and risk can be replaced in the cause-effect dilemma and trigger each other mutually. Based on this argument, the TOE framework utilized in CBRAM as a complexity assessment tool contains also a number of complexity elements that can be generally encountered as risk factors.

CBRAM serves as a practical tool encouraging experts to go beyond the assumption of complexity elements being independent of risks. Depending on the characteristics unique to a particular project, a practitioner could come up with an improved risk management application by means of CBRAM by simultaneously focusing attention on the complexities and risks that have the highest potential to impact the project objectives. The main stakeholders that will benefit from the improvement of risk management through the usage of CBRAM typically would be the owner, the contractor(s), and in turn the end-users of a project, whose common desire is the completion of the project with success.

In order to show the applicability of CBRAM, observe its strengths, and identify potential areas of contribution and improvement areas through further research, the method was applied to an ongoing airport expansion construction project in Germany. In this application, it was shown that linking the risks to project objectives should be performed starting from the complexities in the early project phases. In this way, it was shown that the opportunity of identifying beforehand the risks directly or indirectly stemming from the complexities but being effective during the construction phase increases. Without generalizing, this observation has been considered an indicator of the potential value of CBRAM. Although CBRAM could provide the opportunity of analyzing more than one project objective at the same time, only one single project objective, i.e., the schedule, progress, and timely completion of the project, was handled in the case study for the sake of simplicity. For this reason, the CBRAM needs to be applied in a number of different projects at different phases by simultaneously taking into account multiple project objectives. Another point that is worth investigating and would contribute to the improvement of CBRAM is the statistical modeling of the relationship between the complexities and risks through methods such as system dynamics, fuzzy cognitive maps, or statistical causal relationship analysis, which can be observed in some studies in the literature, and to provide the usage of such models in a way compatible with the practicality of CBRAM.

The results of CBRAM's application to the airport terminal expansion project can be summarized in two bullets:

- In the assessment of project risks, complexity-incorporated risk (complexity/risk) influence diagrams or networks were shown to have contributed with respect to the separate usage of risk registers and RBSs. Through these diagrams, which were built upon the complexity (source)-risk (event)-project objective (effect) structure, the risks regularly updated in the risk register and which were transferred to the RBS were sourced backward to the complexities that directly or indirectly induced risks and also linked forward to the project objective handled. Using this approach, the interactions between the complexities and the risks as well as the interactions between the risks in the risk register were disclosed and the links between the risks and the project objective handled were figured out. This information would provide awareness of the complexity-risk and risk-risk interactions, which in turn help control the risks more effectively, and help improve the risk response actions by increasing the accuracy of prioritization of the risks based on an improved risk analysis.
- Some of the risks on the *complexity-risk-project objective* chains are those that could not be foreseen before the construction phase but occurred later during the construction phase. In case CBRAM had been used earlier during the design phase, it would have been more likely to assign higher *occurrence probability x impact* values to the relevant risks, and accordingly, this would have changed the strength of the risk response actions taken to control the risk of delay that might occur due to the risks in question.

Considering the above points, CBRAM is considered as having the potential to improve risk management. Further research is recommended to verify this potential and observe its effect on project success.

Data Availability Statement

All data, models, or code that support the findings of this study are available from the corresponding author upon request.

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