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Improving the performance of civil engineering projects through the integrated design process

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Abstract

Purpose – Civil engineering projects around the world have been underperforming for a long time. While the complexity of these projects will continue to increase, there is an urgent need to perform better. Although the integrated design process is critical for project success, the literature lacks studies describing the link to project performance. Therefore, this study aims to investigate the dominant variables that affect the integrated design process and consequently project performance.

Design/methodology/approach – A multiple case study was conducted to determine the dominant variables that affect the integrated design process and project performance. The research included four projects. Semi-structured interviews were the main source of data.

Findings – The cases indicated that the extent to which an integrated approach is achieved in the design process is essential for project performance. This applies to the integration of stakeholders' interests as well as the integration of disciplines. Above all, it was concluded that the project team participants' competencies for integration are a dominant factor for project performance, as the integrated design process has changed from a technical challenge to an integrative one.

Originality/value – This study provides insights into the dominant variable of the integrated design process that affects project performance, which is underexposed in the literature. The study results reveal the importance of competencies related to integration and adoption of the design problem context, which are not yet included in civil engineering design methods. In this respect, empathy is introduced as a new and critical competence for the civil engineering industry, which needs further research.

Keywords Design, Project performance, Complexity, Human factors engineering, Integrated design

Paper type research paper

1. Introduction

The problem of underperforming civil engineering projects has been extensively studied, where performance is mainly defined as the extent to which goals are met, related to cost and time. Budgeted project costs show a substantial, average overrun (Flyvbjerg *et al.*, 2013; Odeck, 2014; Locatelli *et al.*, 2017). This is difficult to justify socially since these projects are mainly publicly funded. The literature identifies many interrelated factors that affect project performance (Doloi, 2013; Moschouli *et al.*, 2018; Shane *et al.*, 2009). The front-end development phase or the preconstruction phase have been acknowledged as essential factors of the project life cycle (Gibson *et al.*, 2006; Bosch-Rekveldt, 2011; Cantarelli *et al.*, 2012). The design process is a substantial part of these phases, as it covers critical stages, such as concept development, feasability and scope defintion (Bosch-Rekveldt, 2011; Turner, 2008; PMI, 2017). Additionally, the outcome of the design process defines the project scope, which, in turn, forms the basis for essential project processes, such as cost estimation, stakeholder management and risk management.

The integrated design process can be defined as the process that delivers the artefact's description and integrates the interests of all parties involved (Stock and Burton, 2011). This

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process is related to many variables affecting performance, such as stakeholder management, scope definition, contract changes and technical management. A network of inextricably linked variables affecting project performance appears (Love *et al.*, 2016), of which the integrated design process is a relevant part. Therefore, the design process can provide a valuable perspective to evaluate and improve civil engineering projects. Observations from practice reinforce this assumption. Over the past decades, the integrated design process has been influenced by two important developments that affected projects: an increasing complexity of the design assignment and a transition to integrated contracts.

The design process is strongly affected by complexity (Benabdellah, 2020). While many aspects determining complexity emerge from research (Bosch-Rekveldt, 2011), it is commonly understood that the complexity of civil engineering projects is influenced by internal and external aspects anyway. Internal aspects are often defined as the number of elements and participants within the project system and the extent to which they interact (Simon, 1996; Vidal and Marle, 2008). External aspects refer to the project context (Vidal and Marle, 2008). In this respect, Hertogh and Westerveld (2010) and Maier and Fadel (2006) identify dynamic complexity of projects, which is mainly related to the dynamic and non-rational character of the stakeholders' behaviour. Both types of complexity apply to civil engineering projects and the integrated design process due to their interdisciplinary nature and significant environmental impact. Over the past decades, both types of complexity have increased, and this trend will inevitably continue.

Firstly, civil engineering projects play a key role in anticipating climate change, especially in the urbanised deltas. Therefore, projects will have to accelerate climate adaptation and circularity and stimulate biodiversity (Global Center of Adaptation, 2020; World Wide Fund for nature, 2020). Secondly, the need for mobility and urbanisation will further increase (Eurostat, 2016). An increasing number of functions and disciplines will have to be integrated into the projects when urbanisation and mobility merge. Additionally, a growing number of stakeholders' interests need to be considered when building in more urbanised areas. Thirdly, infrastructure objects built in the post-war period reach the end of their functional or technical lifespan. As a result, extensive rehabilitation is imminent (Lange, 2018). Rehabilitation projects are more complicated because transport systems have to remain in operation during reconstruction, considering the high demands on availability. Fourthly, infrastructure systems have social and economic impacts, especially on disadvantaged groups, either intentional or unintentional (Rodgers and O'Neill, 2012). The impact has both quantitative and qualitative appearances (Wilkinson, 2019). The inclusion of all of these aspects will further increase both internal and external complexity of the design assignment of civil engineering projects and consequently affect their performance.

Another development that has influenced the integrated design process and project performance over the past decades is the transition from construct-only contracts to integrated contracts (Regan *et al.*, 2015; Alleman *et al.*, 2017). The use of output specifications, and a partial shift of the design responsibility and risks from the owner to the contractor are characteristic aspects of integrated contracts. As a result of this transition, design competencies have slowly shifted from the owner to the contractor. Meanwhile, projects were still, at least partly, traditionally awarded based on competitive, low-bid contracting principles. Consequently, contractors were enticed into challenging and risky tender designs as design became a differentiator for winning lowest bid contracts (Alleman *et al.*, 2017; Koppenjan *et al.*, 2020). The convergence of these aspects might have affected design-related project failures over the past decades.

It is concluded that the integrated design process is an important part of a network of variables that affect civil engineering projects' performance and that the complexity of this process is growing. However, the body of literature on critical success factors for project performance lacks studies related to collaborative and integrated design processes (Koutsikouri *et al.*, 2008). Thus, the question is how the integrated design process interacts with project performance and by extension how that process should be adjusted to improve the civil engineering industry's performance. This study aims to identify the determining variables of the integrated design process that affect project performance.

Although the problem of poor-performing projects manifests itself globally, this paper focusses on the Dutch practice, where underperformance has also been identified (Cantarelli *et al.*, 2012; Verweij *et al.*, 2015). Recent examples of large projects with considerable cost and time overruns show the problem's topicality, such as the Sealock IJmuiden and the Zuidasdok in Amsterdam (Clahsen, 2019). Furthermore, since The Netherlands can be characterised as a densely populated delta, the development of increasing complexity is manifest (Delta Commissioner, 2014; Knowledge Institute for Mobility, 2020; Bleijenberg, 2021; RLI Council for Living Environment and Infrastructure, 2020). To that can be added the transition of contracts (Koppenjan *et al.*, 2020).

The study needs proper definitions of the integrated design process and project performance, which will be discussed in Sections 2 and 3. After this, the research method and the method of data analysis are described in Section 4. The study results, as discussed in Section 5, provide insights into the dominant variables affecting the performance of the civil engineering industry. The implications of the results for the industry are concluded in Section 6.

2. Integrated design process

Design may be considered as a process or as a product. Design as a product is the description of the artefact to be manufactured. In a civil engineering context, the artefact usually is a system, being an assembly of different objects that perform the desired functions in their mutual coherence. Design as a process is the course of all actions that contribute to the delivery of the design product or system and has been subject to research since the 60s (Visser, 2020). In general terms, Simon (1996) describes the process as the course of actions aiming at changing existing situations into preferred ones. In this study, the process principles of Roozenburg and Eekels (1995) will be followed (see Figure 1). The application of these principles is common in the civil engineering industry (Visser, 2020). The four steps of the iterative design cycle are somehow recognisable in any design method: analysing and defining the design problem (*Analyse*), externalising and describing ideas (*Synthesise*), technological reasoning and testing (*Simulate*) and evaluating whether the solution meets the requirements and satisfies the needs (*Evaluate*).

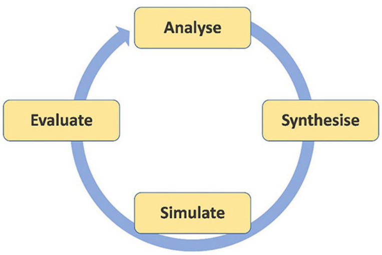

Figure 1. Basic design cycle, after Roozenburg and Eekels (1995)

Although the method seems to represent a logical set of sequential steps, this does not reflect a practical design process. Schön (1983) describes the design process as an "undivided whole with automatic, unconscious steps, actions based on common practice or routine, and moments of reflection and exploration." Human and subjective value judgements and the creation and imagination of several mental design states dominate the process (Roozenburg and Eekels, 1995).

The problem definition in the analysing step initiates the non-sequential and iterative character of the process. Functions and requirements of the design problem are often formulated based on mental solutions (Roozenburg and Eekels, 1995; Cross, 2001); a goal envisioned in human minds before a concrete solution has been visualised. However, problem definitions based on mental solutions will not automatically induce the desired artefact, resulting in adapting the requirements or the solution. A co-evolution of problem definition and solution-finding, and an iterative process result. Moreover, design problems are ill-defined or even wicked, implying that they cannot prescribe the end or goal due to unknowns anyhow. Problem definitions are a function of the complexity of project context variables and associated stakeholder needs and values (Whelton and Ballard, 2002). Drost (2019) argues that the increased complexity of the problem definition, combined with the solution space, has led to the achievement of human cognitive capacities to find solutions using conventional design methodologies. He advocates a more explorative, reflective, practice approach to designing, repeatedly framing the problem situation.

The complexity of defining the design problem depends on the number of elements and the extent to which they affect the problem, where technological elements have been accompanied by elements from the societal and human domain in recent decades. This is the context of the design problem. Kroes and Poel (2009) define the context as "its environment, setting or background that contains all elements that are somehow relevant for the thing involved in the sense that they condition its being or occurrence." Technology and social, intentional context are inseparable (Kroes and Poel, 2009; Witmer, 2018) and should be mutually matched (Simon, 1996). Context guides the design process, but the process can also influence context. In a design process as a transformation process, the context becomes a fluid, natural part of the cyclic design process.

The increasing complexity of civil engineering projects, as discussed in Section 1, is driven by an increase of the design problem's context. More and more aspects need to be included in today's design problem definitions and solutions. Recognising the importance of understanding and adopting the context in the analysing step of the design cycle has become more critical. Therefore, it is necessary to identify two activities in the analysing step; understanding and adopting the context of the design problem and establishing the problem definition (see Figure 2).

Architectural design schools embrace focussing on context by questioning the framework or making the framework part of their assignment (Dooren *et al.*, 2013; Drost, 2019; Holmes, 2020;

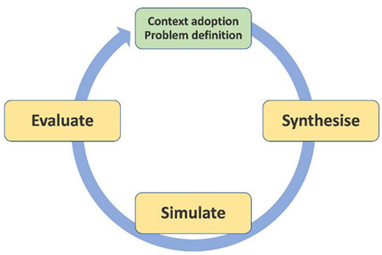

Figure 2.
Basic design cycle after Roozenburg and Eekels (1995), in which the analysing step is split into context adoption and problem definition

Leon and Laing, 2021). The British Design Councils' double diamond approach reflects the emphasis on problem definition in the design process. Civil engineering design methods do not yet explicitly include such an approach.

When the design assignment's scope increases, it becomes advisable to split up the process into phases. The design cycle is then conducted several times sequentially while the design evolves from coarse to fine. At the phase transitions, explicit moments are introduced to verify the status of the design process. Subdividing the process is necessary because it structures and breaks down the complexity into more manageable tasks (Zeiler, 2019). This can be considered a managerial interference; it makes the design process more controllable. Several methods of phasing have been developed. Figure 3 shows the method inspired by (Pahl *et al.*, 2007), which is familiar in civil engineering projects.

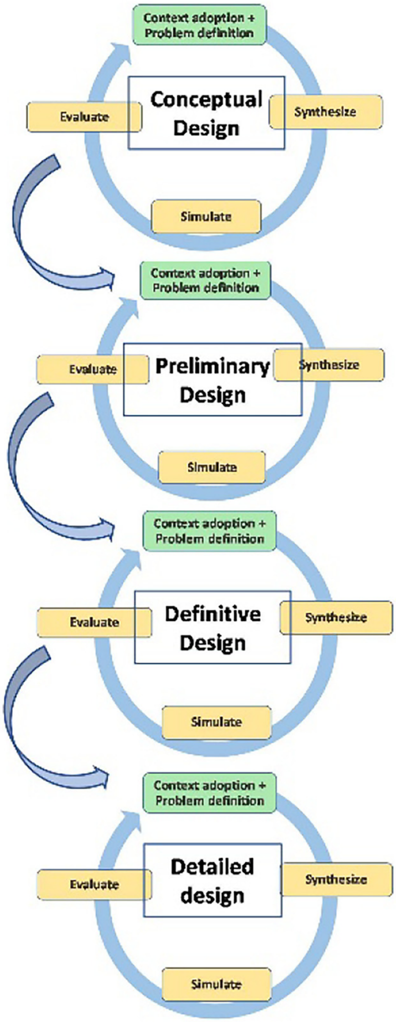

Figure 3.
Phased design process after Pahl *et al.* (2007)

The design process of a complex system requires structuring through a hierarchic, decomposed structure because doing so simplifies the description of a complex system and makes it easier to manage information for the development of the system (Simon, 1996). Decomposing civil engineering systems into subsystems, elements and components using the system engineering approach is a common method in large civil engineering projects to manage complexity. By combining the typical design cycle, a phased approach and the decomposition of the system, the design process can be visualised, as shown in Figure 4. An interdisciplinary process emerges, which requires attention to socio-political aspects in addition to the formal project management methods (Koutsikouri *et al.*, 2008).

The model shown in Figure 4 indicates the presence of the typical design cycle at any level of detail within any subsystem, element or component. At any cycle, the design process is about adopting the context of the design problem and including it in an optimum design solution through an iterative process of problem definition and solution-finding. The context, the problem definition and the solution are unique in any cycle. Referring to the complexity of the design assignment, internal and external complexity can be distinguished (see Section 1). The system level mainly involves integrating stakeholders' interests, which refers to external complexity. The process is governed by evolution and limited predictability and understanding of stakeholders (Hertogh and Westerveld, 2010). The component level is mainly about integrating disciplines, referring to internal complexity. Now, the number of elements and the extent to which they interact dominate the process. The type of complexity of the design assignment gradually shifts from external to internal as the level of detail of the design increases. In integrated contracts of civil engineering projects, the (public) owner normally is responsible for the process at the system level, while the contractor bears the responsibility at the component level. The responsibility gradually shifts, depending on the type of integrated contract.

With respect to a design process, the term "integrated" refers to the highest level of interactivity, referred to as transdisciplinary (Stock and Burton, 2011) or transformative (Kroes and Poel, 2009). An integrated process accumulates knowledge from the participants' perspective or the neighbouring discipline to merge the context in the design process. This type of integration requires participatory approaches, involving all participants in the

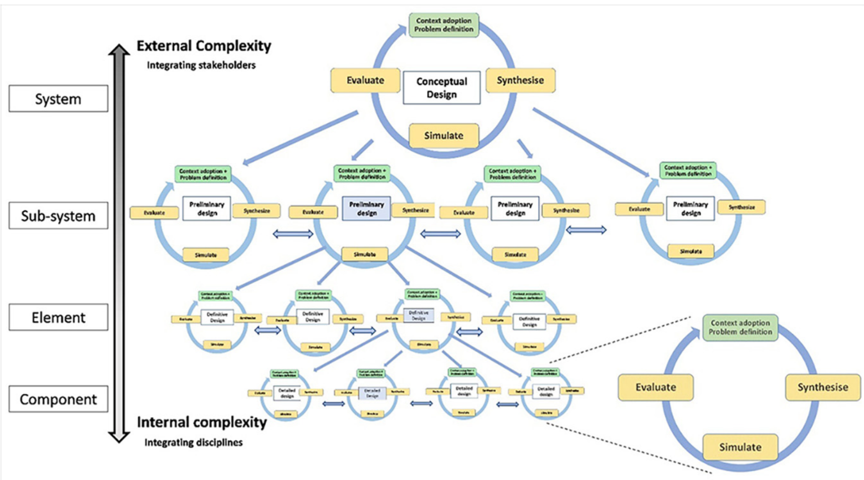

Figure 4.
Phased design process of a complex civil engineering system, comprising the typical design cycle at any level of design

project and balancing their interests to arrive at the best useful overall compromise for the benefit of the whole. As visualised in Figure 4, integration, i.e. merging the context in the design cycle, is present throughout the whole design process and at any level.

This analysis leads to the definition of the integrated design process of civil engineering projects for this study, based on Simon's (1996) basic principle: An integrated design process is the course of all human activities transforming an existing situation into a new one to satisfy needs, including and balancing all parties' interests and disciplines involved.

The increasing impact and assertiveness of stakeholders and the increasing number of aspects that affect the civil engineering design assignment, as referred to in Section 1, can be considered an increase of context over the past decades. Expanding infrastructural networks in green fields in the post-war period has evolved into integrating infrastructure into the existing urban environment. As discussed, this development is set to continue in the coming decades. This complicates the analysing step of the design cycle, aiming to establish the context and define the design problem, as well as running the iterative cycle as a whole.

3. Project performance

Project performance can be defined in many ways and depends on the participant's perspective (Koops, 2017; Kylindri *et al.*, 2012). Costs, time and quality are well-known criteria and are dominant in any civil engineering project. These criteria are often referred to as "the iron triangle." Cost and time are considered in relation to predetermined goals. Quality is what the project or the deliverable must do and the extent to which this is achieved (Nicholas and Steyn, 2017) and can be assessed by considering the degree to which the product or the process meets the specified requirements.

In recent decades, the emphasis has shifted from the project manager's perception to evaluating project success by multiple stakeholder groups when determining project success (Davis, 2014). In the case of civil engineering projects, usually public owners are involved, being responsible for the social performance and representing the stakeholders. These stakeholders can be grouped into an economic, political and cultural system, each having their specific needs and interests (Doloi, 2012). Their satisfaction is an important criterion for the performance of contemporary projects.

In the civil engineering construction industry, safety has lagged compared to other industries. However, safety is considered an important performance criterion by both the owner and the contractor in today's projects. The literature confirms health and safety aspects among the critical criteria for project success (Silva *et al.*, 2019; Ali and Rahmat, 2010). Bakker *et al.* (2010) defined the success criteria as costs, time, quality, safety, client satisfaction and start-up. The relevance of start-up in infrastructure projects has increased since the importance of technical installation and software has risen. In recent years, the delivery of systems with a dominant installation component, such as tunnels, has shown poor performance due to start-up problems. In this research, this aspect has been incorporated in the stakeholders' satisfaction criterion, since it affects the users and owners of the transport systems.

To summarise, in this research, the criteria cost, time, quality, safety and stakeholder satisfaction will be considered to determine project performance. These criteria cannot be mutually compared or weighed. Therefore, satisfaction with each criterion and its interaction with the integrated design process were considered separately. The criteria rule today's civil engineering projects in The Netherlands and correspond with the Economically Most Advantages Tender-criteria (EMAT) of today's tenders (Economic Institute for the Construction Industry, 2015). In integrated contracts, not only the owner representing the clients but also the contractor have a strong influence on the performance criteria (Westerveld, 2003). Therefore, the perspectives of both the owner and the contractor were considered, imposing the constraint that the stakeholders' satisfaction is assessed from the owner's and contractor's perspectives.

4. Research method

The research aims to find the dominant variables of the integrated design process and understand how they interact with project performance. Exploratory research was carried out, followed by a multiple case study.

The exploratory research included a literature study and 10 non-structured interviews with key actors of the Dutch civil engineering industry, such as representatives from owners, contractors and consultants. After 10 interviews, it was concluded that the data was saturated. The interviews were non-structured using open-ended questions to investigate whether the integrated design process was identified among the most relevant variables affecting project performance. Additionally, it was explored which variables dominate the integrated design process. All interviews were recorded and transcribed. The data analysis was conducted using elements of grounded theory (Corbin and Strauss, 2014).

Subsequently, a multiple case study was conducted based on the results of the exploratory research to get a deeper understanding of the interaction between the variables. A case study is an appropriate method when "how" questions need to be answered when examining contemporary events and the relevant behaviour cannot be adjusted (Yin, 2014). Furthermore, "the closeness to real-life situations obtained from case study research is necessary to understand the human behavior, as it cannot be captured by rule-governed acts" (Flyvbjerg, 2006). These conditions applied to the study since the integrated design process is a course of activities governed by humans.

A proper definition of the study's context is required to generalise from a case study. The context is to a high extent determined by the case selection. Therefore, the selection of the cases was driven by the widest possible range of project characteristics (see Table 1). While literal replication requires a minimum of two or three cases (Yin, 2014), in this study, the data converged to shared views and conclusions after conducting four cases, and further research would not have contributed to new insights.

The cases covered involvement of nine different owners, eight different contractors (in joint ventures) and represented all current contract types, i.e. Design-Construct (D&C), Design-Build-Finance-Maintain (DBFM) and Plan-Design-Construct (PDC), which also included the spatial planning design in the scope of the contractor. The contract size varied between 43m and 700m euros. Finally, the scope of the projects was representative of contemporary civil engineering projects and comprised a tunnel, roadworks, bridges, viaducts, high-water protection works and reconstruction works. The projects were situated in urban or more rural areas.

Interviews were the most important data source because they provided insights into the backgrounds of people's acts and behaviour and their effects on the process. The selection of the interviewees was driven by the condition that they should have a good understanding of the project performance, the integrated design process and their interaction. Therefore, in all cases, at least the Project Manager and the Technical Manager of both the owner and the contractor were interviewed. The Technical Manager is responsible for the design management and the construction management. In two cases, we also interviewed the Design Manager to get more detailed data of the design process. In one case, the contractor's Tender Manager was interviewed, who became a steering committee member after the contract was awarded. This respondent provided extra data regarding the tender process and its impact on the design phase. Complementary to the interviews, documents were reviewed to better understand the process (e.g. contract documents, tender documents and design documents). Finally, field notes were registered of observations made during data collection and site visits.

Case nr	Project	Contract type	Contract size [mio euros]	Project scope	Location (The Netherlands)
1	Spatial development and high water protection project	D&C	116	High water protection, spatial area development, infrastructural works (roads bridges)	Province of Limburg
2	Tunnel project	DBFM	700	Infrastructure; tunnel, roads, viaducts	City of Amsterdam
3	Infrastructure project	PDC	415	Infrastructure; roads, viaducts	City of Amersfoort, Province of Utrecht, Gelderland
4	Infrastructure reconstruction project	D&C	43	Infrastructure: roads, movable bridges	Province of Noord Holland

Table 1. Project characteristics of the cases

The interviews were semi-structured, using open-ended questions to gain the widest views on the variables affecting project performance. They were experienced as open and transparent. The interviewees were motivated to participate in the study because they wanted to learn from the projects. Altogether, 19 interviews were conducted, recorded and reported. The interviewees validated the reports. Case analysis reports were made for each case based on the interview reports, reviewed documents and field notes. The project managers of both the owner and the contractor validated their project case analysis report. Only validated data were used for the analysis.

The data were analysed based on elements of grounded theory. The analysis unfolded as the data were being collected. The quotes of events reported during the interviews, such as incidents, activities, examples or statements, were the raw data. In this research, quotes were built up from one or more sentences in such a way that the event could be understood independently (DeCuir-Gunby *et al.*, 2011). Quotes referring to the same phenomena were coded as concepts, potentially relevant phenomena for theory-building. The concepts required precise definitions. New insights during data collection resulted in adjusted definitions and new concepts, making it necessary to recode the data. Thus, an iterative process unfolded.

When the data collection of the last case was completed, the cross-case analysis was updated and finalised. Then, related concepts were aggregated into concept groups representing more abstract phenomena. Finally, concept groups were developed into a theory describing the dominant variables of the integrated design process. Verification of the theory proceeded in the reverse direction from theory to quotes. Atlas TI software was used for structuring and analysing the data.

5. Results and discussion

5.1 Exploratory study

All interviewees from the exploratory study indicated the integrated design process as an essential factor for project performance. Furthermore, a broad range of variables that affect the design process emerged from this study. Complexity appeared as a central theme, which could be decomposed into three dominant variables: *Stakeholder Management, Multidisciplinarity* and *Planning*, representing the time available for the integrated design process. *Stakeholder Management* is linked to external complexity, while *Multidisciplinarity* refers to integrating disciplines and internal complexity, as discussed in Section 2 (see Figure 4). Figure 5 shows the breakdown of the variables and how they relate to project performance.

Stakeholder Management was mainly emphasised by the interviewees representing the owners, and *Multidisciplinarity* and *Planning* were mainly nominated by the interviewees representing the contractors. This arrangement corresponds to what one would expect as a result of the division of responsibilities in integrated contracts, where the public owner mainly bears the responsibility for stakeholder integration, while the contractor bears the responsibility for the integration regarding multidisciplinarity.

5.2 Multiple case study

The variables shown in Figure 5 were the starting concepts for the analysis of the case study data. In the end, coding the data of the four cases resulted in 575 quotes and 52 concepts. Table 2 shows the 10 most grounded concepts, including their definition, groundedness and density, indicating the number of relationships with other concepts. When comparing Table 2 and Figure 5, it can be concluded that the multiple case study confirmed the

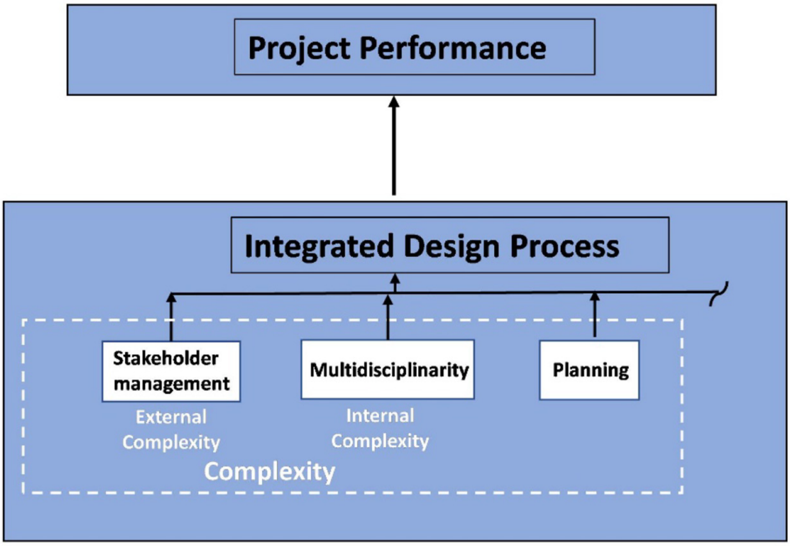

Figure 5.
Results of exploratory research: variables of the integrated design process interacting with project performance

relevance of the three main concepts from the exploratory study in the top 10 and that new, relevant concepts emerged.

Integrated Approach was clearly the most coded concept, meaning that it is important for theory-building. Altogether, 194 quotes related to this concept.

Concepts that frequently co-occur in quotes will be related and might converge to concept groups contributing to theory-building. Figure 6 shows an overview of related concepts grouped with the same colour. The figure indicates the concept co-occurrence coefficient, a number between 0 and 1 indicating the degree of co-occurrence related to both concepts' groundedness. A high coefficient indicates a high co-occurrence and a comparable groundedness. The figure also includes concepts that were relevant for the group but were not in the top 10 grounded concepts shown in Table 2, as well as the concepts that resulted from the exploratory study and were not part of a group (indicated white). For purposes of clarity, only co-occurrence coefficients equal to or higher than 0,10 are presented.

Through aggregating, three concept groups appeared, which again were interrelated. Firstly, a concept group related to the *Integrated Approach* emerged (indicated green). *Multidisciplinarity* and *Constructability* showed a relationship with this concept, referring to the relevance of integrating disciplines and specifically constructability aspects in the design. Furthermore, *Context Adoption* had a relatively strong relationship with this concept group.

Secondly, a group related to *Problem Definition* turned up (indicated red). This concept group referred to the definition of the design problem, which is considered part of the iterative design cycle. The data showed relations with the *Iterative Design Process*, *Design Changes*, *Contract*, *Design Solution*, *Stakeholder Management* and *Context Adoption*, which would be expected from the definition of the integrated design process discussed in Section 2.

Thirdly, *Context Adoption* (indicated yellow) showed a relatively high groundedness and a high density indicating many relations with other concepts. The interaction with *Human Behaviour*, *Culture*, *Open Minded* and *Ownership* designated a broad interpretation of this concept. This concept group was interrelated to the groups *Integrated Approach* and *Problem Definition*.

Nr.	Concept	Definition	Grounded	Density
1	Integrated approach	The design approach of integrating all parties' interests and all disciplines in a design solution in a balanced way for the benefit of the whole	194	4
2	Stakeholder management	Integrating the stakeholders' interests in the design	120	5
3	Problem definition	The description of the design problem from function through design specifications	114	7
4	Context adoption	Context is the total environment in which something gets meaning or that gives meaning to something, (Kroes and Poel, 2009). Context adoption is understanding the context and its relevance and taking care of the coherence between the context and the artefact; integrating context in the design	113	10
5	Design process	The course of all human activities transforming an existing situation into a new one to satisfy needs	101	0
6	Multidisciplinarity	>1 discipline within the artefact, interacting to a certain extent	93	4
7	Level of detail	Level of detail of the description of the artifact	74	0
8	Planning	Course of design activities set out along a timeline defining the time available for the design process activities	73	1
9	Contract	Contract between the owner and the contractor	63	2
10	Design changes	Adjustments of a (conceptual) design already issued, resulting in additional activities not initially foreseen	57	4

Table 2.
Top 10 concepts based on groundedness

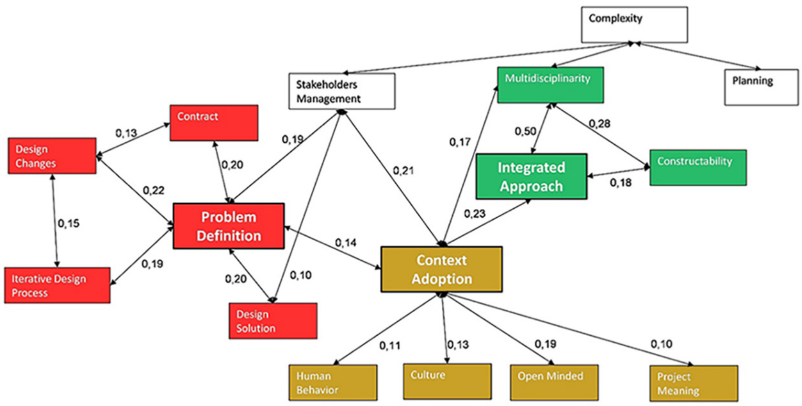

Figure 6.
Overview of the most relevant concepts, co-occurrence coefficients ≥ 0,10 and concept groups

From the definition used in this study, an integrated approach refers to both integration at the component level, which links to *Multidisciplinarity* and *Constructability* and the integration at the system level, which links to the integration of stakeholders' interests (see Figure 4). Therefore, a relationship between *Integrated Approach* and *Stakeholder Management* would be expected as well. However, this interaction did not dominantly emerge from the data, which was explained by the observation that the interviewees did not link stakeholders' integration to the definition of the *Integrated Approach*. Nevertheless, the high groundedness of *Stakeholder Management* demonstrated the importance that the interviewees attached to integrating stakeholders' interests. Finally, *Complexity* and *Planning* are presented in Figure 6 since they were the starting concepts of the analysis. After aggregating, they were not part of concept groups.

The following discusses the identified concept groups in more detail.

5.2.1 Integrated approach. All cases demonstrated a clear relationship between an integrated approach of the design process and project performance. At the system level, the project teams of all cases focussed on adopting the stakeholders' context and integrating their interests in the design. This positively affected the satisfaction with project performance criteria, especially quality and stakeholder satisfaction. At the component level, awareness of integrating disciplines was noticed. However, the cases showed differences in the extent to which integration between disciplines was truly successful, even within the same project. In particular, integrating construction aspects in the design process was challenging in all cases and negatively affected the cost criterion of the project performance on the contractors' side. The interviewees indicated the project participants' ability to adopt context as a necessary condition for an integrated approach.

5.2.2 Problem definition. The concept group *Problem Definition* referred to the ill-defined design problem and the iterative process of problem definition and solution-finding. Section 2 showed that this iterative process can be applied at any level of the design process. The data confirmed the importance of the process of problem definition for project performance given the high groundedness and density, see Table 2 and Figure 6.

At the system level, all cases showed a relation between proper interaction with stakeholders and adoption of the project context on the one hand and satisfaction with project performance criteria on the other. Furthermore, the cases showed that awareness of the interaction between problem definition and the contract affected performance positively. Recognition by the participants that solution-finding might result in modifying the problem definition due to the iterative nature of the design process, and consequently the contract specifications, contributed to a better-integrated design process and finding best for project solutions. *Collaboration* and *Trust* between parties turned out to be conditional for such an iterative process (groundedness 52 and 17, respectively, code co-occurrence with *Problem Definition* 0.10 and 0.06). The awareness of parties that problem definition related to the contract fostered a robust process of verification and validation of the design specifications. This process contributed to the proper integration of stakeholders' interests and the definition of the design problem.

On the other hand, in all cases, limited awareness of the issue of problem definition at the component level was observed. Adopting the context of adjacent disciplines and defining the design problem through an iterative process was not anchored in the process. This observation seemed to be related to the failures of integration between disciplines that were indicated in Section 5.2.1.

5.2.3 Context adoption. The concept group *Context Adoption* was tied to achieving an integrated approach and determining the problem definition through an iterative process. In Section 2, the importance of this concept was outlined from a theoretical perspective. The case study confirmed the relevance of a mutual understanding of the context by parties and disciplines. However, all cases reported that mutual adoption of context was hard to achieve.

In particular, poor interaction between the design and construction disciplines caused problems with project performance in all cases.

A more detailed analysis of the concept of *Context Adoption* was conducted by analysing the related quotes. Each quote was matched with an act that reflected the interpretation of adopting context. When possible, the acts were taken literally from the quotes; in other cases, they were derived. The acts represented the behaviour that the participant should exhibit to adopt and include context in the design process. Since the quotes were in Dutch, a translation into English was required. Table 3 shows the results of this analysis and indicates how often the act appeared in the interviews. In total, 133 acts related to context adoption were reported during the interviews, 56 of which were different.

A broad interpretation of *Context Adoption* appeared. The interviewees indicated a wide range of competencies and behaviour that the participants of the project teams should exhibit to understand and adopt the interests of the stakeholders or the adjacent disciplines. The essence is a mode of interaction that leads to understanding and internalising the other and its anticipation. The data presented in Table 3 seem to point towards empathy as a relevant competence for context adoption since it is interpreted as identifying with and understanding the other's feelings or thoughts (Kouprie and Sleeswijk Visser, 2009). Empathy comprises both cognitive and affective aspects (Davis, 1994). The importance of empathy in design processes has been recognised in product design (Devecchi and Guerrini, 2017; Postma *et al.*, 2012) and to some extent in architecture and landscape design (Van der Ryn, 2013). It has even been considered conditional for ethics in design in general (Vallero and Vesilind, 2006). Furthermore, empathising is an essential step in design thinking, a problem-solving method that gained ground in recent decades (Köppen and Meinel, 2015). A relationship between emotional intelligence, which also includes aspects of empathy and team performance and project performance has already been demonstrated by Rezvani (2019) and Khosravi *et al.* (2020).

5.2.4 Aggregating the concept groups. The cases showed that an integrated approach of the design process is critical for project performance. Moreover, the ability of the

Table 3. Interpretation of acts related to *context adoption*, derived from interview quotes, including the number of times the act was indicated

Act	No.	Act	No.	Act	No.
Understand	17	Think	2	Consult	1
Be involved	8	Be interested	2	Take time	1
Speak the same language	6	Change perspectives	2	Think along with	1
Watch along with	6	Talk with each other	2	Experience	1
Create acceptance	5	Sit together	2	Have contact	1
Interact	5	Interfere	2	Be together	1
Explain	4	Find integrality	2	Communicate	1
Weigh interests	4	Exchanging views	2	Find each other	1
Adopt	3	Stay in touch	1	Stay close	1
Pay attention	3	Listen	1	Play chess	1
Be open	3	Be curious	1	Take responsibility for context	1
Share	3	Have affinity	1	Anticipate	1
Collaborate	3	Want to know	1	Analyse	1
Know each other	3	Respect	1	Have a broad vision	1
Translate problems	3	Be proactive	1	Translate knowledge	1
Connect knowledge	3	Have ownership	1	Act beyond ones discipline	1
Align	3	Be the same worlds	1	Have shared views	1
Ask questions	3	Create trust	1	Combine	1
Meet each other	3	Come together	1		

participants of the design teams to adopt the context of the design problem and integrate it into the design process is a dominant variable that is conditional for an integrated approach and, subsequently, project performance. This interaction is visualised in Figure 7. When comparing Figures 7 and 5 from the exploratory study, it is concluded that *Planning* does not appear as a dominant variable after conducting the case study. Generally, a short lead time of the design process contributed to project complexity and negatively affected project performance in most cases. However, in this study, *Stakeholder Management* and *Multidisciplinarity*, together determining an integrated approach, appeared more critical.

Adopting the design problem's context applies at any level of design. It is necessary to integrate the stakeholders' interests at the system level (referring to stakeholder management and external complexity), as well as the adjacent disciplines at the component level (referring to multidisciplinarity and internal complexity). The importance of context adoption and problem definition in the typical iterative design cycle can be recognised, as stated in the literature and discussed in Section 2. The study confirms this importance. Furthermore, the study shows that proper context adoption is not obvious in civil engineering projects and that lack of context adoption negatively affects project performance.

Integrating the context of the design problem in the process is more common in architecture, spatial planning design and landscape design, as their interface with the environment has been more intense by nature. However, context has also become an essential part of the design process in civil engineering projects, and its relevance will grow. Civil engineers play an important role in managing the challenges resulting from climate change, urbanisation and mobility. The growing impact of the design problem's context and multidisciplinarity of civil engineering projects requires competencies of the participants of the design team that have been only called upon to a limited extent to date. This comprises a shift from the technological to the human perspective and from a problem-solving to a more problem exploration-oriented design approach (Drost, 2019) and a contextual engineering approach (Witmer, 2019).

5.2.5 Other relevant variables. The project size emerged from the study as a relevant variable. It might be connected to stakeholders and multidisciplinarity because large projects will often imply many stakeholders and disciplines. Trust between parties and

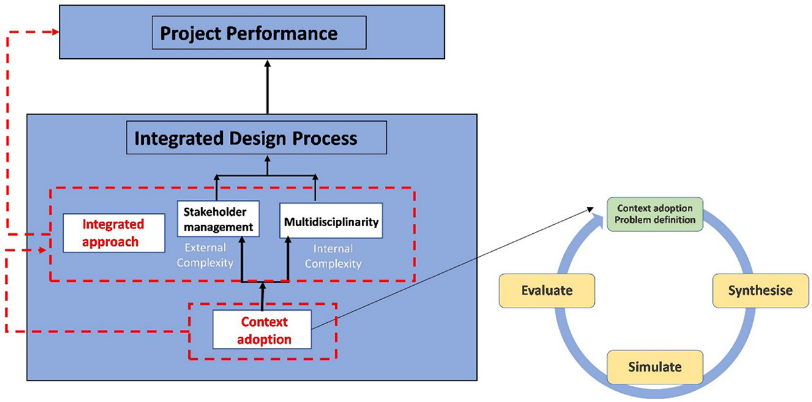

Figure 7. Overview of the dominant variables of the integrated design process affecting project performance, indicating the dominant variables in red

collaboration turned up as conditional variables for the design process, as its iterative character inevitably introduces modifications of the problem definition and, consequently, contract changes. Furthermore, opportunism on the contractor's side appeared as a variable affecting the design process and project performance, since it resulted in opportunistic designs during tender stages that could not be realised after the contract was awarded. On the other hand, technology did not appear as a dominant variable. Apparently, the project teams master the technical challenges of today's civil engineering projects, and other variables dominate project success. Finally, the cases did not show any distinction in the interaction with project performance related to the type of integrated contract.

5.2.6 Project performance. The interviewees were asked to reflect on the interaction between the integrated design process and each project performance criterion, as discussed in Section 3. Although they could not always detail each criterion's interaction and the figures should be considered subjective judgements, analysing the data for all cases provided additional insights into the interaction. Table 4 shows the number of times the interviewees indicated a direct relationship between the integrated design process and the specific project performance criterion and whether the design process positively or negatively affected the project performance aspect.

In case no interaction with the performance criterion was noticed, a 0-score was appointed. A score of 1 point was awarded in case a positive or negative interaction was indicated. Finally, if the interviewee explained that the integrated design process affected performance both positively and negatively, a score of 0,5 was appointed to both the positive and negative effects. By doing so, the interviewees could award in total 0 or 1 points to the interaction with each performance criterion. Since 19 interviewees were asked to consider the interaction, a maximum score of 19 could be obtained for each criterion.

The table indicates that the integrated design process mainly affected the performance criteria cost, quality, and stakeholders' satisfaction, which were confirmed in 84%, 95% and 100% of the cases, respectively. Furthermore, the table shows that interviewees almost unanimously confirmed that the integrated design process positively affected quality and

Project performance criterion	Case 1	Case 2	Case 3	Case 4	Subtotal	Total	% of maximum score (=19)
Cost							
Effects on cost neg	0	3.5	5	1.5	10	16	84
Effects on costs pos	2	1.5	0	2.5	6		
Time							
Effects on time neg	1	1	3	0	5	10	53
Effects on time pos	0	1	0	4	5		
Quality							
Effects on quality neg	0	0	0	1.5	1.5	18	95
Effects on quality pos	5	4	5	2.5	16.5		
Safety							
Effects on safety neg	0	1	0	1	2	11	58
Effects on safety pos	2	2	4	1	9		
Stakeholers' Satisfaction							
Effects on stakeholders neg	0	0	1	0	1	19	100
Effects on stakeholders pos	5	5	4	4	18		

Table 4. Confirmed numbers of interactions between the integrated design process and project performance, negatively or positively

stakeholders' satisfaction, while costs and time were affected both negatively and positively. The results indicate that the interaction with time and safety performance criteria were the lowest. The relatively high scores on stakeholders' satisfaction and quality could be explained by the fact that stakeholders' participation is legally defined. This implies that projects are *de facto* not permittable if stakeholders are not adequately consulted. In fact, the stakeholder satisfaction criterion is prioritised in this way in the design process.

5.2.7 Limitations of the study. The cross-case analysis revealed an integrated approach and adoption of the problem context as the dominant variables. It indicates that the results and conclusions of the study apply to projects that are dominated by integration challenges related to stakeholders' interests and multidisciplinarity. The selected cases represent this type of project, and they can be considered representative of contemporary projects in The Netherlands. Generally, the study results will be applicable for multidisciplinary civil engineering projects in complex, urban environments.

6. Conclusions

Although the integrated design process is considered an important phase in the civil engineering project life cycle, its interaction with project performance has been researched to a limited extent. Therefore, this study aimed to investigate this interaction and identify the dominant variables of the integrated design process that affect project performance, considering the poor performance of the projects today and the increasing complexity of the design assignment in the future.

A multiple case study was conducted to investigate the interaction between the integrated design process and project performance. We conclude that the integrated design process is essential for project performance and that an integrated approach of the process is critical. This applies to integrating stakeholders' interests at the system level and integrating disciplines at the component level of the design process. Above all, the project team participants' abilities to adopt and integrate the context of the design problem is the dominant variable to achieve an integrated approach at any level of design and improve project performance. The study reveals that competencies focussing on integration are not obvious in civil engineering projects and that a lack of these competencies negatively affects project performance.

The complexity of civil engineering projects is increasing, while those projects have been facing poor performance for a long time already. Project teams need to integrate a growing number of stakeholders' interests and aspects, a process which is driven by growing urbanisation, the need for mobility, climate adaptation, biodiversity, circularity and the renovation of the existing infrastructure systems. Where projects used to be technically driven, integration challenges dominate today; integration of civil engineering objects in their increasingly complex context and integration of a growing number of disciplines. Therefore, design teams of civil engineering projects should stimulate the development of competencies focussing on integration to improve performance. This also implies a shift from a solution-driven design attitude to a more problem exploration-oriented design approach. Empathy seems to be a competence of the design team participants that fosters problem orientation and subsequently an integrated approach and project performance. While empathy has been acknowledged as a relevant competence in disciplines that have been affected by problem context by nature, there is reason to further investigate the role of empathy in civil engineering projects.

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