Dealing with uncertainties in the design phase of road projects

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Abstract

Purpose – Uncertainty management (UM) in projects has been a point of attention for researchers for many years. Research on UM has mainly been aimed at uncertainty analyses in the front-end and managing uncertainty in the construction phase. In contrast, UM components in the design phase have received less attention. This research aims to improve knowledge about the key components of UM in the design phase of large road projects.

Design/methodology/approach – This study adopted a literature review and case study. The literature review was used to identify relevant criteria for UM. These criteria helped to design the interview guide. Multiple case study research was conducted, and data were collected through document study and interviews with project stakeholders in two road projects. Each case's owners, contractors and consultants were interviewed individually.

Findings – The data analysis obtained helpful information on the involved parties, process and exploit tools and techniques during the design phase. Johansen's (2015) framework [(a) human and organisation, (b) process and (c) tools and techniques)] was completed and developed by identifying relevant criteria (such as risk averse or risk-taker, culture and documentation level) for each component. These criteria help to measure UM performance. The authors found that owners and contractors are major formal UM actors, not consultants. Empirical data showed the effectiveness of Web-based tools in UM.

Research limitations/implications – The studied cases were Norwegian, and this study focussed on uncertainties in the project's design phase. Relevant criteria did not cover all the criteria for evaluating the performance of UM. Qualitative evaluation of criteria allows further quantitative analysis in the future.

Practical implications – This paper gave project owners and managers a better understanding of relevant criteria for measuring UM in the owners and managers' projects. The paper provides policy-makers with a deeper understanding of creating rigorous project criteria for UM during the design phase. This paper also provides a guideline for UM in road projects.

Originality/value – This research gives a holistic evaluation of UM by noticing relevant criteria and criteria's interconnection in the design phase.

Keywords Large projects, Uncertainty management, Design process, Human and organisation, Process, Tools and techniques

Paper type Research paper

1. Introduction

Projects are efforts to create unique products and values that benefit society (Johansen, 2015). Managing projects is not an easy endeavour. Constraints, challenges and risks exist in the different project phases. Opportunities exist to reduce project costs and time and improve projects' performance simultaneously through introducing scope reductions, planning

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choices and so on (Kendrick, 2015). Projects' dynamic environment results in many changes and variations, and stakeholders with different needs exemplify such dynamicity.

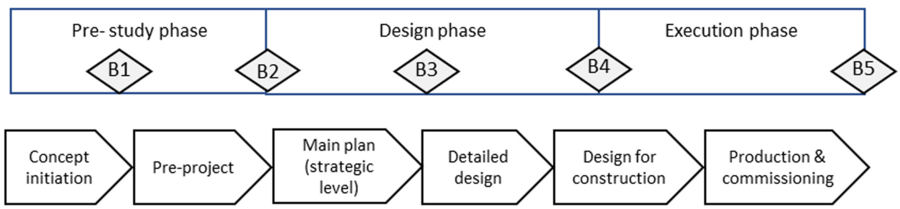
Various models describe construction project phases and stages (Johansen *et al.*, 2019). According to Project Management Institute (PMI), all projects generally go through initiation, planning, execution and closing (PMBOK, 2013). Johansen *et al.* (2019) suggested that different industries have various phase models. Models used in public road construction projects in the Nordic countries are akin to Morris' (2002) and the PRINCE2 model (Hedeman and Seegers, 2009). Figure 1 shows Johansen *et al.* (2019)'s typical project phases. The pre-study phase entails concept definition, feasibility studies and project appraisal. In the design phase, the owners define the project's core plan and a detailed design that consultants or contractors run. In the execution phase, the contractor will conduct the construction design, and the final stage will be producing the final product and commissioning the project.

Most models focus on project development (planning) and execution (building the road or railroad) and less on the front-end (project appraisal) and operation stage, where the actual project value is delivered (Johansen, 2015). Our adjusted model focusses mainly on the design phase, and this paper will focus on uncertainty related to detailed design and design for construction.

Uncertainty relates to different parameters, such as cost, time, quality and scope, and needs to be addressed to avoid failures (Andenæs *et al.*, 2020). The design phase is one of the most uncertain and complex (Ackermann *et al.*, 2014). The concept is not chosen, the design and development of the concept are in the early phase and the project delivery model is not yet decided (Johansen *et al.*, 2019). The iterative process of developing the solution is combined with more formal efforts like planning the construction phase and developing the contract strategy. Designers, owners and contractors interact with each other to satisfy all parties' needs. Otherwise, the project may face unsatisfied users and owners, failure in cost, time, design and environmental problems (Klakegg and Haavaldsen, 2011).

Atkinson *et al.* (2006) said projects' premature definition led to cost and time overrun and emphasised the design phase's necessity. Recognising design phase uncertainties helps estimate their impact on the execution phase and addresses problems sooner (Vaagen *et al.*, 2017; Rostami and Oduoza, 2017). For example, one of the problems could be the changes in design and probable discussions amongst designers, owners and contractors. Although measures to deal with changes might be defined in contracts, their management and belonging details and parties' satisfaction are essential and involves considerable uncertainty. The ability to predict future scenarios and related uncertainties could help project parties be ready to deal with future issues, prepare resources and conduct necessary activities (Farooq *et al.*, 2018). Besides, understanding the uncertainty of different design options would help make better design decisions.

Changes after the design phase often cost more for owners (Samset, 2010). Design changes can increase projects' costs by 2–21% (Aslam *et al.*, 2019), and they need to be noticed early. Early uncertainty evaluation satisfies not only the iron triangle of cost, time and quality, but also



Source(s): Based on Johansen *et al*. (2019)

Figure 1.
Public construction projects' stage gate model

creates value for different project parties in the operation phase (project delivery). Construction projects create value through design management (Savolainen *et al.*, 2018). Late recognition of design uncertainties and poor response might lead to poor performance and low value.

With all necessities for the design phase, research is lacking on the uncertainty of projects and evaluation of important components in the process of uncertainty management (UM) simultaneously (Osipova, 2007; Wuni *et al.*, 2021). Such evaluation of the design phase evaluates UM broadly by considering important criteria in each component and noticing their interconnection. There exist some models and tools which focus on UM.

Arena *et al.* (2013) developed a tool providing managers with a dynamic representation of adopted risk response strategies and supporting their decision-making by analysing risk profiles. These tools can also analyse the company's risk management (RM) system and identify its strengths and weaknesses. Adam and Lindahl (2019) developed a company dynamic response map (CDRM) risk management model using dynamic capabilities and evaluated Arena *et al.*' (2013) model to better respond to risk and opportunities according to dynamic capabilities. Wang *et al.* (2016) developed an infrastructure risk assessment framework based on the Analytical Hierarchy Process (AHP)-based risk assessment and considered the environmental, project implementation and decision-making behaviour risks. Dikmen *et al.* (2022) developed a tool and process model to estimate project risk and contingency level by evaluating complexity factors and contextual information such as contract situation, managerial and technical risk cost and mitigation strategies. There exist other tools such as Monte-Carlo simulation-based approach by Han *et al.* (2017) or the systematic approach to managing uncertainties using the multiple-case approach by Augusto *et al.*, (2019).

Johansen (2015) developed a framework for managing project uncertainties with reliance on the three components *Human and organisation*, *Process* and *Tools and techniques*. This framework supported practical UM, which was applied in different industries and projects (Hald *et al.*, 2008; Johansen *et al.*, 2014; Johansen, 2015). This framework's advantages are as follows: First, these components are not removable from the UM study. If one component is removed, the UM in the project is considered incomplete, but it will still be able to deal with some uncertainty aspects. Second, the framework is broad, meaning it could cover many criteria within it, but the criteria are not originally designed for analysing UM in the design phase. Humans and organisations had more generic criteria such as roles and responsibilities, competency and effective communication. Third, the framework suggested that the three components should be integrated and interrelated to each other and work at a similar performance level. For instance, assume if there are competent people without suitable tools for handling uncertainties or vice versa. The model's simplicity and holistic nature make it useful for analysis of UM in large project – but it needs to be developed further with specific criteria for the design phase.

There exist different tools and methods as mentioned above. However, few frameworks exist to evaluate UM's performance in projects, such as Arena *et al.* (2013) and Serpell *et al.* (2017). We will contribute to the literature by improving an existing framework (Johansen, 2015) with related criteria (for e.g. risk averse or risk-taker, ownership of risk and workforce competency) that can analyse UM performance in the road projects' design phase. This research aims to improve the knowledge of the key components of UM in the design phase using multiple-case study approach. The following research questions (RQs) are addressed in this research:

RQ1. How is uncertainty managed in the design phase?

RQ2. What are the relevant criteria of UM in the design phase of road projects?

This paper has the following structure. After the introduction explains the topic's importance, section two provides the theory about uncertainty and its management in the project's design phase. Section three presents the research method. Section four explains the results, and section five elaborates on the discussion. The final section presents the paper's conclusion and possibilities for further research.

2. Theory about uncertainty management in the design phase

The theory sections consist of three parts. (1) The first part covers the design phase, its characteristics and related challenges. (2) The second part defines UM and the relation between risk and uncertainty in construction projects. (3) The last part introduces the criteria for UM.

2.1 The design phase of construction projects

Design is a process; usually, most designs are not done before execution begins, and there is often an overlap between design and execution (Smith *et al.*, 2006). The design process balances clients' needs and actual understanding of project execution. Misalignment always exists between the risk and profits of designers and clients. On the one hand, designers want to benefit from the design; on the other hand, clients want the best design. Therefore, designers should balance between profit and the best design for the satisfaction of both parties (Lohne *et al.*, 2017).

Design management includes determining consultants' duties, resolving project content, planning, resourcing and determining deliverables and controlling and interfering when project objectives are not met (Chapman, 2001). Design process characterise with iteration, using simple ideas for testing solutions, having sequences as design phases, sequences for information exchange and the influence of external agencies and client changes (Chapman, 2001; Johansen *et al.*, 2019). This process is seen as communication between problem and solution aided by the three activities of analysis, synthesis and evaluation (Lawson, 2006). The road design process could have the following steps: feasibility study and preliminary design and detailed design based on the study by Rwakarehe and Mfinanga (2014). Design is not a logical and tidy process in projects and is semi-messy (Lawson, 2006) and wicked problems with no single solution but multiple solutions (Buchanan, 1992).

Different demands and requirements in the project's design convey many challenges for involved parties. Lohne *et al.* (2017) represented the ethical concerns practitioners meet in the design phase of architecture, engineering and construction (AEC) projects. The most important challenges mentioned were hidden agendas and power actions from different parties. Therefore, the parties need to acknowledge that various requirements and interdependencies in the design phase need to be handled. The design phase is an ongoing and continuous process (Lawson, 2006). It could have uncertainties related to lack of constructors' cooperation (Samset, 2010), setting more ambitious projects goals, ill-defined project scope and weak design (Johansen *et al.*, 2019), inappropriate design, poor engineering, delayed in design activities, delay in buying land and change in raw material cost (Smith *et al.*, 2006; Mhatre *et al.*, 2017) as well as lack of designers' involvement in the primary decision process together with the owner, which might lead to organisational risk (Jaafari, 2001).

Projects with high technical, procurement and contract complexity require careful design. Besides, political, economic and environmental issues also influence them (Johansen, 2015). In other research by Asadi *et al.* (2018), they found that shortages in design documents could affect safety performance and construction projects negatively. Thus, design consequence develops in later project phases, and design difficulties rely on project complexity and the project type, which could be different. Early management of design uncertainties may mitigate these effects.

2.2 Uncertainty management

Galbraith (1974) said that uncertainty stems from a lack of information. He explains that uncertainty undermines firms' ability to plan proactively and make proper decisions before project execution. Risk and uncertainty are used interchangeably in which risks are related to something negative, and uncertainty is a negative or positive event that has been identified but is unknown (Ward and Chapman, 2003; Walker *et al.*, 2017). Many authors declared the relationship between uncertainty and risk in the literature on uncertainty and **RM** (Jaafari, 2001; Johansen *et al.*, 2019).

Risk is part of uncertainty with negative consequences on the project's objective. It will be an opportunity with positive effects (Wideman, 1992). According to Thamhain (2013), many managers spend much time on risk-related issues in the projects' early and design phases. Perminova *et al.*, (2008) said that uncertainty "is an event or a situation which was not expected to happen, regardless of its prediction". Uncertainty is when established facts are questioned and thereby the basis for calculating risk (known negative event) or opportunities (known positive events).

According to Winch (2010), uncertainties can be defined on a spectrum from "known knowns" to "unknown unknowns":

(1) **Known knowns**: According to identified risk source, a probability can be assigned to the occurrence of the risk event;

(2) **Known unknowns**: The risk source has been identified, but the probability of a risk event occurring cannot be determined;

(3) **Unknown knowns**: Risk source and associated probabilities are known but kept confidential and

(4) **Unknown unknowns**: No risk source and risk event have been identified.

The range of growing uncertainty from "known knowns" to "unknown unknowns" distinguishes risk from uncertainty and unexpected events, which connects the concept to the availability of information and decision-making.

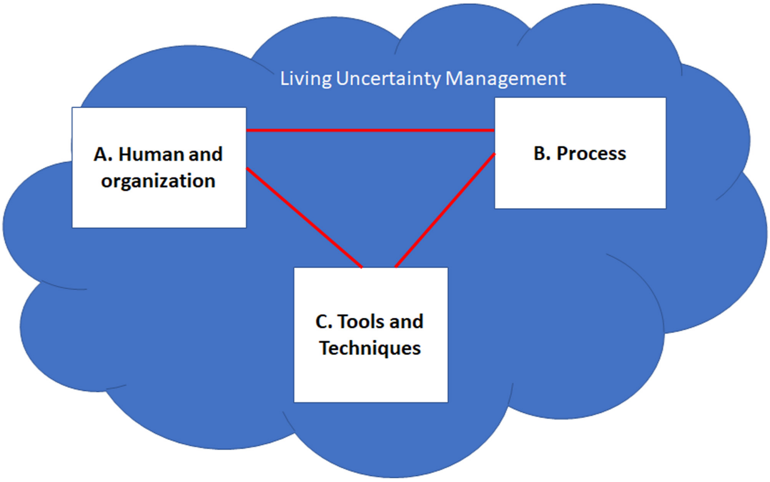
Chapman and Ward (2007) defined five preliminary questions in addressing uncertainties: "Who are involving parties?", "What are the motives of the parties?", "How is it to be done?", "What resources are required?" and "When should it be done?" These are main questions for tackling uncertainties in each project's phase.

Each phase may call for different ways to address uncertainties. For example, price increases of construction materials for building a bridge in the initial phase cause owners to consider higher contingency or contractors change their suppliers to find low prices suppliers and compensate the cost or look for cheaper solutions. This uncertainty in the execution phase might need different strategies such as cost-cutting tasks, reducing unnecessary work and changes in design.

2.3 Criteria for uncertainty management

Figure 2 depicts the Johansen's (2015) theoretical framework utilised in this paper, with "human and organisation", "processes" and "tools and techniques" as the three main UM components. All three need to be functional and work together if "living uncertainty management" should be obtained in the project's design phase.

Klakegg *et al.* (2010) suggested that for conducting uncertainty analysis, both the sophisticated criteria associated with "good" and the practical options associated with "simple" are needed. He noted a tendency towards more complex tools and techniques; this might be due to larger and more complex projects over the years. Zidane *et al.* (2013) identified project characteristics that serve to differentiate between small, medium, large and



Source(s): Johansen (2015a, b)

Figure 2. Uncertainty management framework with three components

megaprojects. These include the budget, the timeline, the number of stakeholders and the complexity level. These characteristics might help decide the complexity level in processes, tools and techniques and organisations. This section describes criteria with three components of human and organisation, process and tools and techniques.

2.3.1 Criteria in human and organisation component. The "human and organisation" component embraces people's professions, abilities and roles in project teams. This part begins with a human's explanation, continues with roles and concludes with the organisation. UM is primarily done by humans who have intuition, knowledge and experience. Humans are both important and challenging components of UM (Hillson and Murray-Webster, 2017).

Generally, people could have different opinions about the same issues seen in projects and related to project risk. Smith *et al.* (2006) linked risk to personal opinions and explained that RM behaviour could be divided into the roles of being a risk-taker or risk averse. Project owners and investors are risk-takers, and contractors are risk averse (Smith *et al.*, 2006). Contractors could take many risks if they get paid. Van Os *et al.* (2015) showed that the relation between group members is weakened by the responsibility of the risk shifted to other stakeholders. Shi *et al.* (2015) found that the management of social risks should focus on "sufficient communication", "timely response", "effective trust building" and "enhancement of social benefit". Chapman (1999) said that efficient management of design projects requires clear and effective communication. Risk analysis and management in these projects must be communicated and understood clearly.

A competent and skilled workforce can act effectively against uncertainty. Besides personal skills, stakeholders' cooperation is necessary for UM (Chapman and Ward, 2011; Walker *et al.*, 2017). According to Klakegg *et al.* (2010), project owners' lack of involvement hinders uncertainty analyses and management. Karlsen (2011) emphasised the role and commitment of the senior managers in UM process for being effective. Adafin *et al.*, (2021) identified the consultants' competency as a budgetary risk factor in projects' performance in the design phase. According to Podgórska and Pichlak (2019), change in key personnel during the design phase hinders the project's progress. Rashid and Boussabiane (2021) found that project manager's trait and cognitive biases influence their risk-taking behaviour with the project outcome. We concluded that a lack of participation, poor communication, cognitive biases and incompetence may be the leading causes of poor UM performance.

Organisation and project culture (holistic view of UM, openness, focus on opportunities and proactive UM) affect project managers' desire for risk (Karlsen, 2011; Rashid and Boussabiane, 2021). The findings show that countries with various cultural origins recognise and handle project risks differently (Liu *et al.*, 2015). Successful RM depends too much extent on an explicit understanding of culture. Participation in meetings, enhanced communication and team spirit are important factors in organisations (Smith *et al.*, 2006; Chapman and Ward, 2011). Early involvement of actors in dialogue, effective communication, information exchange, open attitude and trustful relationship support open discussion about the projects' risks (Osipova, 2008). According to Aslam *et al.* (2019), effective communication and coordination amongst stakeholders could reduce many design changes. Based on the literature review, the following criteria are listed for humans and organisations:

(1) Risk responsibility/ownership (Klakegg *et al.*, 2010; Johansen, 2015);

(2) Workforce competency (Chapman and Ward, 2011; Adafin *et al.*, 2021);

(3) Team members' role (Osipova, 2008; Chapman and Ward, 2011; Johansen *et al.*, 2019);

(4) Effective communication (Osipova, 2008; Aslam *et al.*, 2019) and

(5) Organisational culture (Karlsen, 2011; Rashid and Boussabiane, 2021).

2.3.2 Criteria in the process component. This section starts with process definition, UM process and, finally, criteria which improve UM process. A process involves a beginning, ending and expected results. Chapman and Ward offer Shape, Harness and Manage Project Uncertainty (SHAMPU), a nine-step paradigm for addressing project uncertainties. There are other processes in the Project Risk Analysis and Management (PRAM) and Project Management Body of Knowledge (PMBOK) guide (Austeng *et al.*, 2005a). Scandinavian countries mostly use a step-by-step process for uncertainty and risk analysis based on successive principles (Lichtenberg, 2000; Klakegg, 1994). In PMBOK, the RM process includes planning, identification, analysis, responses, monitoring and control of the risks.

Projects with a long timeframe need regular risk assessment processes and updates. The RM process focusses on the needs and requirements of clients and the different tools and techniques that can be used (Smith *et al.*, 2006). Johansen *et al.* (2019) defined the general steps for UM based on the literature study from previous research on UM and RM in the project as follows: (1) defining the goals for UM (initiation), (2) identifying key stakeholders, (3) identifying uncertainties and determining its effect on project objective (quantifying), (4) prioritising opportunities and threats, (5) checking if the response has expected effect (review) and (6) updating of uncertainty register and searching for new opportunities and plan and execution of new responses (follow). According to Johansen *et al.* (2016) and based on empirical data from complex public and private projects, there is often poor performance in managing opportunities in projects.

Lichtenstein (1996) stated that different factors determine the best RM method and process. His study found seven important factors in the risk assessment model: usability, credibility, complexity, completeness, adaptability, validity and cost. Qazi and Simsekler (2021) developed a simulation-based risk assessment model to help an organisation prioritise risks and assign resources correspondingly to the critical risks identified. Prioritising and assigning resources could be one of the essential criteria related to the process.

Whilst Simister (2004) and Johansen (2015) emphasised the importance of undertaking RM as a formal process aligned with the overall project management approach, Krane and Langlo (2010) underline the necessity of informal interaction and communication. They claim that informal actions make it possible to cooperate and respond quickly without spending unnecessary resources. However, a formal structure must exist as a "backbone" for the informal interaction to work. Formal and informal meetings facilitate communication amongst different actors.

Osipova (2008) found that there is direct relation between actors' participation level and UM. Collaboration and information exchange in decisions are other factors that affect the projects' UM process. Walker *et al.* (2017) presented that collaboration might reduce ambiguity for people and processes in project delivery. They also found that unexpected ambiguities always are not recognised before emergence. This shows uncertainties which are unknown-unknowns. Derived from the literature review, the following factors are proposed:

(1) Equal consideration for risk and opportunity (Johansen *et al.*, 2016);

(2) Usability (Lichtenstein, 1996);

(3) Formal or informal (Simister, 2004; Krane and Langlo, 2010; Johansen, 2015);

(4) Documentation (Johansen *et al.*, 2019) and

(5) Collaboration and information exchange level (Osipova, 2008).

2.3.3 Criteria in the tools and techniques component. In this section first tools and techniques were defined, then some tools were introduced and finally concluded with some identified factors. "Tools and techniques" are analytical and visualisation methods and techniques for project uncertainty identification, analysis and management. Klakegg *et al.* (2010) showed that criteria for analytical processes like UM processes could differ from good to simple. Each one (good and simple) has its own advantages and disadvantages. For example, good (complex) could be precise, objective and so on. Simple could be understandable by anyone in the project.

Tools can be an advanced Excel spreadsheet, estimation tool for cost uncertainty (Anslag 4.0), web-based risk registers which is called Process Information Management System (PIMS) web and uncertainty matrices. Techniques are brainstorming, interviews, checklists and the Delphi method. Choosing the right project, deciding upon the best design and estimating the time and cost of the project are all done to minimise the risk involved. Still, it is not part of the UM. Project owners utilise different tools and techniques to identify, estimate and manage the uncertainty that is not shared with other partners (design firms or contractors) (Johansen, 2015).

Different methods and tools combine the power of computer-based tools with structured processes and systematic approaches for uncertainty, risk analysis and management (Klakegg *et al.*, 2010). Qazi *et al.* (2020) said that interdependency modelling of uncertainty had been discussed using different qualitative and quantitative techniques. These models were based on the interpretive ranking process and system dynamics (Mhatre *et al.*, 2017), Artificial Intelligence (AI) (Afzal *et al.*, 2021), fuzzy system (Valipour *et al.*, 2015), meta-network analysis (Wang *et al.*, 2021), Building Information Modelling (BIM) (Zhou *et al.*, 2021) and multi-criteria decision-making model (Albogamy and Dawood, 2015; Burcar Dunovic *et al.*, 2016). All these models were used to forecast the influence of uncertainties on project objectives.

Johansen (2015) emphasises on visualisation capability and documentation's level of tools in UM. Self-confidence arises from clearly recording risks and opportunities (documentation) and knowing how to manage uncertainties (Johansen, 2015). Criteria for evaluating tools and techniques on UM are various, and the proposed criteria are as follows:

(1) Complex or simple (Klakegg *et al.*, 2010);

(2) Precise or imprecise (Klakegg *et al.*, 2010);

(3) Resource demanding or less resource demanding (Klakegg *et al.*, 2010);

(4) Visualisation capability (Smith *et al.*, 2006; Johansen, 2015) and

(5) Documentation capability (Johansen, 2015).

3. Research method

This study aimed to improve the knowledge about the key components of design phase UM. The literature review helped to know UM and UM in the project's design phase as well as the relative criteria for the UM's components which was introduced by Johansen (2015). Second, it was essential to understand how UM was done in the project design phase, which was accomplished by case studies. The case study employed document study and interviews to develop new knowledge regarding the application of the UM in the design phase (Gustafsson, 2017). Interview as a qualitative strategy demonstrated how uncertainties are managed in projects. Project manager interviews supplemented document study data.

3.1 Literature review

As shown in Table 1, a systematic literature review started with selecting important keywords for study topics. We investigated human and organisation, processes and related tools and techniques of UM. To decide the different literature's relevance for this paper, one of the authors searched all journal articles in all issues (2015–2022). The search concentrated on databases Scopus, Web of science and Emerald as illustrated in Table 1. In the first step, articles were filtered based on search keys in title-abstract-keyword, journal articles, English articles and peer-reviewed articles. In the second step, abstracts of the papers were read, and articles were chosen based on the inclusion criteria with a focus on three components of UM and RM models in construction, infrastructure and highway projects. The numbers in the last column of Table 1 show the total number of articles after reading the abstract. Then in the third step, abstract and conclusion of the articles were read and data were reflected on paper.

The number in the parentheses indicates the articles that can be accessed by reading the abstract. The inclusion criteria in the third step were if the result was relevant to uncertainty

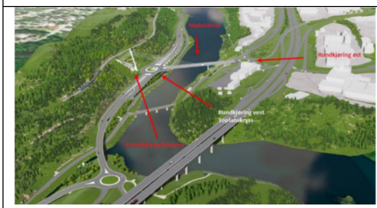
Road case 1 (bridge and road close to the city-urban area)	Road case 2 (Long national road – with road, tunnels, bridges and crossing-rural area)
1.2 km new road 1.7 km cycling road 2,1 km ramps	19 km road Four tunnels with double tunnels
150 million dollars	621 million dollars
	
Interviews and document study	Interviews and document study

Table 1.
Characteristics of cases for investigation

framework, models and components of UM or RM in projects. All articles (45) were read and reflected upon in the introduction, theory section and discussion.

3.2 Choice of research method

Yin (2018) suggests using case studies and histories to answer how and why questions and explanatory research studies. Multiple case studies allow the evaluation of a phenomenon in different situations. Case studies help understand case complexity, such as changes over time, the work processes and the interaction of different parties. A case study also facilitates grabbing the project's contextual condition (Yin, 2018). RQs in this study seek to know how uncertainties are managed in the design phase, identify key criteria for UM framework and how relevant framework components play a role in UM. The research is a case study as a qualitative approach which uses empirical data, a document study and interviews to answer the RQs. The process of UM was not examined in detail in the design phase of Norwegian projects, and we required some criteria for determining its performance. A case study involving two cases with two different owners was the most appropriate way to understand the complexity of cases. This helps to compare cases and evaluate them with identified criteria.

Researchers can see differences and similarities between the two cases, and the data are more reliable (Baxter and Jack, 2015). Two cases were homogeneous in the context of the project's operation. This study analyses and verifies theoretical propositions using theory and data. Triangulation is a research strategy using different data sources (Bryman, 2016), and we used this strategy for data collection to improve the findings' reliability. Table 2 illustrates the characteristics of two road projects used for data collection. We conducted semi-structured interviews as part of the data collection.

The two cases studied are large projects. Both cost more than US$150m, have many stakeholders, medium to high complexity and medium/high uncertainty about the design and execution phase. Both projects had two different owners in Norway. The description of the studied cases in Table 2 is as follows:

Case 1. Construction of a cable bridge and surrounding infrastructure.

The new cable bridge is going to replace an old bridge. The estimated project cost is around US$150M, and the bridge will be connected to a new tunnel. The old bridge will be replaced by a new pedestrian and bicycle bridge. The new 183-m-long bridge with a tower will be presented as a landmark in the city, which increases the project's importance. The project includes a 1.2 km of road, 2.1 km of ramps, 570 metres secondary roads, 1.7 km bicycle road, 14 constructions and a 160-m tunnel. The construction includes a new road, two new bridges and an old bridge will be updated and changed to a pedestrian and bicycle bridge.

Case 2. Construction of a four-lane highway.

The old road was a corridor and part of the national transport network with many problems related to safety and traffic with a high risk of accidents which needs to be improved. The estimated cost of the project is around US$621m. The new four-lane road will replace the previous two-lane road. Higher speed limits and a shorter length, together with higher quality, will reduce travel time and increase safety on the highway. This project has four double tunnels and the road length is approximately 19 km.

3.3 Document study

A document study was performed to get information about project characteristics, important uncertainties related to the two case studies and project uncertainty analysis processes. Document study was a preliminary study before doing the interviews. There are some

	Search keys	Selected journals [where]	Years of research	Items ()
Scopus	"Uncertainty management" Title-Abstract- Keyword	*International journal of project management*	2015–2022	10 (0)
		Management decision		10 (5)
		Academy of management journal		3 (0)
		Administrative science		5 (2)
		International journal of management and decision making		3 (0)
	("Risk management") or ("risk assessment") or ("risk evaluation") and ("road projects") or ("construction projects") or ("infrastructure projects") or ("transport projects") Title-Abstract- Keyword	*International journal of project management*	2015–2022	7 (2)
		Transportation research record		7 (1)
Web of Science	"Uncertainty management"	*Journal of construction engineering and management*	2015–2022	2 (0)
		Journal of management organisation		2 (0)
		Transportation research part E - logistic and transportation review		2 (0)
		Journal of management		3 (0)
		Academy of management journal		2 (0)
		Project management Journal		3 (1)
	Risk management in Topic (Title-Abstract- Keyword)	*International journal of construction management*	2015–2022	24 (9)
		Journal of civil engineering and management		30 (10)
Emerald	(Abstract:"uncertainty management") OR (abstract:"risk management") OR (abstract:"uncertainty evaluation") OR (abstract:"risk evaluation") OR (abstract:"uncertainty assessment") OR (abstract:"risk assessment") AND (abstract:"road projects") OR (abstract: "construction projects") OR (abstract: "infrastructure projects") OR (abstract: "transport projects")	*International Journal of managing projects in business*	2015–2022	70 (11)
Total				183 (45)

Table 2. The process of literature review in this paper

sources of risk documentation in non-traditional ways: interactive websites, digital media, video reports, workshops, chat rooms, wikis, discussion groups and electronic files.

In the process of document study, experienced authors, at the first step, choose the related documents. Then each author reviewed the documents and wrote the project's description and related information from meetings during the project's design phase. All these documents are publicly available and do not contain confidential information. During the research process, information was completed with new documents in contact with project parties. The studied documents are presented in Table 3:

Documents		Reference	Content
Guideline published by the project owner			
	Guideline for uncertainty management	Veidirektoratet (2011)	UM process and how the owner has done it. Tools which the owner uses for UM
Project-Specific documents			
	Nydalsbrua with connections	Vegvesen (2021)	
	Nydalsbrua – new bridge over Sluppen	Kommune (2022)	Project description – Case 1
1	Plan for Kvithammar-Åsen	Nyeveier (2022a)	Project description – Case 2
2	Recording of information meeting about E6 Kvithammar-Åsen 01.02.2	Nyeveier (2022b)	Project description – Case 2
3	Risk or vulnerability analysis for the zoning plan of the project	Stemland *et al.* (2021)	Uncertainty and risk management process and roles of people in the processes – Case 2
4	Measures for alien spices in the project field	Bjølstad (2021)	Using competent people for risk assessment and defining measures for risk management – Case 2
5	Detail regulation for railway culvert in Levanger	Kommune (2021)	Implying for using expert people in different subjects for the process of uncertainty and risk management–Case 2
6	Emergency plan for Case 2	Clarson (2020)	Evaluation of physical and psychological conditions of the personnel after exposure to risk situation by the general contractor -Case 2
7	Risk assessment of Langstein underpass	Værnes and Tunheim (2019)	Uncertainty and risk management process and roles of people in portion of the project (railroad underpass) - Case 2

Table 3.
List of documents which has been studied in this paper

3.4 Semi-structured interviews

Semi-structured interviews can be conducted by developing an interview guide covering specific topics. The interviewer is not obliged to follow the interview guide; sometimes, the interviewer could ask some questions that do not exist in the interview guide to get a better insight into the topic (Bryman, 2016).

After the pre-interview, note-taking and recording are utilised to collect data. The cases differed; experts interviewed client project managers, winning contractors and designers. Interviews lasted one to one-and-a-half hours, depending on the interviewees' schedules. We used coding based on essential criteria for each UM component for data analysis. For instance, we chose documentation-level, formal or informal, information exchange for the process component. Table 4 shows the paper's interview process and provides information regarding interview duration, interviewees' role in projects, data collection method and follow-up meetings or contacts with interviewees.

We interviewed about the UM process, tools and methods and related criteria. We asked about people involved in the UM process during the project's design phase and how they acted in such a process. Seven interviews have been conducted for two projects.

4. Results

The findings from the study are presented according to Johansen's framework components in the theory section (2–3), including human and organisation, processes and tools and techniques. Findings also cover the identified criteria for each component. The summary of findings from three components can be found in Appendix.

Interviews	Duration of interview	Persons' role	Method of data gathering	Date	Follow-up after the interview	Date
1	1 hour	Project manager (owner side) Case 1	Note-taking during a physical meeting	5 July 2021	20 minutes telephone interview	15 August 2021
2	1 hour	Project manager (owner side) Case 1	Recorded interview using digital meeting	30 August 2022		
3	1 hour 20 minutes	project manager (main contractor) Case 1	Recorded interview using digital meeting and note-taking	3 August 2021		
4	1 hour 20 minutes	Design manager (consultant) Case 1	Recorded interview using digital meeting and note-taking	24 July 2021	Asking questions by email	20 December 2021
5	1 hour	Leader of project planning (owner side) Case 2	Recorded interview using digital meeting and note-taking	9 September 2021		
6	1 and half hour	Project controller (main contractor) Case 2	Recorded interview using digital meeting and note-taking	7 May 2021	Asking questions by email	7 October 2021 and 30 August 2022
7	1 hour	Design manager (consultant) Case 2	Interview using digital meeting and note-taking	10 August 2022		

Table 4.
Interview process

4.1 The human and organisation component in the design phase

Case 1 document examination indicated that various stakeholders, health, environment and safety (HES), geotechnical consultants and owner design managers participated in UM. The owner's UM process is built on group work led by a competent facilitator (competent: based on experience and education) who has taught people to manage it. All members of UM team conduct risk registers throughout various periods.

The contractor collaborated closely with a client in UM. The owner selected the contractor through a design contest. For example, near the railroad, the railway and design consultants, the builder (owner), and the general contractor all participated in risk analysis sessions. Before evaluating the design, they meet with six or seven competent individuals linked with the uncertain issues. The owner said:

> We chose a highly qualified contractor based on price, experience, and design competition. Besides, the people in our team have enough experience in UM process. Senior managers support choosing competent people in our team and the contractor. Organization have some guidelines and procedures for choosing qualified contractors.

The contractor said that:

> Different roles were involved in the UM's meeting with competency in their tasks. Their competency was based on the years of experience and the successful project they conducted

Built on the contractor's interview documents with famous magazines in transport and infrastructure, the contractor affirmed their abilities and risk-taking behaviour, which denotes competency by saying (Holm, 2021):

> We have previously carried out major infrastructure projects in the city and have a group of people with local affiliation who want to help to make Trondheim a better city to live and travel in.

Consultants said that,"*Our team members are not involved in formal meetings for UM, and we follow our UM independently based on our requirements*".

The approach for picking a competent contractor relies on a repeated iterative design process until the owner selects the optimal solution. Risk and uncertainty ownership was outlined in the contract, and the owner said that:

> We were responsible for safety management at the project level and strategic uncertainties. At the same time, the contractor was responsible for safety at the operational level.

In both cases, people with varied expertise and competence in UM project team are involved. They lacked a dedicated role for UM, and the project manager on the owner side was responsible for UM with other experts such as economy experts, planners, construction managers, and assistant project managers. In addition, an external expert was selected to manage UM process and meetings. Case 1's UM confirmed efficient communication with various participants. Interviews with the project owner and contractor indicate a satisfying level of communication. For instance, during COVID-19, they conducted various virtual meetings (such as technical meetings) with appropriate digital tools. They observed information exchange between actors. The owner said they had consented with property owners to use the land within the project path. The project manager (owner) stated:

> For technical risks, we had regular meetings during the design phase with contractors and designers, and they were independent of design meetings. We recommend people use collective transportation more on heavy workdays in the project route to reduce the traffic in the area.

In Case 1, the consultant (designers) analysed projects based on document examination, owner meetings, and questions about the project. They directly studied the project site and created documents based on their observations and opinions. Processing an agreement with neighbours and landlords or relocating residences from the project field to other regions. In an interview, designers indicated that:

> Project owner successfully managed neighbours (environmental factors) and land acquisition.

The explanations provided by stakeholders demonstrate the level of contact with various parties, including third parties, contractors, designers, and end users. Communication level with designers and their participation in the UM process indicated a lack of consultants' (designers') ownership of project risks. Consultant said:

> We are not involved specifically with UM in the design phase. But in new projects, it becomes common that consultants work with uncertainty systematically.

In Case 2 UM's meetings were conducted with sector authorities, municipalities, and owners. These meetings were evaluated positively, issues were highlighted, and the contractor could present various solutions (the contractor was responsible for the design). The contractor participated early in the project and gained ownership of solutions. Sector authorities had a positive impression of their cooperation. The support for UM in the project team by the organisation and top-level managers (both by owner and contractor) was confirmed. This support indicates a supportive culture of the organisation for UM practice and its importance.

The owner organised risk and uncertainty analysis meetings every two weeks with the contractor. The owner confirmed the effective communication and competency of the contractor verbally. The owner said that:

> We evaluated solutions (design alternatives) provided by the contractor, and according to their experience, prices, and track record, we chose them for this project.

Owners undertook their analyses personally and examined numerous facets of risks and alterations, and the contractor validated this cooperation. For instance, when they decided to make a design change, they consulted with designers, lawyers, and geotechnical engineers to analyse it from several angles: In an iterative process with the owner, the contractor made changes until the owner was satisfied with the result. The contractors have internal meetings informally (without a plan beforehand). The contractor focusses on operational risks, and the owner focusses on business-level risks. The contractor focusses on HES-related risks, operational risks and force majeure events.

The contractor should deliver weekly risk reports to the owner. They share their internal risk register at the HES and operational level with the owner, which implies satisfying communication and information sharing between them. They had a common risk register with the owner at the overall level. The contractor's project manager has long years of experience in UM. Consultants in Case 2 are involved in issues that require design or plan changes and should submit their suggestions to the owner or contractor. Consultants just provide a detailed project design and deliver it to the contractor. The designer said,

> We are not involved in the formal UM process, and we had only our internal UM, which focuses on our daily tasks.

The contractor was responsible for the project design. They confirmed information sharing with the owner, demonstrating the two actors' trust level.

4.2 The process component in the design phase

UM on Case 1, based on the project owner's guidelines, are as follows: (1) defining goals and execution strategy; (2) identifying uncertainties; (3) qualitative evaluation; (4) quantitative assessments; (5) managing risks reducing consequences and sharing risk, transfer, insure against risk and accept (6) managing opportunities; (7) monitor and control and (8) communicating and reporting (Veidirektoratet, 2011). This UM procedure was the same in both cases (1 and 2).

The owner led and controlled the UM process in Case 1. Priority-based measures are developed to address the identified threats and opportunities according to design solutions. The owner said,

> Regarding observed risks, resources are allocated, and actions are taken until the risks and consequences diminish. We are more concerned about risk than opportunities. The contractor said that we mainly focus on risks and consider opportunities but not as much as risks.

The owner stated that they have a formal process with the contractor every three months during the design phase. The contractor's role in RM is (chromatic) bold in this project. Consultants (designers) are not actively involved in the projects' UM process. However, consultants (designers) conducted all the projects' detailed engineering and used owners' guidelines. They do not have any formal process for their UM, but they emphasise the owners' formal role. The consultants stated,

> We have different uncertainties in our daily work which we decide and tackle daily and informally.

The project manager in Case 1 believes that the formal meeting for UM is held twice a year. However, the actual UM process is systematic and is conducted daily during the project because they believe all the problems they found during the design phase are somewhat related to uncertainties.

Case 1's owner and consultants met with the railway authority to mitigate railway-related risks, indicating formal process and collaboration. The construction site is close to a heavily travelled roadway. In their qualitative risk assessment analysis, all risks were deemed acceptable, and a risk-mitigation strategy was developed for each risk item (Sivalingam *et al.*, 2018).

Their strategy in the design phase was to identify uncertainties and "dive into matters" in a friendly and collaborative environment with the owner. This process directs contractors into the entire process of the tendering phase, and they evaluate clients' risks, see the big picture and define risk-reducing measures. They see the important uncertainties and biggest expected challenges in the project execution. Simultaneously, they go through the negotiation phase with the client. In the bidding process, they check all the risks. The contractor said,

> In preparing the first proposal, we checked all the risks and opportunities and found construction client risks to know what changes we should make to achieve a specific price. We believe each project has its project-specific risks and opportunities; our focus was mostly on risks rather than opportunities.

The contractor said that they follow a standard process for each project. First, they have a heatmap with a sheet that records what projects contain. Second, they have an application for getting permission to use resources. They defined the five most significant uncertainties and calculated their risk and opportunities. They had six meetings (for checking registered uncertainties in the system log) with the core uncertainty team before preparing an offer to the owner. Besides, they should fill out the owner's risk matrix. Sometimes they receive some pointers from the owner's side, which say:

> Yes, but we perceive this as the contractor's risk." This negotiation happens during "bid evaluation" to accept the contract.

The above quote was an example of information exchange between owner and contractor and sharing risk during formal meetings. After delivering the design to the contractor, owners share less information with designers and consultants.

The ability to support prioritising risks and assign resources to a contractor in critical risks depends on the relationship between owner and contractor and the predefined procedure for UM. Contractors affirmed,

> There is no clear line between ours and the owner's risk. The contractor explained that they conducted an uncertainty analysis early in the bidding process. The design was delivered to the contractor completely, but they made changes during execution and presented their proposal to the owner.

Stemland *et al.* (2021) explained that the UM process included describing the planning area, identifying possible unexpected events, risk assessment and vulnerability, identifying measures to reduce risk and vulnerability and documenting the analysis and its effect on the project plan. In the zoning plan, design alternatives were defined and evaluated to choose the one with a lower possibility of risk for the project's goals.

Case 2's project contractor stated during the interview that they were liable for the project's UM. Within the scope of his remit, the project manager is the decision-maker for addressing operational risks connected to progress and the economy. In Case 2, the owner meets with the contractor every two weeks (confirmed by both parties) to assess risk and uncertainty jointly (formal UM process). The contractor must notify the client of the error before the deadline. Otherwise, the contractor (designer) should accept the risk of design flaws. Depending on the contract and risk category, the owner shares risks with a contractor. For instance, the ground condition is the owner's risk as other aspects of the contract's requirements.

The contractor, in the interview mentioned the collaboration level with the owner and other actors by saying,

> The level of collaboration and information exchange with the owner was satisfactory, and all parties participated in meetings. We trust and the owner shares the risk register platform with us. But there exists less information sharing with consultants.

According to the contractor, uncertainty is not formally discussed regularly. The contractor said,

> The day before discussions with the owner, we hold internal meetings and review newly detected risks or modifications to previously recognised concerns. Uncertainty is not a phenomenon we formally evaluate, but informally we evaluate it daily.

The operational-level risk register system of contractors differs from that of the owner, yet they share information. UM is the key activity in the contractor's management system since they seek to find opportunities or cost-optimisation alternatives to meet the owner's budget (shows contractors' competency). Between project meetings, they hold meetings to select one alternative for design with a comprehensive exploration of alternatives. For instance, consultants travel to the site to assess the ground condition. In Case 2, consultants attended project meetings but were not actively involved in the UM process, according to the interview. Consultant commented,

> We were not actively involved in the uncertainty management process, and both owners and contractors were responsible for uncertainty management.

The document study also confirmed this. Contractors provide suggestions or new solutions to the owner for design and plan changes (Værnes and Tunheim, 2019).

4.3 Tools and techniques component in the design phase

Document study and interviews of the Case 1 show that the owner uses a spreadsheet and uncertainty log for risk register, uncertainty analysis and UM. They utilised a tool called "Anslag 4.0" (translates to "estimates") to calculate the road project's cost, including its uncertainty in different phases (quantitative tool). They have an economy follow-up system called "G-Prog project economics". Both risks and opportunities can be logged and managed with this application (Vegvesen, 2014). The owner in Case 1 stated,

"Tool's visualisation capabilities should be enhanced, and dealing with tools is somewhat complicated. The tools could provide somewhat precise answers, and track record of a successful project from a cost perspective shows this success. Tools are not resource demanding in comparison with project's cost, but it takes much time and energy to provide input data for the tool".

The contractor has types of risk registering systems which contribute to outlining what projects contain and how to exploit resources for UM (qualitative). Besides, the contractor had risk register logs during the design and proposal review, and UM's team members have access to the risk registers.

> We (contractor) have a system in the company which evaluates the risk and opportunity profile of the project before accepting it." The system does not have high complexity.

In Case 1, designers followed the owners' spreadsheets for the design competition and used owners' guidelines and tools for detail engineering. An interview and document study (Veidirektoratet, 2011) revealed that the register systems are qualitative; later, they calculate the consequences in cost for each item separately, which helps them to quantify the results. They said,

> As designers, we do not utilise the system that the owner and contractor use.

Case 2's owner stated that the project's design complied with integrated concurrent engineering (ICE) sessions. They successfully made it paperless and BIM enabled. The Case 2 interview with owners demonstrates that they have a complete and adaptable web-based application, namely PIMS online, with many tabs and modules for registering and managing risks. According to empirical data, this tool had high and satisfying visualisation capability and documentation. The owner said,

> We documented project-related risks and opportunities in the system daily. We have a system for risk registering, and we use brainstorming to identify upcoming risks in the project's design phase.
>
> We utilized qualitative and quantitative tools, adding complexity to its understanding. We have a scoring system for each risk and determine its cost. The system we are using has some complexities in calculations and quantifications." The tool is not resource-demanding compared to project cost and is easy to use, but feeding subjective data to the system could take some time and thinking.

They have various alternatives for projects, and they try to detail, evaluate and choose one of them. It's possible that, after selecting one alternative, they realised it was incorrect after more investigation. Case 2 document analysis and empirical findings demonstrated the contractor's early involvement in the project and ownership of the solutions. Sector authorities had a positive impression of this type of cooperation. They used a risk matrix for identifying risk relying on the owners' risk documents (Stemland *et al.*, 2021). According to reports for the project's section, with high uncertainty and nearby the railway, the triple estimates of quantities and unit prices have been used as input values in the analysis. Consultants have included uncertainty factors in the analysis, and the results were obtained through Monte-Carlo Simulation. Both owner systems had good visualisation, allowing them to follow risk from red to green zone (safe areas). With visualisation, they can prepare reports on different dates and track changes.

Consultant's cost estimates were based on builders' and owners' estimates (Sivalingam *et al.*, 2018). Based on empirical data, the consultant also fills out the project's risk matrix and sends it to the owner and an offer for the design competition. The owner's prepared forms of the risk matrix had no room for an opportunity register, and the focus was on the risks.

5. Discussion

First, we need to mention that the two project cases were similar in terms of operating country, culture, operation region and project type. In contrast, they had different owners. However, the final owner is the Ministry of Transport in Norway. Both projects were complex and large in absolute terms, but from a cost perspective the size of operations and timeframe were different. We investigated how uncertainties are identified and managed in the road projects' design phase. The literature study provided related criteria for essential components of UM in this study. Then through document study and interviews, this information evolved.

5.1 Uncertainty management in the design phase

In the design phase, actors prioritise clashes, most probably when they are suspected of following their agendas rather than general project objectives. The design process is a crucial linkage point between the expressed needs of the client and the actual realisation of the construction project. From one perspective, owners seek to avoid such extra cost and time (project outcome) as important parameters of UM and to have better solutions (design outcome) through an iterative design process. From another perspective, designers and consultants think long term. Better design means longer cooperation and more opportunities for future work. Therefore, it is a win–win game for all designers, contractors and project owners. Both cases' trust and collaboration levels could signify having a relationship between actors (a win–win game).

Both projects' owners and contractors follow a structured process for UM. They begin the process early and own the uncertainties at the strategic level, which needs competent people and efficient communication between actors. This implies on supportive organisational culture from UM process. For example, the owner accepts ground conditions or price increases (because of COVID-19 or unexpected events such as war) as uncertainty in the design phase early in the process. They know that after the design phase, the project manager might disclose ground conditions modifications that can add extra costs to the project. The owner considers contingencies for these types of uncertainties. Therefore, uncertainty ownership and supportive culture, such as management support, are important criteria in UM of the design phase. Qazi and Simsekler (2021) considered support for prioritising risks and assigning resources to critical risks as important criteria for the UM process.

5.2 Important criteria for uncertainty management framework in the design phase

We chose Johansen's (2015) framework as a theoretical framework. For each component [(a) human and organisation, (b) process and (c) tools and techniques)], some criteria were developed according to literature as relevant criteria for evaluating UM performance. These introduced criteria could not cover all criteria which show or measure UM performance. It is just starting point for knowing which criteria could be considered for UM to become successful in projects. This model was tested with empirical data to know how they play a role in the UM process in the design phase. Although for a better and more precise evaluation, it needs more data from different projects.

The selected criteria reveal the portion of the story. However, they cover significant ones. For instance, communication has been recognised as one of the essential components in humans and organisations. Notable is the fact that communication could be enhanced with better tools and competency. Therefore, these criteria are interconnected and are not independent of the UM process. Three important components also are interconnected in UM. For instance, a process with effective communication needs suitable infrastructure to support it. Owners who follow the formal UM process must have suitable systems and infrastructure to support such collaboration. Efficient UM and successful processes need to have competent people. They are not only independent components, but we could evaluate them independently. The overall performance of UM in projects depends on their performance collectively.

5.2.1 Criteria for human and organisation. Smith *et al.* (2006) stated that project owners and investors are risk-takers. Furthermore, the owner's function as a risk-taker by accepting risks related to ground conditions and strategic-level risks is consistent with empirical facts and theory. Although we can deduce that, if compensated, independent contractors may also be risk-takers. Risk-taking behaviour is comparable, but ownership is slightly greater in Case 2 due to the number of meetings and the owners' efforts to reduce risks. Being risk averse in group decisions of UM could be justified by the project's contract type, and a document study showed clear instructions by the owner for risk decisions in contracts (Veidirektoratet, 2011). By choosing specific contract types, the owner and contractor try to avoid risks, so project stakeholders usually are risk averse, which is the typical trait of organisations in project execution because each party seeks their benefit and hidden agendas as stated by Lohne *et al.*, (2017).

Workforce competency is a criterion that may be determined through performance, and their inclusion in this study was contingent on their years of experience and skills. Chapman and Ward's (2011) explanation regarding prerequisites for workforce competency based on personal skills and cooperation was approved through meeting documents and interviews with different stakeholders. Skilful people in related roles contribute to UM for each risk issue and uncertainty.

Effective communication and collaboration is reflected in meetings for design and tender competitions before and after contracting, and it could change amongst stakeholders according to empirical data. For example, at the beginning of the design process, the consultants' role is chromatic, but later it could fade or reduce as contractors play the major roles in UM in the design phase. Osipova (2007) demonstrated contractors' significant level of participation and collaboration in UM and the low level of communication and participation by consultants. Chapman (1999) also confirms that efficient management in the design phase needs clear and effective communication. This implies that road projects should consider the designers' role as essential and actively participate in the UM process. This could impose extra costs on the owner, but on another side it could make the consultant and owner closer to each other instead of the contractor who has a mediator role.

Collaborative relations of stakeholders were evident in both cases and affirmed the theory about the necessity of effective communication and collaboration during the project's design phase (Osipova, 2007; Aslam *et al.*, 2019). Besides, using competent people for UM and RM was strongly confirmed according to empirical data. In both cases, budgetary performance was one of the criteria for choosing consultants and contractors. Adafin *et al.* (2021)'s research show how workforce competency in the budgetary analysis of projects in the design phase could be a risk factor. For example, the competency of consultants, information flow and experience of the project team are risk factors that influence clients' costs. Based on interviews, we recognised these factors introduced by Adafin *et al.* (2021) strongly confirmed.

5.2.2 Criteria for the process of uncertainty management. Norwegian quality assurance systems for large road projects require quality checks and documentation before financing, which is in the design phase. In both cases, project managers follow the parent organisation's guidelines and instructions. Rashid and Boussabiane (2021) found that project organisational culture influences RM motivations and processes.

The owners implied the formal UM process in both projects. This trend is in coordination with the literature about the necessity of formal UM in projects by Simister (2004) and Johansen (2015) and less participation of consultants. Along with this formal process led by the owners, the informal UM process was noticed by the owners, contractors and consultants working on the project. The design process is iterative and needs helpful information sharing with consultants and contractors. Krane and Langlo (2010) indicated the necessity of having an informal process of UM for project success that serves as a supplement to the formal process; any policy by the owner or limitation in sharing necessary information for design could affect the final result. Empirical findings conform to Osipova (2008), which found that effective communication and trust support open discussion about project risk. The informal UM process could be improved by having trust and a culture that supports open communication and information sharing in the project. Karlsen (2011) introduced UM culture with openness, respect and a positive attitude.

The ability of companies to prioritise risks and opportunities in both cases depends on their experience and the competent people they use in their UM process. To some extent, stakeholders can have conflict because of the subjective nature of project risks and opportunities, according to Johansen (2015) and Qazi and Simsekler (2021).

Collaboration levels of actors in UM practices could be a reason for their benefit from the project. For example, it is hard to expect consultants with less project benefit to participating formally in UM unless their contract obliges them to do that or have benefits. Contractors and owners benefit from this cooperation, and reducing their role in this process is inevitable. However, the strategy and effort they put into effect could depend on the risk levels. Operational-level risk is more the concern of the contractors' project managers, and their effort during the projects' design is expected compared to the owner. Communication level and information exchange between designer and owner change after design delivery to owner or contractor.

5.2.3 Criteria for tools and techniques in the uncertainty management process. Both cases have difficult-to-measure criteria. One of them was the preciseness of tools and techniques. Tools have quantitative input, and results might be considered more precise than qualitative ones. Smith *et al.* (2006) explained that computers with high complexity in models need fewer manual calculations and the accuracy increases but complexity increases. In contrast, UM in road projects based on empirical data relies somewhat on the subjective judgement, which might increase manual calculations and reduce accuracy. Competency and experience could play an important role and could reduce deviation from actual costs. Austeng *et al.* (2005b) say tool preciseness depends on how detailed the UM is. In both cases, based on a document study (Vegvesen, 2014) and interviews, the owner defined acceptance criteria for calculating uncertainty and risks in all project phases. A high level of detailing capability, such as a long list of uncertainties and defined measures for tackling uncertainties, are samples for the tools' detailed level. There exists discussion about to what extent such detailing is helpful and improves work efficiency or is preventive. There were some voices from interviewees about the capacity for improving the visualisation capability for better management of the long list of uncertainties in missing some uncertainties.

UM tools utilised in large projects outweigh their costs but, from time and energy perspectives, are resource demanding. When it takes much time to prepare input data to model, the result is expected to be accurate. Therefore, there is a direct relation between tool preciseness and cost. According to Smith *et al.* (2006), computer systems make such analysis easier and facilitate visualisation. This capability depends on parent organisation support, the process and defined specifications for project UM. Case 2 exploited "web-based tools" which provide better visualisation capability. In Case 1, empirical data demonstrated visualisation needs for improvement. Dikmen *et al.* (2012) pointed out that web-based tools provide better visualisation and documentation capability as confirmed by empirical data with high documentation capability. The Norwegian projects had pre-requirements for a demanding level of documentation.

5.3 Practical implications of the research

Project evaluations showed that the choice of skilled people, UM process and suitable tools and techniques for UM depends on the projects' characteristics, stakeholders' collaboration level and owner company's organisational variation. High uncertainty in design influences the contracts strategy of the projects, and they made a competition for a design to find the best solution. For example, having a project constructed inside the city with existing uncertainties and a symbolic structure affects the city from aesthetic dimensions.

Furthermore, it directs the owners towards design competition to get a better bridge design result before the project's construction.

In contrast, a large-scale project with long roads and long-time frames with different tunnels and bridges outside the city could direct the owner to involve in more collaborative participation and choose the main contractor with high experience in managing different contractors. Trust could be an influencing factor in such collaboration to monitor the work in all phases and overall have better control over the project. The risk manager in Case 2 also confirmed this collaboration as an open and satisfying relationship (trust). These empirical data were in coordination with Osipova's (2008) findings, which show that an open attitude, effective communication and information exchange supports project risk. According to Karlsen (2011) organisation culture influences and determines the effectiveness of UM.

When there is a collaborative contract between owner and contractor, they share more information and use integrated systems for UM. For example, the study of Case 2 shows more information sharing in risks and uncertainties and having integrated systems in which both sides have access to the system. The integration level in Case 1 was less than in Case 2. When needed, information sharing and collaboration levels can signify trust between owners and contractors. Generally, designers have less information sharing of uncertainties with contractors and owners, which Osipova (2007) in the research confirm the low collaboration of consultants in UM process.

Identified criteria in the paper gave a better insight to practitioners, project managers, owners and policy-makers in the UM process and evaluation of it in the design phase. Project managers will notice criteria such as effective communication, web-based tools, better documentation, visualisation capability and sharing information as important criteria which are interconnected and are important for the design phase. Owners know that early information sharing with designers leads to better product design. The benefits of better design directly are for project owners who will experience lower changes and higher value (fewer cost overruns). For contractors, based on contract type, the result could be different. Policy-makers would comprehend the significance of the design phase and define stringent requirements for projects to pass quality checks. They have an integrated approach with a special focus on UM process, standard tools (such as web-based tools or documentation standards) and important uncertainties (such as ground conditions and market conditions). Quality checks in the design phase enhance road project performance during execution, which directly benefits society.

In this paper, we tried to fill this gap in the literature by developing Johansen's (2015), framework by identifying relevant criteria for measuring UM in the design phase. For instance, Xiahou *et al.* (2022) mentioned that existing research mostly notices post-accident management, and there is a shortage in pre-management awareness. Therefore, with better pre-measurement, we could expect a better design process with fewer changes and redundant work later. This pre-measurement in the design phase is essential for successful project execution and achieving a better result with lower consequences for unexpected or expected ambiguities, variations and uncertainties. For instance, effective communication, better visual capabilities, information sharing and efficient documentation in the design process lead to better product design.

6. Conclusion and further work

This paper aimed to improve knowledge about key components of UM. The case study approach contributed to getting a deep analysis of these components. Johansens' (2015) framework with identified relevant criteria was evaluated using empirical data. According to the literature review, we grasped some relevant criteria for each component. Relevant criteria are used for assessing UM in the road projects' design phase. Two RQs were answered in this paper as follows.

First, the design phase is a process in which designers have an essential role in delivering the project design. Project designers seem less involved in the formal UM process and use fewer necessary tools than owners and contractors. It seems logical that people are involved in a process based on their perceived risk. Owners mainly focussed on strategic uncertainties, and contractors focussed on technical and operational uncertainties related to design and constructability. Collaboration was strong between contractors and owners. For a successful risk and opportunity management process, all stakeholders must collaborate, which relies on a culture of efficient UM. Therefore, designers must have more formal involvement in the UM process than today as Osipova (2008) reminded the important role of consultants in the design phase. Both cases had different owners and consultants, but the designers' involvement in the formal UM process for both projects was low.

Second, we used triangles of "human and organisation", "process" and "tools and techniques" that need to work together. According to relevant criteria from the literature, we recognised these criteria in both cases and how these criteria function in both cases. For instance, competent people and supportive culture are needed to better communicate and share information from tools and techniques.

In conclusion, despite limitations, this research presents guidelines for road projects concerning the UM in the design phase and its measurement. For this purpose, project owners should notice a culture of trust and senior managers' trust in the design phase. Having a trusting culture contributes to open communication and information sharing. Effective communication and information sharing also need better tools with visualisation capability and documentation, besides the involvement of all parties and consultants in the formal UM process. All the criteria are interrelated and should work together for a successful UM.

This study provides a holistic view of the important components of UM [(a) process, (b) human and organisation and (c) tools and techniques)] by providing an explicit overview of their important criteria and role in each component. Evaluating these components and following them in the later phases could give insight to practitioners, project managers, owners and policy-makers in the UM process and evaluation of it in the design phase. They will learn about the quality of the UM processes, applied methods and tools in each case and the differences between the two cases. Future studies will develop this qualitative evaluation by using a quantitative approach. Evaluation of criteria in three aspects is subjective and needs to be completed by survey-based quantitative evaluation to become precise. For instance, determining the tools' complexity level, user-friendliness or documentation level could be conducted by experts' analysis through a questionnaire.

References

Ackermann, F., Howick, S., Quigley, J., Walls, L. and Houghton, T. (2014), "Systemic risk elicitation: using causal maps to engage stakeholders and build a comprehensive view of risks", *European Journal of Operational Research*, Vol. 238 No. 1, pp. 290-299.

Adafin, J., Rotimi, J.O.B. and Wilkinson, S. (2021), "An evaluation of risk factors impacting project budget performance in New Zealand", *Journal of Engineering, Design and Technology*, Vol. 19 No. 1, pp. 41-61.

Adam, A. and Lindahl, G. (2019), "Dynamic capabilities and risk management: evaluating the CDRM model for clients", *Emerald Reach Proceedings Series*, Vol. 2, pp. 85-92.

Afzal, F., Yunfei, S., Nazir, M. and Bhatti, S.M. (2021), "A review of artificial intelligence based risk assessment methods for capturing complexity-risk interdependencies: cost overrun in construction projects", *International Journal of Managing Projects in Business*, Vol. 14 No. 2, pp. 300-328.

Albogamy, A. and Dawood, N. (2015), "Development of a client-based risk management methodology for the early design stage of construction processes", *Engineering, Construction and Architectural Management*, Vol. 22 No. 5, pp. 493-515.

Andenæs, E., Engebø, A., Time, B., Lohne, J., Torp, O. and Kvande, T. (2020), "Perspectives on quality risk in the building process of blue-green roofs in Norway", *Buildings*, Vol. 10 No. 10, pp. 1-18.

Arena, M., Azzone, G., Cagno, E., Ferretti, G., Prunotto, E., Silvestri, A. and Trucco, P. (2013), "Integrated risk management through dynamic capabilities within project-based organizations: the company dynamic response map", *Risk Management*, Nature Publishing Group Vol. 15 No. 1, pp. 50-77.

Asadi, P., Rezaeian Zeidi, J., Mojibi, T., Yazdani-Chamzini, A. and Tamošaitienė, J. (2018), "Project risk evaluation by using a new fuzzy model based on Elena guideline", *Journal of Civil Engineering and Management*, Vol. 24 No. 4, pp. 284-300.

Aslam, M., Baffoe-Twum, E. and Saleem, F. (2019), "Design changes in construction projects – causes and impact on the cost", *Civil Engineering Journal*, Vol. 5 No. 7, pp. 1647-1655.

Atkinson, R., Crawford, L. and Ward, S. (2006), "Fundamental uncertainties in projects and the scope of project management", *International Journal of Project Management*, Vol. 24 No. 8, pp. 687-698.

Augusto, L., Gomes, D.V., Brasil, V.C., Facin, F., Augusto, R., Reis, S., Lu, A., Gomes, D.V. and Salerno, M.S. (2019), "Proposing a multilevel approach for the management of uncertainties in exploratory projects", *Project Management Journal*, Vol. 50 No. 5, pp. 554-570.

Austeng, K., Jordanger, I., Magnussen, O.M. and Torp, O. (2005a), "Usikkerhetsanalyser – Kontekst Og Grunnlag", Concept report no 10, NTNU, Trondheim, Vol. 1.

Austeng, K., Torp, O., Terje Midtbø, J., Helland, V. and Jordanger, I. (2005b), "Usikkerhetsanalyser Metoder", Concept report no 12, NTNU, Trondheim.

Baxter, P. and Jack, S. (2015), "Qualitative case study methodology: study design and implementation for novice researchers", *The Qualitative Report*, Vol. 13, doi: 10.46743/2160-3715/2008.1573.

Bjølstad, O.K. (2021), *Tiltak fremmede arter – E6 Kvithammar-Åsen*, Report NO.N0-YM-10, available at: https://www.statsforvalteren.no/siteassets/sf-trondelag/dokument-fmtl/miljo-og-klima/tiltaksplan-for-fremmede-arter.pdf

Bryman, A. (2016), *Social Research Method*, 5th ed., Oxford University Press, London.

Buchanan, R. (1992), "Wicked problems thinking in design", *Design Issues*, Vol. 8 No. 2, pp. 5-21.

Burcar Dunovic, I., Radujkovic, M. and Vukomanovic, M. (2016), "Internal and external risk based assesment and evaluation for the large infrastructure projects", *Journal of Civil Engineering and Management*, Vol. 22 No. 5, pp. 673-682.

Chapman, R.J. (1999), "The likelihood and impact of changes of key project personnel on the design process", *Construction Management and Economics*, Vol. 17 No. 1, pp. 99-106.

Chapman, R.J. (2001), "The controlling influences on effective risk identification and assessment for construction design management", *International Journal of Project Management*, Vol. 19 No. 3, pp. 147-160.

Chapman, C. and Ward, S. (2007), "Project risk management: processes, techniques and insights", 2nd ed., available at: https://www.amazon.com/Project-Risk-Management-Processes-Techniques/dp/0470853557

Chapman, C. and Ward, S. (2011), *How to Manage Project Opportunity and Risk*, John Wiley & Sons.

Clarson, J.T. (2020), *Beredskapsplan*, available at: https://docplayer.me/213680690-Beredskapsplan-gjelder-for-408-e6-kvithammar-asen.html

Dikmen, I., Birgonul, M.T., Tah, J.H.M. and Ozer, A.H. (2012), "Web-based risk assessment tool using integrated duration–cost influence network model", *Journal of Construction Engineering and Management*, Vol. 138 No. 9, pp. 1023-1034.

Dikmen, I., Atasoy, G., Erol, H., Kaya, H.D. and Birgonul, M.T. (2022), "A decision-support tool for risk and complexity assessment and visualization in construction projects", *Computers in Industry*, Vol. 141, doi: 10.1016/j.compind.2022.103694.

Farooq, M.U., Thaheem, M.J. and Arshad, H. (2018), "Improving the risk quantification under behavioural tendencies: a tale of construction projects", *International Journal of Project Management*, Vol. 36, pp. 414-428.

Galbraith, J.R. (1974), "Organization design: an information processing view", *Interfaces*, Vol. 4 No. 3, pp. 28-36.

Gustafsson, J. (2017), *Single Case Studies vs Multiple Case Studies: A Comparative Study*, Academy of Business, Engineering and Science Halmstad University, Sweden, pp. 1-15.

Hald, L.C., Amdahl, E., Johansen, A., Lund, J.P. and Johansen, T.I. (2008), "Living uncertainty: experiences from two large construction projects", *IPMA World Congress*, Vol. 22, pp. 1-6.

Han, Z., Porras-Alvarado, J.D., Sun, J. and Zhang, Z. (2017), "Monte Carlo simulation-based assessment of risks associated with public-private partnership investments in toll highway infrastructure", *Transportation Research Record*, Vol. 2670 July 1989, pp. 59-67.

Hedeman, B. and Seegers, R. (2009), *Prince2: A Pocket Guide*, 1st ed., available at: https://www.amazon.com/PRINCE2-2009-Prince2-Hedeman-Seegers/dp/B00CF6CEIS (accessed 18 November 2021).

Hillson, D. and Murray-Webster, R. (2017), *Understanding and Managing Risk Attitude*, 2nd ed., Taylor and Francis, pp. 1-183, available at: https://www.perlego.com/book/1575130/understanding-and-managing-risk-attitude-pdf (accessed 14 October 2022).

Holm, L. (2021), "Nydalsbrua løser viktig floke", available at: https://www.samferdselinfra.no/nydalsbrua-loser-viktig-floke/

Jaafari, A. (2001), "Management of risks, uncertainties and opportunities on projects: time for a fundamental shift", *International Journal of Project Management*, Vol. 19 No. 2, pp. 89-101.

Johansen, A. (2015), "Project uncertainty management a new approach: the 'lost opportunities'", NTNU Doctoral Dissertation, Trondheim, Vol. 6.

Johansen, A., Halvorsen, S.B., Haddadic, A. and Langlo, J.A. (2014), "Uncertainty management – a methodological framework beyond 'the six W's'", *Procedia - Social and Behavioral Sciences*, Elsevier B.V. Vol. 119, pp. 566-575.

Johansen, A., Eik-Andresen, P., Dypvik Landmark, A., Ekambaram, A. and Rolstadås, A. (2016), "Value of uncertainty: the lost opportunities in large projects", *Administrative Sciences*, Vol. 6 No. 3, p. 11.

Johansen, A., Olsson, N.O.E., George, J. and Asbjørn, R. (2019), *Practical Risk and Opportunity Management, Project Risk and Opportunity Management*, Routledge. doi: 10.1201/9780429430589-6.

Karlsen, J.T. (2011), "Supportive culture for efficient project uncertainty management", *International Journal of Managing Projects in Business*, Vol. 4 No. 2, pp. 240-256.

Kendrick, T. (2015), "Project opportunity - risk sink or risk source?", *PMI Global Congress Proceedings*, pp. 1-10.

Klakegg, O.J. (1994), "The step-by-step principle – a systematic approach to project planning under uncertainty", *12th IPMA World Congress on Project Management, "Dynamic leadership through project management"*, Oslo, Norway.

Klakegg, O.J and Haavaldsen, T. (2011), "Governance of major public investment projects: in pursuit of relevance and sustainability", *International Journal of Managing Projects in Business*, Vol. 4, doi: 10.1108/17538371111096953.

Klakegg, O.J., Torp, O. and Austeng, K. (2010), "Good and simple – a dilemma in analytical processes?", *International Journal of Managing Projects in Business*, Vol. 3 No. 3, pp. 402-421.

Kommune, L. (2021), *E6 Kvithammar – Åsen: Detaljregulering Levanger Kommune*, Report No: ST-13732-1, available at: http://www.e6-kvithammar-aasen.no/pdf/Regplan-KAA-parsell-Levanger/KU/R2-PLAN-02%20Temarapport%20konsekvensutredning%20Friluftsliv,%20by-%20og%20bygdeliv.pdf.

Kommune, T. (2022), *Nydalsbrua (ny bru på Sluppen) - Miljøpakken*, available at: https://miljopakken.no/prosjekter/sluppen-bru (accessed 20 January 2022).

Krane, H.P. and Langlo, J.A. (2010), "Project risk management: challenges and good practices in active project ownership", *24th IPMA World Congress*, p. 3.

Lawson, B. (2006), *How Designers Think: The Design Process Demystified*, 4th ed, Elsevier, Architectural Press, Oxford, Burlington, MA.

Lichtenberg, S. (2000), *Proactive Management of Uncertainty Using the Successive Principle*, Lichtenberg & Partners, Vedbæk.

Lichtenstein, S. (1996), "Factors in the selection of a RA Method.pdf", *Information Management and Computer Security*, Vol. 4 No. 4, pp. 20-25.

Liu, J., Meng, F. and Fellows, R. (2015), "An exploratory study of understanding project risk management from the perspective of national culture", *International Journal of Project Management*, Elsevier and IPMA Vol. 33 No. 3, pp. 564-575.

Lohne, J., Svalestuen, F., Knotten, V., Drevland, F.O. and Lædre, O. (2017), "Ethical behaviour in the design phase of AEC projects", *International Journal of Managing Projects in Business*, Vol. 10 No. 2, pp. 330-345.

Mhatre, T.N., Thakkar, J.J. and Maiti, J. (2017), "Modelling critical risk factors for Indian construction project using interpretive ranking process (IRP) and system dynamics (SD)", *International Journal of Quality and Reliability Management*, Vol. 34 No. 9, pp. 1451-1473.

Morris, P.W.G. (2002), "Science, objective knowledge and the theory of project management", *Proceedings of the ICE - Civil Engineering*, Vol. 150 No. 2, pp. 82-90, doi: 10.1680/cien.2002.150.2.82.

Nyeveier (2022a), *Opptak av informasjonsmøte om E6 Kvithammar – Åsen*, available at: https://www.nyeveier.no/arrangementer/informasjonsmoter/opptak-av-informasjonsmote-om-e6-kvithammar-asen-01-02-22/ (accessed 01 February 2022).

Nyeveier (2022b), *Plan for E6 Kvithammar – Åsen*, available at: https://www.nyeveier.no/prosjekter/e6-trondelag/e6-kvithammar-asen/nyhetssaker-for-e6-kvithammar-asen/plan-for-e6-kvithammar-asen/ (accessed 02 March 2022).

Osipova, E. (2007), "Risk management in the different phases of a construction", *Proceedings of 4th Nordic Conference on Construction Economics and Organisation*, Luleå, Sweden, pp. 1-13.

Osipova, E. (2008), "Risk management in construction projects: a comparative study of the different procurement options in Sweden", Master's Thesis, Luleå Tekniska Universitet, Luleå.

Perminova, O., Gustafsson, M. and Wikström, K. (2008), "Defining uncertainty in projects - a new perspective", *International Journal of Project Management*, Vol. 26 No. 1, pp. 73-79.

PMBOK (2013), *A Guide to the Project Management Body of Knowledge(PMBOK® Guide)*, 5th ed., Project Management Institute, Pennsylvania.

Podgórska, M. and Pichlak, M. (2019), "Analysis of project managers' leadership competencies: project success relation: what are the competencies of polish project leaders?", *International Journal of Managing Projects in Business*, Vol. 12 No. 4, pp. 869-887.

Qazi, A. and Simsekler, M.C.E. (2021), "Risk assessment of construction projects using Monte Carlo simulation", *International Journal of Managing Projects in Business*, Vol. 14 No. 5, pp. 1202-1218.

Qazi, A., Dikmen, I. and Birgonul, M.T. (2020), "Mapping uncertainty for risk and opportunity assessment in projects", *EMJ - Engineering Management Journal*, Taylor & Francis Vol. 32 No. 2, pp. 86-97.

Rashid, A. and Boussabiane, H. (2021), "Conceptualizing the influence of personality and cognitive traits on project managers' risk-taking behaviour", *International Journal of Managing Projects in Business*, Vol. 14 No. 2, pp. 472-496.

Rostami, A. and Oduoza, C.F. (2017), "Key risks in construction projects in Italy: contractors' perspective", *Engineering, Construction and Architectural Management*, Vol. 24 No. 3, pp. 451-462.

Rwakarehe, E.E. and Mfinanga, D.A. (2014), "Effect of inadequate design on cost and time overrun of road construction projects in Tanzania", *Journal of Construction Engineering and Project Management*, Vol. 4 No. 1, pp. 15-28.

Samset, K. (2010), *Early Project Appraisal: Making the Initial Choices*, Palgrave Macmillan, doi: 10.1057/9780230289925.

Savolainen, J.M., Saari, A., Männistö, A. and Kähkonen, K. (2018), "Indicators of collaborative design management in construction projects", *Journal of Engineering, Design and Technology*, Vol. 16 No. 4, pp. 674-691.

Serpell, A., Ferrada, X. and Rubio, N.L. (2017), "Fostering the effective usage of risk management in construction", *Journal of Civil Engineering and Management*, Vol. 23 No. 7, pp. 858-867.

Shi, Q., Liu, Y., Zuo, J., Pan, N. and Ma, G. (2015), "On the management of social risks of hydraulic infrastructure projects in China: a case study", *International Journal of Project Management*, Elsevier and International Project Management Association Vol. 33 No. 3, pp. 483-496.

Simister, S.J. (2004), *Qualitative and Quantitative Risk Management*, The Wiley Guide to Managing Projects, Wiley & Sons, Hoboken, NJ.

Sivalingam, T., Stemland, E. and Skogvang, Ø (2018), "Rams-analyse for nydalsbrua – *Risiko for jernbanen I anleggsfasen*", Main report (Report No: ST-13732-1) Safetec, Trondheim (in Norwegian).

Smith, N.J., Merna, T. and Jobling, P. (2006), *Managing Risks in Construction Projects*, 2nd ed., Blackwell, Oxford.

Stemland, E., Værnes, R. and Tunheim, E. (2021), "Risiko- Og sårbarhetsanalyse til reguleringsplan for Kvithammar-Åsen i levanger", Main report (Report No: R2-PLAN-07).

Thamhain, H. (2013), "Managing risks in complex projects", *Project Management Journal*, Vol. 44 No. 2, pp. 20-35.

Vaagen, H., Kaut, M. and Wallace, S.W. (2017), "The impact of design uncertainty in engineer-to-order project planning", *European Journal of Operational Research*, Vol. 261 No. 3, pp. 1098-1109.

Værnes, R. and Tunheim, E. (2019), "Detaljregulering Jernbanekulvert Langstein, Risikovurdering RAMS langstein undergang", Main report (Report NO:R1-RAMS-01), E6 Kvithammar – Åsen (in Norwegian), available at: https://docplayer.me/181468609-E6-kvithammar-asen-detaljregulering-jernbanekulvert-langstein-risikovurdering-rams-langstein-undergang-rapport-nr.html

Valipour, A., Yahaya, N., Md Noor, N., Kildiene, S., Sarvari, H. and Mardani, A. (2015), "A fuzzy analytic network process method for risk prioritization in freeway PPP projects: an Iranian case study", *Journal of Civil Engineering and Management*, Vol. 21 No. 7, pp. 933-947.

Van Os, A., Van Berkel, F., De Gilder, D., Van Dyck, C. and Groenewegen, P. (2015), "Project risk as identity threat: explaining the development and consequences of risk discourse in an infrastructure project", *International Journal of Project Management*, Elsevier, APM and IPMA. Vol. 33 No. 4, pp. 877-888.

Vegvesen, S. (2014), *Håndbok R764, Anslagmetoden (Handbook for the Stepwise Method)*, The Norwegian Public Road Authorities (Statens Vegvesen), Oslo, available at: http://www.vegvesen.no/Fag/Publikasjoner/Handboker (in Norwegian).

Vegvesen, S. (2021), *Rv. 706 Nydalsbrua med tilknytninger*, available at: https://www.vegvesen.no/vegprosjekter/riksveg/rv706nydalsbrua/ (accessed 05 May 2021).

Veidirektoratet (2011), "Veileder for usikkerhetsstyring", *Rapport, Veg- Og Transportavdelingen*, November, available at: http://folk.ntnu.no/drevland/PUS/Veileder_for_usikkerhetsstyring.pdf

Walker, D.H.T., Davis, P.R. and Stevenson, A. (2017), "Coping with uncertainty and ambiguity through team collaboration in infrastructure projects", *International Journal of Project*

Management, Elsevier and Association for Project Management and the International Project Management Association Vol. 35 No. 2, pp. 180-190.

Wang, T., Wang, S., Zhang, L., Huang, Z. and Li, Y. (2016), “A major infrastructure risk-assessment framework: application to a cross-sea route project in China”, *International Journal of Project Management*, Elsevier and Association for Project Management and the International Project Management Association Vol. 34 No. 7, pp. 1403-1415.

Wang, T., Gao, S., Liao, P., Ganbat, T. and Chen, J. (2021), “A stakeholder-based risk assessment and intervention framework for international construction projects: a meta-network perspective”, *International Journal of Managing Projects in Business*, Vol. 14 No. 2, pp. 345-368.

Ward, S. and Chapman, C. (2003), “Transforming project risk management into project uncertainty management”, *International Journal of Project Management*, Vol. 21 No. 2, pp. 97-105.

Wideman, R.M. (1992), *A Guide to Managing Project Risk and Opportunities*, Project Management Institute, Newton Square, PA, Vol. 1.

Winch, G.M. (2010), *Managing Construction Projects*, 2nd ed., Wiely-Blackwell, Singapoure.

Wuni, I.Y., Shen, G.Q. and Antwi-Afari, M.F. (2021), “Exploring the design risk factors for modular integrated construction projects”, *Construction Innovation*. doi: 10.1108/CI-02-2021-0025.

Xiahou, X., Li, K., Li, F., Zhang, Z., Li, Q. and Gao, Y. (2022), “Automatic identification and quantification of safety risks embedded in design stage: a BIM-enhanced approach”, *Journal of Civil Engineering and Management*, Vol. 28 No. 4, pp. 278-291.

Yin, R.K. (2018), *Case Study Research and Applications: Design and Methods*, 5th ed., SAGE, Los Angeles.

Zhou, M., Tang, Y., Jin, H., Zhang, B. and Sang, X. (2021), “A BIM-based identification and classification method of environmental risks in the design of Beijing subway”, *Journal of Civil Engineering and Management*, Vol. 27 No. 7, pp. 500-514.

Zidane, Y.J.-T., Johansen, A. and Ekambaram, A. (2013), “Megaprojects-Challenges and Lessons Learned”, *Procedia - Social and Behavioral Sciences*, Elsevier B.V., Vol. 74 May 2014, pp. 349-357.

Appendix
Summary of findings based on relevant criteria for two cases

Aspects	Case 1	Case 2
Human and organisations	• Risk ownership: contractor role was chromatic/consultant showed less participation. This criterion is defined in the contract. For instance, strategic-level uncertainties are owned by the owner • Workforce competency is satisfactory based on defined criteria (experience, track record and education) • Team member's role: Defined roles for uncertainty management (besides their primary role in the project team) based on the Anslag method but not dedicated just to UM • Effective communication: mostly between owner and contractor confirms their active role. Consultants have less participation, communication and involvement in UM process	• Risk ownership: owner and contractor both were active, but this criterion is mainly defined in the contract. Low level of ownership by consultants confirmed • Workforce competency: It was at a satisfactory level based on (experience and track record) • Team members' role: Defined roles for uncertainty management (besides their primary role in the project team) but not dedicated just to UM • Effective communication: High level of communication and information sharing based on collaboration level and contract type (collaborative)
Process	• The documentation level is high based on the guidelines of owners and interviews • Formal or informal: highly structured and following a formal process • Ability to support risk prioritisation/ assign resources to critical risks: process with the involvement of people in different positions, strategic and operational and facilitates the opportunity for prioritising risks • Usability: It is not easy to measure the usability of the process, but from a qualitative level, based on interviews was efficient and could support the project objective • Participants (owner, contractor and designer) collaboration level/ information exchange: In comparison with Case 2 has a low level of information exchange based on the contract type. Culture has an important role, such as the leadership and support of managers	• Documentation level: high level of documentation based on interviews and observing the system • Formal or informal: level of the formal process is less than Case 1, but they follow a structured process • Ability to support risk prioritisation/ assign resources to critical risks: Risks and opportunities were evident from the owner side, and better collaboration between actors facilitated this work • Usability: Same as Case 1, this measure could be confirmed by interviewees but not quantitatively. They mentioned that it could help avoid many risks and discover opportunities • Participants (owner, contractor and designer) collaboration level/ information exchange: Participants' collaboration level was significant compared to Case 1

(*continued*)

Aspects	Case 1	Case 2
Tools and techniques	• Complex or simple: Anslag method in Case 1 is flexible for complexity level according to the project's complexity level but working with it has some complexities base on the interviews. This complexity might reduce work efficiency • Precise or imprecise: Theoretically used tools had a good score in preciseness based on previous experience/but how much they help to reach for intended results in not measured • Resource demanding or less resource demanding: In comparison with the level of the total cost of the projects is not significant monetary. Still, the owner confirmed it needs much time and energy to calculate and estimate the uncertainty value • Visualisation capability: It is satisfactory based on an interview with the contractor, but in an interview with the owner, they mentioned it has room for improvement. From the document study of the tool, it is evident that the tool has a good level of visualisation • Documentation capability: Documentation is part of the process and tool (Anslag) in Case 1. Based on the document study, there are strict instructions for data documentation in the uncertainty management process according to owner guidelines	• Complex or simple: The tools used for uncertainty management are not as complex as in the first project. The interviewee did not mention the tool's difficulties or intricacy • Precise or imprecise: Theoretically used tools have a good score in preciseness based on previous experience/but how much they help to reach for intended results in not measured • Resource demanding or less resource demanding: In comparison with the level of the total cost of the projects is not significant • Visualisation capability: High level of visualisation capability based on observation of the web-based tools during an interview with the owner and contractors' confirmation • Documentation capability: Like visualisation, web-based tools improve documentation capability, which is high in Case 2

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