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Real option applications in megaproject planning: trends, relevance and research gaps. A literature review — Source link

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ABSTRACT

Abstract

Megaprojects are complex and contain multiple risks and uncertainties. The dominant ‘predict and control’ planning method mainly ignores risks and uncertainties, making megaprojects inflexible and vulnerable to unforeseen changes. Insights and methods from real options theory (ROT) in economics and finance have the potential to improve planning of megaprojects in three ways: (a) better management and assessment of risks and uncertainties, (b) a more transparent and explicit identification and communication of risks and uncertainties, and (c) a monetary valuation of flexibility. An in-depth literature review of 42 papers of real options applications to megaprojects serves as a benchmark to analyse if current real options literature meets these three expectations. Through this review, we identify the main trends, relevance and research gaps. While its theoretical relevance is illustrated, three main gaps impede real options’ practical relevance for megaprojects: the applications paint an incomplete picture of megaprojects; its mathematical complexity; and the lack of empirical evidence of real-life cases. Based on a plea for more interactive research between scholars and planning practitioners, we provide an agenda for further research as to how ROT can better meet its expectations and fulfill its potential for the planning of megaprojects.

1. Introduction

The planning of megaprojects is complex and characterized by multiple sources of uncertainty. To integrate uncertainty analysis within the evaluation of megaprojects, scholars have put significant attention to the real options theory (ROT) during the past two decades. ROT rose in the fields of finance and economics in the 1970s following increased criticism against static and inflexible methods used in investment decision-making, mainly the cost–benefit analysis (CBA). In a CBA, discounted future cash flows are calculated for an investment decision over a certain period. ROT scholars criticize this

method for not properly considering the impact of uncertainties that can alter these cash flows. These approaches often neglect the value of managerial flexibility to adapt to future changes (Trigeorgis, 1996).

ROT offers an alternative approach in which real options – relating to real assets – are valued throughout the decision-making process, so decision-makers can adapt to future changes by exercising the options they hold. With roots in finance, the potential of ROT is now increasingly explored in planning and design of construction projects, and in particular in megaprojects. 'Megaprojects are large-scale, complex ventures that typically cost US$1 billion or more, take many years to develop and build, involve multiple public and private stakeholders, are transformational, and impact millions of people' (Flyvbjerg, 2014, p. 6). Examples include hospitals, wind farms, large-scale signature architecture, or transport infrastructure (Flyvbjerg, 2014). Megaprojects' main challenges are its complexity and multiple uncertainties; planning for an uncertain future; and inaccurate forecasts and cost–benefit estimations.

In this paper, we focus specifically on real options applications in large transport infrastructure, generally the largest subcomponent of megaprojects. Transport infrastructure is a physical or tangible asset providing essential services and important for economic growth (Biatour et al., 2017). It encompasses roads, car parks, rails, ports (shipping), and airports. Transport infrastructure makes up the bulk of case studies and data sets in megaproject literature. Therefore, we use the term 'megaprojects' throughout this paper when discussing real options applications in large transport infrastructure projects.

We question '(I) how ROT is applied to megaprojects?', and '(II) to what extent these applications are solutions for the challenges megaprojects face?' Answering these research questions allows us to illustrate and facilitate real option's potential for megaprojects. We conducted a qualitative and in-depth literature review (Petticrew & Roberts, 2008) of 42 articles of real options applications to transport infrastructure projects. While overviews on ROT applications in transport infrastructure exist (Martins et al., 2015), our analysis of the literature aims to provide insight on the trends, relevance and gaps of ROT applications; with the aim to explore the potential of ROT as a method for adaptive planning in megaprojects.

The introductory subsections that follow provide a theoretical background of megaprojects' challenges and ROT. In Section 2, our method of an in-depth literature review is explained, followed by an overview of the results in Section 3, illustrating the main trends. In Section 4, we discuss the relevance and gaps of real options applications in megaprojects, by connecting the main trends to the challenges identified in megaprojects literature. We introduce areas for further research for closing existing research gaps so the relevance and

practical applicability of ROT for megaprojects could increase. The conclusion summarizes the main statements and contributions of this paper.

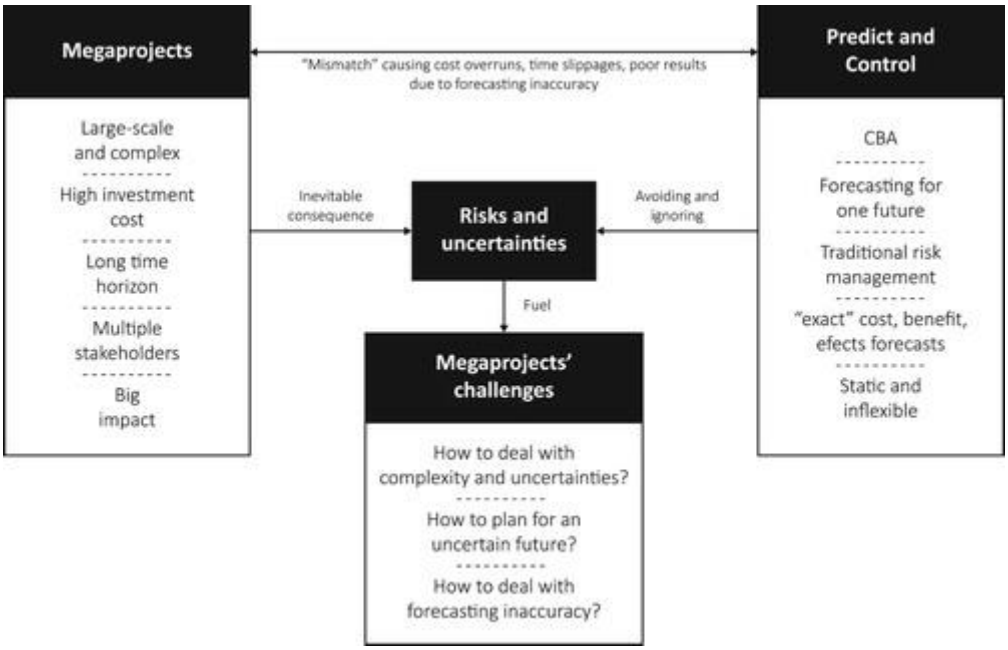
1.1. Megaprojects and their challenges

There is an abundance of literature covering megaprojects and their challenges (e.g. Flyvbjerg, 2017; Priemus & Van Wee, 2013; Priemus et al., 2008a). Megaprojects are complex, contain many uncertainties and are 'risk-rich'. The possibility for an unexpected turn of events makes it difficult to make plans and predictions for decades into the future, and to make (all) decisions at an early stage. This often leads to inaccurate forecasts about expected costs and benefits (Flyvbjerg et al., 2005). Frequently returning inaccurate forecasts lead to cost overruns and time slippages. Nine out of 10 projects have cost overruns (Flyvbjerg, 2014).

Explanations on cost overruns dominating megaproject literature are economic, psychological, or political in nature (Flyvbjerg et al., 2002). Optimism bias (psychological) means the initial costs are underestimated while the benefits are overestimated, because forecasters are overly optimistic, a form of self-deception or delusion (Flyvbjerg et al., 2009). Strategic misrepresentation (economic, political) implies that inaccurate forecasts are deliberately falsified through deception and lying to satisfy politicians and ease project approval (Flyvbjerg et al., 2009).

However, technical or methodological explanations for inaccurate forecasts are of equal importance. Many inaccurate forecasts, cost overruns and time slippages originate from the management method, rather than megaprojects' complexity itself. Despite the well-known history of inaccuracies, traditional but deficient methods are still widely used to manage the megaproject process, predict outcomes, and assess risks. Megaproject management is based on the dominant 'predict and control' approach (Koppenjan et al., 2011), attempting to reduce complexity. Costs and benefits are predicted in a CBA, which deals with only one possible future at a time, making it a static and inflexible method. CBAs often lack an incorporation of uncertainties, ignoring unforeseen changes and creating an illusion of certainty about the future (Beukers et al., 2012; Van Wee & Rietveld, 2013). Traditional risk management aims to push out risks and uncertainties through risk avoidance, risk reduction, or shifting risks to other parties (Bruzelius et al., 2002). The 'predict and control' method, therefore, leaves little room for adaptation (Giezen, 2013), making megaprojects inflexible and vulnerable to uncertainties. Figure 1 summarizes Megaprojects' characteristics, the predict and control approach, and megaprojects' challenges in a conceptual framework.

Figure 1. Megaprojects: characteristics, dominant approach and their challenges.



1.2. Real options theory

ROT offers an alternative addition to the inflexible 'predict and control' approach. The theory was a response to the dissatisfaction of academics, strategists and corporate practitioners with the traditional techniques of capital budgeting, more specifically CBA (Trigeorgis, 1996), with the articles of Black and Scholes (1973) and Myers (1977) as two important milestones. CBA works well for passive investments in bonds and stocks, but less so in strategic planning (Trigeorgis, 1996). Trigeorgis (1996) described this failure as 'their inability to properly recognize the value of active management in adapting to changing market conditions or properly capture strategic value' (p. 9).

ROT is applied to investment decisions that are irreversible, where there is uncertainty about the future benefits and/or costs of the decision, and where the decision-maker has a choice in the timing of the investment (Dixit & Pindyck, 1994). Analogue to financial options, opportunities to acquire real assets can be called 'real options' or 'flexibility options'. The name 'real options theory' refers to an approach involving real assets, projects, or physical objects, contrary to purely financial agreements such as stock options (Trigeorgis, 1996). The holder of the option can either exercise or 'kill' it by choosing to invest, or delay the investment and wait for new information to arrive that dissolves some, but not all uncertainty about future benefits that might affect the timing of the investment (Dixit & Pindyck, 1994). The holder of the option will only exercise or 'kill the option' when the value of the underlying asset is higher than its strike price. This option to wait has a value in itself, which increases the overall benefit of the investment decision. It is important to

understand that investing has an opportunity cost: If you invest, you lose the value of waiting. Because of this timing aspect, exercising an option is a right, not an obligation (Dixit & Pindyck, 1994). ROT not only calculates the value of holding options, but it also determines the optimal timing to exercise or 'kill' it.

1.2.1. Real options types

The different types of 'real options' form a crucial part of the theory. Based on the overview from Trigeorgis (1996), seven option types are defined:

- The option to delay an investment.
- The option to stage, which means an investment or megaproject can be divided into different phases.
- The option to scale, which is a built-in flexibility in the design or operations that allows a project to either expand or contract. For example, the option to construct extra lanes on reserved land next to a highway (design) or increase/decrease the frequency of trains on a rail line (operations).
- The option to abandon, which means stopping a project altogether, with the possibility to receive salvage value.
- The option to switch use, which allows for a change in functional use, for example, by allowing a change from road lanes to rail road infrastructure in the design.
- The option to shut down and restart, which implies operations can better be shut down for some time when the operational costs surpass the benefits, and restarted again once the benefits surpass the operational costs.
- Growth options, often present in R&D projects, which set the path for future opportunities by creating multiple future options. For example, acquiring a plot of land creates new options on how to use the acquired land.

While we refer to these as the 'classical real options', other forms of risk management in megaprojects can be modelled by a real options approach. Examples include contractual agreements such as renegotiation claims or risk mitigation measures (e.g. government guarantees, subsidies, etc.).

1.2.2. Real option valuation methods

There are different quantitative techniques for valuing options. We briefly explain the most common and important ones. The standard works of Dixit and

Pindyck (1994) and Trigeorgis (1996), as well as the overviews in Cheah and Garvin (2009) and Martins et al. (2015) provide a more extensive overview.

- The binomial option pricing model (BLM) is a 'tree-like model' and a simple representation of the evolution of an underlying asset, of which the value can only go up or down to two possible values. Multiple sequential periods result in a binomial tree with a large set of paths. Its main advantage is its simplicity, with values going two possible ways and the incorporation of only one uncertainty. However, this simplicity limits the use of the binomial tree in cases with multiple uncertainties (Martins et al., 2015).

- The decision tree analysis (DTA) is similar to the binomial tree model – a flowchart-like model representing a tree. It allows for infinite branches and thus more possible directions (options) a project could go, enabling it to better fit more complex problems and multiple uncertainties. Financial knowledge is required less as the probabilities of the different nodes of the branches could be approximate or relative valuations of flexibility and different options. Therefore, it lacks the provision of a project's true value. Another disadvantage is its possible complexity. When several branches are developed, the tree becomes more complex, difficult to read, and results too complicated to interpret (Martins et al., 2015).

- As opposed to the previous models, the Monte Carlo simulation (MCS) is a probability simulation model. Thousands or millions of simulations produce a probability distribution of different outcomes. It can incorporate multiple uncertainties and uses spreadsheet software, such as Microsoft Excel (Martins et al., 2015). It offers more precise and realistic results than the other two methods but is – despite available software – regarded as a more difficult and complex method.

- The three previous methods calculate the value of flexibility. Dynamic programming (DP) can be used to determine the optimal timing to exercise the option. It breaks the sequence of decisions in two: the immediate/initial decision, and a valuation function with consequences of all subsequent decisions (Dixit & Pindyck, 1994). By working backwards to the initial decision, values can be calculated for each scenario, identifying the best timing for exercising an option (Kozlova, 2017). This method can determine the optimal timing, but requires an understanding of advanced mathematical techniques (De Neufville et al., 2006).

1.2.3. Uncertainties and risks

Risks are defined as 'an uncertain event or condition that, if it occurs, has a positive or negative effect on a project's objectives' (PMI, 2008). Risks have a consequence and probability that can be determined with given data. With uncertainty, the probability of the outcome of an event is unknown or relative,

not exact. In both ROT and megaproject literature, risk and uncertainty are used interchangeable.

We can identify three main uncertainty types in real options literature. The first is market uncertainty, related to the costs and benefits of a project. An example is the demand uncertainty in transport infrastructure, where revenues of, for example, toll roads depend on how many cars use the toll road. The second type is technological uncertainty over the physical difficulty of completing a project, or the effectiveness of a new technology used in a project (Dixit & Pindyck, 1994). The third type is policy uncertainty concerning future policy regulations – for example, when the timing and level of certain taxes or subsidies are being discussed (Dixit & Pindyck, 1994).

1.3. Real options' potential for megaprojects

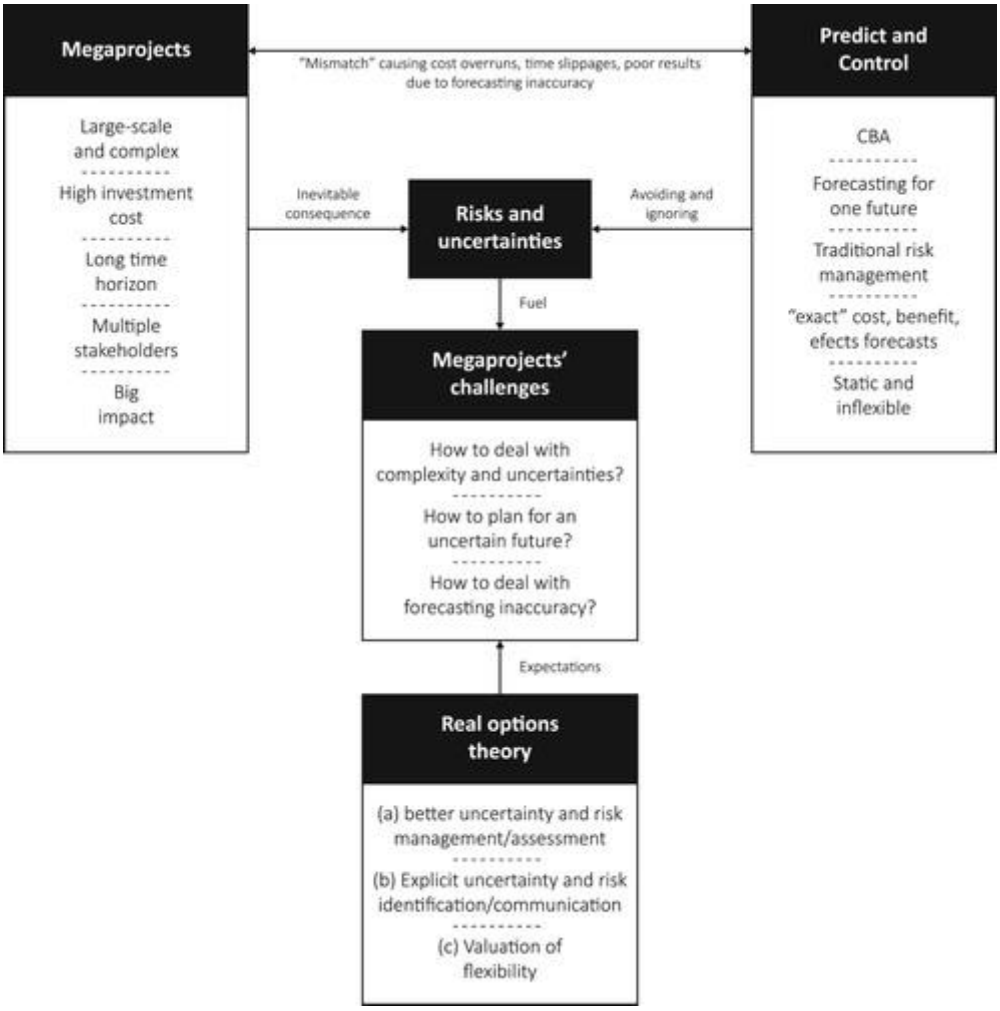
ROT removes the urge to make every decision at the start of a project, but offers an approach for built-in flexibilities (real options), giving the decision-maker the ability to better cope with uncertainties or risks and respond to circumstantial changes. Gathering information – albeit without ever reaching a state of complete certainty – creates the possibility to delay certain decisions and 'keep options alive'. How to cope with risk and uncertainty is an ever returning question in megaprojects (Priemus et al., 2008b), and flexibility or 'adaptive planning' in decision-making is strongly represented in megaproject literature:

It is very important to keep open as many options as possible so that unexpected surprises, new insights and changed circumstances can be tackled in a flexible way. During the preparation and elaboration of the mega-projects it is crucial to maintain many options, which give the opportunity, at least at a number of strategic moments to make choices: adapt to changing environments, changing insights and improved knowledge, changing the scope or changing the time planning. (Priemus, 2010, p. 1038)

We strongly believe ROT has the potential to aid and improve the quality of megaproject decision-making, as a tool for adaptive planning. Three arguments summarize this introduction and serve this premise, and allow us to extend the conceptual framework in Figure 2. (a) A real options approach allows for better risk and uncertainty management and assessment, instead of ignoring uncertainties, through more adaptive and flexible decision-making, addressing the limitations of the 'predict and control' model. (b) ROT is a tool for more transparent and explicit identification and communication of risks and uncertainties. (c) ROT is a predominantly quantitative approach that could be used as a tool to formally evaluate flexibility options and quantify their value. In current megaproject decision-making, the value of flexibility is absent from forecasting and cost and benefit estimations, and thus not considered. We consider these three points the main expectations of ROT for megaprojects,

for which the in-depth literature review serves as a benchmark to analyse to what extent current trends in real option applications meet these expectations.

Figure 2. ROT and megaprojects, conceptual framework.



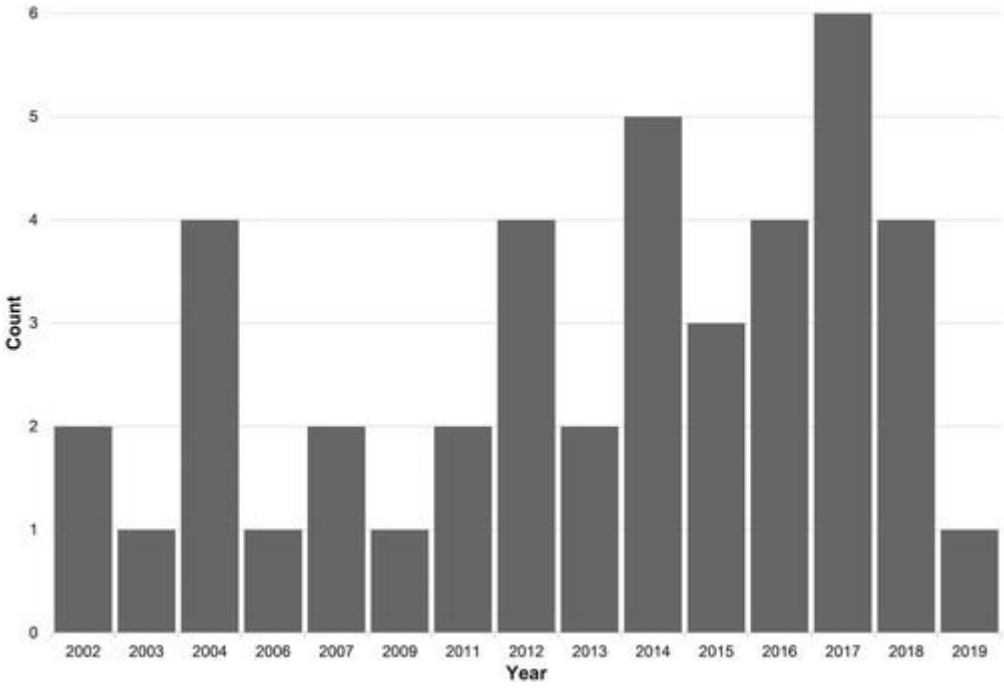
Note that the real options theory's potential is not limited to megaprojects. However, the paper focuses on megaprojects only because of the strongly developed theories in planning literature regarding this subject. Furthermore, nearly all references found in the current literature on real options and transport infrastructure applied to large transport infrastructure projects.

2. Methodology

Articles were collected for the in-depth literature review in which ROT is applied to megaprojects, specifically transport infrastructure projects. 'Web of Science' was our main search engine. We used the term 'real option*' in combination with 'megaproject', 'infrastructure', 'transport infrastructure', 'project management', 'road/rail/port/airport infrastructure' as topics or parts of

the title. The result was a total of about 425 articles, with duplicates in the results of multiple search combinations. The initial results were further refined by reading the abstracts of the articles, resulting in a selection of 31 articles. The search was then extended with references from the initially obtained articles and searches in Google Scholar using the same search terms. The final selection contains 42 articles published between 2002 and 2019. Figure 3 shows that over half of the reviewed papers were published between 2014 and 2019. Therefore, they have not been a part of earlier overview/review articles (e.g. Martins et al., 2015). It illustrates the increased attention for infrastructure from real options scholars, or vice versa for real options from infrastructure scholars; and justifies the added value of this review paper.

Figure 3. Reviewed papers, publication date.



The review itself was conducted by answering the following six questions (Qs):

- Q1. What is the main research objective of the authors in the reviewed articles?
- Q2. To which type of transport infrastructure do the authors apply the ROT?
- Q3. Are these case studies hypothetical, ex post evaluations or part of an ongoing or future project?
- Q4. Which uncertainties and risks are considered and modelled in the real options application?

- Q5. Which real options are applied, and which built-in flexibilities are introduced in these applications?
- Q6. Which valuation models or methods are used in the applications?

The answers to the six questions were processed in an Excel spreadsheet, in which descriptive analyses were performed to identify the main trends. The supplemental data of this paper provides an overview table summarizing the reviewed papers. Where possible, we refer in the tables of the results section to the numbered references in the supplemental data. It was impossible to discuss all 42 reviewed articles.

3. Results

3.1. Research objectives (Q1)

Four (I–IV) research objectives can be identified in the reviewed articles (Table 1). Real options are applied to case studies with the goal of displaying the benefits through (numerical) illustrations of ROT in three ways. (I) Quantitatively valuing flexibility (VF) allows to compare project values with or without flexibility options. (II) Some proceed further and determine the optimal timing (OT) of exercising the option, and how the threshold for optimal timing is affected by uncertainties. For instance, Couto et al. (2015) determine the optimal demand level for investing in a high-speed rail project in Portugal. (III) Other authors developed new quantitative real option models to fit a specific case type, often focusing on instruments or contractual agreements for risk mitigation (RM) that fall outside the group of 'classic' real options. Mirzadeh and Birgisson (2016) develop a real options model for the valuation of PACs – price adjustment clauses to protect contractors from increasing material or fuel prices during the construction of roads.

Table 1. Research objectives in ROs applications (Q1).

Aside from displaying real options' potential, (IV) the articles propose ROT through a case study example as a valuable decision-making method for policy makers, project managers, or other actors involved in project management. They stress its practical relevance (PR). Buyukyoran and Gundes (2018) presented a model determining the lower and upper boundaries (values) of, respectively, a minimum revenue guarantee (MRG) and a maximum revenue cap (MRC) in concession contracts. They concluded that the public and private sector could use this model to test the effect of MRG and MRC on project value. Most articles take a private or public-private, profit maximizing perspective and do not take into account external costs like congestion or socio-environmental impacts.

While these articles succeed to illustrate the benefits of valuing real options through quantitative results, empirical evidence to support research results lacks in the reviewed papers.

3.2. Case types (Q2–3)

Table 2 shows that road infrastructure is the most popular case type (25 out of 40), especially toll roads (18 cases). Toll roads are a textbook example of public–private partnerships (PPPs) in transport infrastructure. In PPPs, proper risk allocation between public and private actors is crucial for a project's success, and therefore real options analysis is a valuable approach, as it integrates uncertainty and allows for the evaluation of different risk hedging mechanisms. Other transport infrastructure projects covered include (high-speed) rail cases (10) – including one subway and one metro line project – airports (4), car parking garages (2), and one container terminal case (port).

Table 2. Transport infrastructure types and application type (Q2/Q3).

Twelve of these articles apply ROT to a hypothetical case study (Table 2). Hypothetical means there is no reference to an actual project, nor the use of data from an actual project. Zhao et al. (2004) apply a real options model to a hypothetical 50-mile long highway section in the US to argue how decision-making optimality can be achieved. Similar to this example, others use data from actual settings but not projects for their hypothetical cases (e.g. discount rate in a specific country).

As for actual cases or projects, 24 articles are an ex post evaluation of existing projects, looking back at cases and using these to illustrate how these projects could have been developed or managed through a real options approach. In other words, these projects have not been developed, managed, or valuated from a real options viewpoint in reality, but serve as illustrations for real option models. Martins et al. (2017) compare the values of the original terminal container expansion project in Ferol (Spain) without flexibility, with their adjusted case that includes the flexibility option to expand the port in different phases to avoid overcapacity. These articles have some overlap with hypothetical case studies, since ex post additions or adjustments to projects could be interpreted as hypothetical. In addition, sometimes hypothetical data is used if certain data for these projects is unavailable. However, we regard them as ex post evaluations because they still refer to existing projects.

Only six cases discuss or have direct links with ongoing or existing projects wherein important decisions still have to be made. Four articles discuss the value of a real options application for decision-making on future airport expansion through flexible strategies (e.g, Martins et al., 2014). Another example is the article by Fawcett et al. (2015), which is part of a collaborative European research project (CILECCTA) on the application of ROT for software

creation to evaluate the impact of flexible and responsive strategies for highways.

3.3. Uncertainty sources (Q4)

Based upon Dixit and Pindyck (1994), we distinguished three uncertainty types: market, technological, and policy uncertainty. Market uncertainty – mainly transport demand – dominates the results and is present in 39 of the 42 reviewed articles (Table 3). Private, profit-maximizing firms need to understand how to protect themselves from demand volatility when they must decide on building a new bridge, (toll) road, rail line, or expanding an airport. Martins et al. (2014) apply the option to stage to the New Lisbon Airport for Low Cost Carriers. They argue that by incorporating the flexibility option to stage the design in different phases, the project is better adapted to future changes of market uncertainty in the form of passenger traffic evolution.

Table 3. Uncertainty types and sources in ROs applications (Q4).

Technological uncertainty – the performance or possible difficulties for completing construction of a system or project, or uncertain effectiveness of new technology – is less frequent (four articles), and if present, possibly in combination with market uncertainty (two of four articles).

Most articles (33) implement one uncertainty source in their real option application model (Table 4). This leads to ‘less complex’ and ‘more manageable’ valuation methods or possible applications of ROT. Real option valuation models can become very complex real quick, and simplifying applications to one uncertainty source is a deliberate methodological choice. Market uncertainty is often the first choice, since this is a crucial element in the success or failure of not only transport infrastructure, but megaprojects in general. Another explanation could be that, beside some exceptions, one of the objectives of most articles is to prove the value of ROT for more accurate decision-making. Reducing the model’s complexity then helps to increase the transparency or understanding of real options applications’ results.

Table 4. Number of uncertainty sources in ROs applications (Q4).

Thijssen (2015) is one of the few who incorporates two different uncertainty types in his model. He illustrates that the project value and the optimal timing to invest is affected by both revenue uncertainties or demand (MU), and uncertainties or possible delays in the construction phase (TU).

Despite the clear distinction between three different uncertainty types in ROT literature (e.g. Dixit & Pindyck, 1994), none of the reviewed papers consider policy uncertainty.

3.4. Real options applied (Q5)

The three most applied 'classic' real options are the options to delay (12), scale (8) – expand or contract – and abandon (6) (Table 5). For example, Wooldridge et al. (2002) examine the option to delay an investment decision to build a highway, based on an ex post evaluation of the Dull Toll Road in Virginia, which was constructed between 1993 and 1995. Less frequently used are the growth option (two), the option to switch use (one), and the option to stage (one). Martins et al. (2014), for example, show that a flexible design leads to a more modular or phased airport expansion (option to stage). This facilitates an adaptive approach in response to changing demand or market conditions, thus avoiding overcapacity when expanding in one phase.

Table 5. Real options used in applications (Q5).

Beyond the 'classic' real options described by Trigeorgis (1996), in 17 papers, researchers also interpret other forms of case-specific built-in flexibilities as real options, which can be modelled and valued through a real options approach. Xiong and Zhang (2016) apply a real options model to capture the value of (contract) renegotiations. They interpret renegotiations as a real option for which a claim to renegotiate contract terms can be raised with flexibility in timing during the operational phase of a toll road by either the concessionaire or the government. Another example are different risk mitigation instruments. For example, Brandão et al. (2012) apply a real options model to the São Paulo Metro Line 4 extension. To make PPPs more attractive for private actors, they incorporate government guarantees for minimal demand in the contract. The government will financially compensate the private actors operating the infrastructure when demand or profit drops below a predetermined level. Risk mitigation measures are an important part of megaprojects, especially when balancing risks between public and private actors in PPPs. The reviewed papers show that properly calculating their value can be done with ROT.

Only a small number of articles (five) looks at multiple embedded real options and their interactions (Table 6). Bowe and Lee (2004) combine the options to delay, expand and contract in their real option model for the Taiwan high-speed rail project. They examine the interactions between these options rather than valuing them individually. Similar to the uncertainty sources, most articles (37) only use one real option. However, the few examples like Bowe and Lee (2004) illustrate the value of researching multiple embedded real options.

Table 6. Number of real options in applications (Q5).

3.5. Application models and methods (Q6)

In a minority of cases, a descriptive or qualitative approach is adopted, without calculations and valuation models (Table 7). Cheah and Garvin (2009) used the Texas High-Speed Rail project in the early 1990s as an illustrative example demonstrating the possibilities of ROT. When, as in most cases, a quantitative method is used, the Monte Carlo simulation (18) and the binomial lattice method (13) are most frequent. The use of an MCS is often combined with one of the 'tree-like' models. A sensitivity analysis to test the robustness of the results was performed in seven articles. When determining the optimal timing of exercising an option is the research objectives – as illustrated in Table 1 – the mathematically advanced technique of dynamic programming is used. Other less frequent occurring methods are adaptions of the original Black–Scholes method, the inclusion of game theory, the system dynamics model and dynamic adaptive policies. Elaborating on these methods is beyond the scope of this paper. Different methods can be used in similar applications. Therefore, it remains hard to tell which valuation method is more suitable for which application type.

Table 7. Valuation methods in ROs applications (Q6).

Contrary to descriptive cases, a quantitative approach makes it possible to compare the net present values of projects with or without flexibility, and in some articles determine the optimal timing of a decision. Opting for the quantitative approach offers numerical results, but significantly increases complexity and the mathematical requirements for decision-makers and project managers (Garvin & Ford, 2012). The qualitative descriptive method is easier to understand but lacks numerical evidence or valuations to strengthen its case (Cheah & Garvin, 2009).

4. Relevance and research gaps for real options integration in megaproject practices

We analyse to what extent these trends are solutions for megaprojects' challenges, and meet the expectations from real option's theory for megaprojects: (a) better risk and uncertainty management and assessment; (b) transparent and explicit uncertainty identification and communication; and (c) valuing flexibility (quantitatively). In relation to megaproject literature, this allows us to stress its relevance, identify research gaps for the integration of ROT in megaproject planning practices, and define areas for further research.

4.1. Relevance of real options theory to megaprojects

a. *Better uncertainty management and assessment*. The reviewed papers first of all reflect the objective ROT shares with recent megaproject literature. Uncertainty and complexity are increasingly recognized by planning researchers, resulting in different streams – e.g. adaptive planning (Giezen, 2013) and scenario planning (Chakraborty & McMillan, 2015) – each advocating a proactive identification and management of uncertainties. It has been argued that simplification and ignoring uncertainties limit the possibility of adapting to changes in context, and thus dealing with unforeseen future changes (Giezen et al., 2015). With ROT, megaprojects have a tool that forces you to assess and manage uncertainties; one that specifically focusses on the deficiencies of conventional decision support tools such as the CBA. The higher the uncertainty, the higher real option's relevance becomes (Couto et al., 2015).

b. *Explicit uncertainty identification and communication*. Identifying uncertainties is an important prerequisite for adaptive planning. You can only be adaptive once you know which uncertainty sources or future scenarios you want to be adaptive for. While the strength of ROT is the provision of quantitative results, the reviewed papers also illustrate the importance of the process towards these results itself. Identifying, describing and modelling the uncertainty in applications is an important part of the real options model. Understanding or applying ROT requires the identification of uncertainty sources. ROT can strengthen adaptive planning by increasing the attention for uncertainty identification. The regular use of real options could lead to an increased description and expanded perception of uncertainties (Ford et al., 2002).

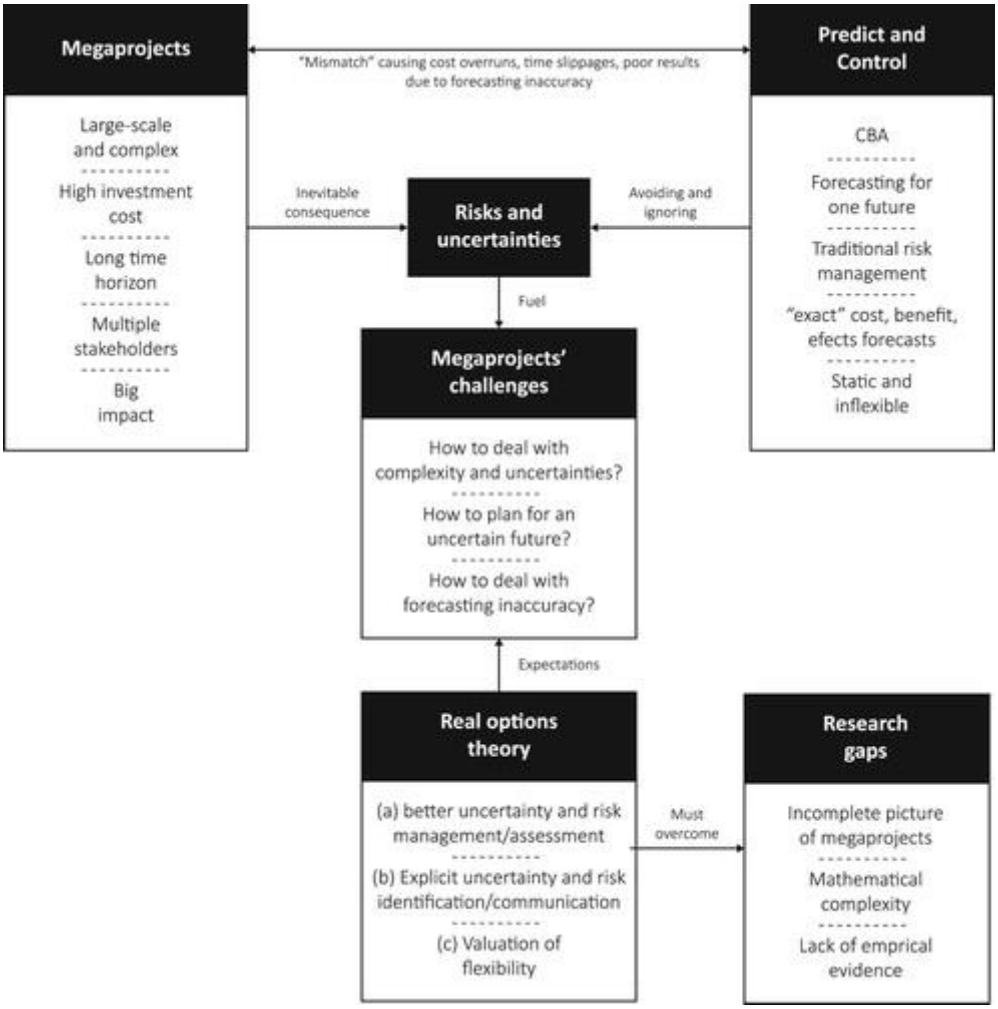
c. *Valuing flexibility*. What ROT adds to existing concepts of adaptive planning in megaproject literature is its possibility for valuing flexibility. The quantitative results in the reviewed papers support the idea of adaptive planning by providing numerical results. This illustrates the advantage of valuing flexibility over valuing projects without taking into account uncertainties. Uncertainty and flexibility then become less vague terms once they are given a quantifiable face, increasing the relevance and added value of ROT for megaprojects.

The relevance of real options for megaprojects. ROT thinking and modelling in megaprojects could help facilitate a shift from the dominant but unrealistic premise that we can exactly predict and forecast the future, to the more realistic premise that we should accept an uncertain future. In the 'predict and control' model, there is an overall aim to improve and increase the exactness of estimations on costs, benefits, forecasts and effects. While it can only be encouraged to improve forecasting methods, an overemphasis on 'exact'

estimations has resulted in a lack of incorporating uncertainties in tools such as a CBA (Beukers et al., 2012; Nicolaisen, 2012). ROT and adaptive planning do not simply try to improve forecasting accuracy, but want offer an approach to manage uncertainties through flexibility – if such options exist. ROT does not try to tell what will happen, but rather what could happen.

Despite its relevance, gaps impede its applicability in planning practices and megaproject decision-making today, which are included in a further extension of the conceptual framework in Figure 4.

Figure 4. ROT and megaprojects, conceptual framework and research gaps.



4.2. Research gaps of real options theory for megaprojects

An incomplete picture of megaprojects. As illustrated in the main trends, mostly one uncertainty source – often market (demand) uncertainty – and one real option or risk mitigation instrument are considered. Technological uncertainty is underrepresented and policy uncertainty completely absent in the applications. Planning literature offers multiple and more extensive

classifications of uncertainties and risks in megaprojects, emphasizing the presence of different and possibly interacting uncertainty sources. Table 8 provides a non-exhaustive overview of such classifications. The dominance of demand uncertainty in real option applications relates to an emphasis on (private) profit maximization. However, without comparable uncertainty assessments of different types of uncertainty within one megaproject, the dominance of market uncertainty does not mean market uncertainty is the most important uncertainty source in every case. Technological and policy uncertainty are underrepresented, but equally important, depending on the megaproject, and should thus receive equal academic attention.

Table 8. Uncertainty and risk classifications.

Furthermore, real options applications to transport infrastructure ignore uncertainties and flexibility options that relate to the positive or negative socio-environmental effects of projects, presenting an incomplete picture of the complexity of megaprojects. Trigeorgis (1996) noted more than 20 years ago that 'Despite its enormous theoretical contribution, the earlier literature is of limited practical value because it focuses on valuing individual real options. Real-life projects are often more complex in that they involve a collection of multiple real options, whose values may interact' (p. 19). The results show this statement is not outdated and still holds for recent real option literature on transport infrastructure and megaprojects.

Mathematical complexity. Narrowing down applications to one uncertainty and flexibility option is related to the mathematical complexity of real option valuation models. Grimes (2011) noted that while the intuition behind the ROT is straight-forward, the mathematics are complex. Critics are quick to say the real options field is mathematically elegant, but hardly useful in practice due to a lack of skills and understanding of the models (Cheah & Garvin, 2009). Education is necessary and the mathematical complexity limits the accessibility for average decision-makers (Garvin & Ford, 2012). Due to the variety of valuation approaches, it is unclear which one is the best in which case or situation (Cheah & Garvin, 2009). As long as a practical real options toolkit or hands on real options approach to assist project managers and decision-makers is missing (Herder et al., 2011), decision-makers will prefer the 'easy road' and keep using the conventional approach (Garvin & Ford, 2012). Decision-makers in megaproject management are bounded rational (Simon, 1997); existing procedures, norms, and legislation are difficult to change and often exclude more advanced approaches in CBA calculation. A toolkit could be a practical guide that helps decision-makers or planners determine how their specific project might benefit from the adoption of ROT, or which valuation method is best suited for a specific case. A toolkit including best-practice examples and empirical evidence could encourage policy makers and planners to adopt an real options based adaptive management approach in megaproject decision-making.

Lack of empirical evidence and good practices. Unfortunately, while the main trends help to understand the relevance of ROT, they painfully expose lacking evidence on how this theory could be integrated in the planning, design and decision-making of actual megaprojects. The results do not allow us to conclude whether or not ROT actually has an impact on decision-making, to what extent or how it is used in planning practices today. As a consequence, real options applications currently raise more questions than answers about how to incorporate ROT in existing megaproject practice. The practical possibilities of real options theory are not clear without empirical evidence and best-practice examples. For example, does an optimal real options approach for public megaprojects differs from one for public–private partnerships; or how can flexibility through real options in megaprojects be harmonized with procurement rules require that steady contracts to guarantee legal certainty; or how should ROT be applied in different megaproject phases (e.g. exploration, planning, design, implementation, operation)? These are just a few examples of important future research questions for which empirical evidence is currently missing.

4.3. Areas for future research

Given the theoretically proven potential of ROT for megaprojects, research should focus on how its relevance can be practically illustrated. We need to look for ways to overcome existing gaps, so ROT can better meet its expectations and fulfill its potential for megaprojects. For this, we believe the main starting point for further research should be to interact more with planning practitioners and decision-makers in megaprojects, and that the process of interaction should be documented in publications. The interactive process of applying ROT is equally important as the (quantitative) results. Real options thinking alone – valuations aside – can already extend uncertainty identification and communication, along with the generation of project flexibility (Cheah & Garvin, 2009). Valuing flexibility remains an important point of relevance, but in-between ‘baby-steps’, including qualitative case studies, are required to increase our knowledge on real options integration in megaproject practice.

Furthermore, interactive research and documenting the process of applying real options in actual megaprojects allows to identify opportunities and obstacles in existing planning legislation, procedures and instruments for the inclusion of real options or flexibility as an official assessment criterion. Planning legislation in most developed countries consists of rigid and sequential planning procedures that require decisions to be made early on, leaving little room for flexibility. Furthermore, the rational planning model is permeated by a culture of recurrent and more irrational elements such as: time pressure to make decisions (Gil, 2017); optimism bias, strategic misrepresentation or strategic behaviour (Flyvbjerg et al., 2009); power relations; lock-inn leading to inflexibility and closure of alternatives (Cantarelli

et al., 2010); consensus-building between multiple stakeholders (Winch, 2017). In this chaos of complexity, simplification is preferred. Our current planning frameworks are not designed to properly take into account uncertainty and integrate flexibility as an official evaluation and assessment criterion.

We believe this review paper has raised the following research questions that should be added to the research agenda of those interested in uncertainty, risk and flexibility, or applying real options in megaprojects:

1. How do we identify uncertainties collaboratively and reach a consensus on which uncertainties are important and how they should be further assessed, modelled, and managed, given the context of multiple uncertainties in megaprojects?

2. Following this, how to communicate the impact and possible consequences of the uncertainties modelled in a transparent, more explicit and understandable way to a broad range of megaproject stakeholders?

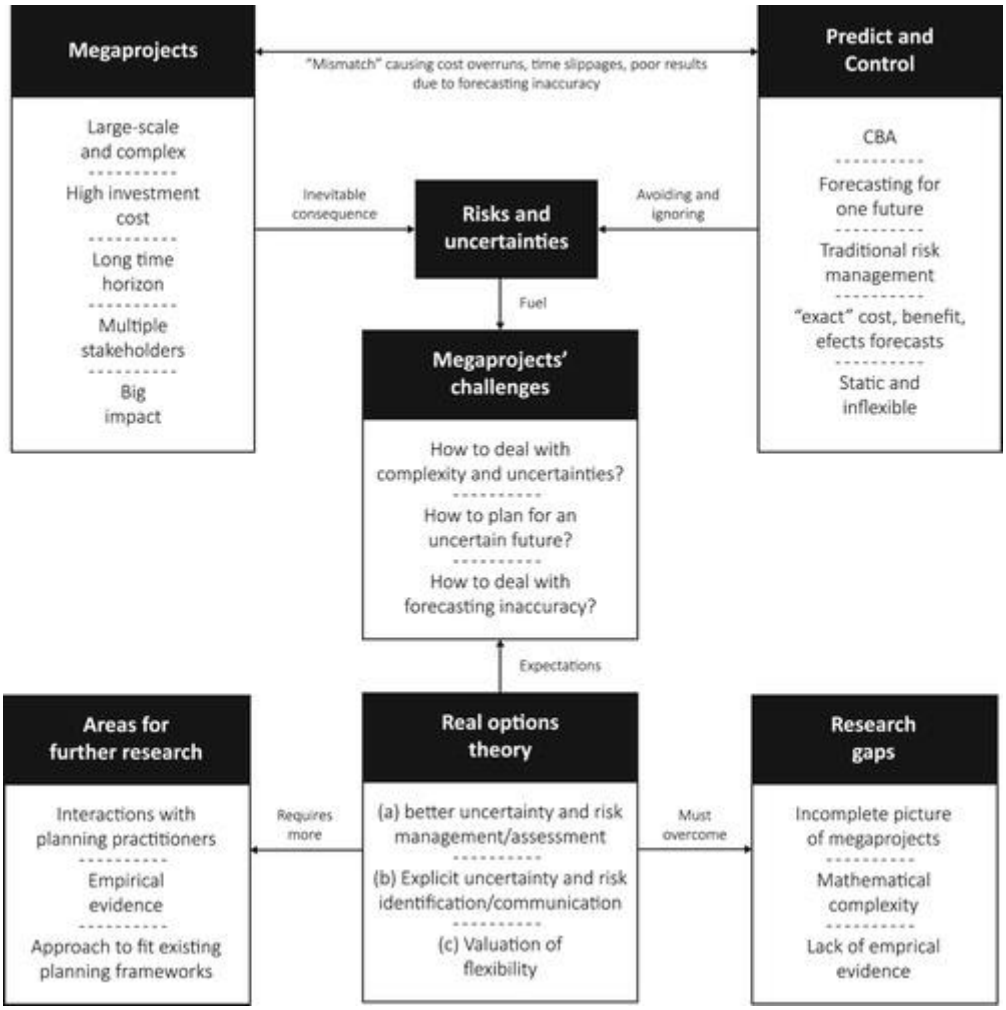
3. How to adapt, use or communicate existing valuation methods to address the issue of mathematical complexity? Are qualitative or intuitive flexibility values a first step towards quantifying flexibility in a more accessible way?

4. How can ROT fit within existing planning frameworks, and to what extent can a 'toolkit' facilitate a shift towards a more adaptive planning, making flexibility a decision-making criterion in megaprojects?

Questions one and two are directed at expectations (a) and (b), question three at expectation (c). Question four aims to encourage more awareness of the complex planning conditions and context in which real options are applied, acknowledging the diverse possibilities of applications regarding, for example, different megaproject types, phases and procurement methods.

To sum up, future research should focus on how ROT can actually improve and contribute to decision-making in megaprojects. For this, more empirical evidence is needed which should be achieved through interactive research with the field of planning. We understand its relevance, but we do not yet know how to capture its value in practice, and how ROT can meet its three expectations. This research agenda is added to the conceptual framework as shown in Figure 5.

Figure 5. Conceptual framework: ROT and megaprojects, relevance and research gaps.



5. Conclusion

Megaprojects have received increased attention from ROT scholars. Our first objective was to identify and illustrate the main trends of the increasing number of real options applications to transport infrastructure, for which we conducted a literature review with 42 articles. ROT clearly has relevance and potential for implementation in megaproject planning practices, through its (a) improved assessment and management of uncertainties and risks, its (b) emphasis on identification and communication of uncertainties; and (c) its value of quantifying the value of flexibility. This could cause a shift towards a more realistic planning 'climate' in which we acknowledge an uncertain future to enable planning and designing flexible responses and strategies.

Significant gaps for further implementation in practice impede its relevance. Current applications of the ROT consider real options as a methodological tool to integrate uncertainty and put a value on flexibility. These applications do not cover the full complexity of megaprojects due to methodological choices and

mathematical complexity. More importantly, most papers lack to discuss how the ROT can be practically implemented in current megaproject practice. We argue that to embed ROT into planning practice, ROT should not be merely used as a tool, but its features (irreversibility, uncertainty, and flexibility) should be stepwise discussed, analysed, and communicated, during the different phases of megaprojects. Hence, future research should focus on how to apply ROT – not as a tool – but as a strategy for adaptive project management. Research in interaction with planning experts and practitioners could help to offer insights on how to develop a toolkit to aid and improve dealing with uncertainties through flexibility in the planning, design and decision-making of megaprojects.

Its relevance has been theoretically proven. The time has come to broaden our research scope and figure out how to translate theory into practice through interaction with the field of planning and megaprojects. The research gaps can only be addressed by working in close collaboration with decision-makers and practitioners. For current planning practices, such participatory research will allow for the explicit acknowledgement of the importance of uncertainty identification, communication and assessment. Furthermore, embracing a flexible approach could have major policy implications. When taking into account uncertainty and flexibility values, decision-makers and planning policy must open up for possible changes to existing planning frameworks, legislation, rules, procedures and practices.

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