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What are the cost drivers of infrastructure projects? Definition, classification, and conceptualisation

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Abstract

Reducing cost is a critical objective for project teams. However, unlike the research on topics such as cost overruns, cost reduction literature is limited. Previous studies have primarily examined cost estimation/reduction models or high-level cost reduction strategies. Therefore, it is necessary to identify specific actions that project teams can take to reduce cost. By focusing on the "cost drivers" of infrastructure projects, researchers have a practically relevant lens through which cost reduction can be promoted and studied. Thus, this integrative literature review establishes a foundation for infrastructure project cost drivers knowledge, addressing three research questions revolving around deriving a definition, classification scheme, and conceptual framework of cost drivers. This paper first produces a definition of cost drivers by critically analysing cost drivers concepts/perspectives and existing definitions. Second, cost drivers were drawn from relevant articles and classified to produce a taxonomy of 14 key cost drivers. Third, a conceptual framework (two-by-two matrix) of cost driver types was developed to acknowledge the influence project teams can have. Finally, a research agenda proposes further investigation in cost drivers/reduction research regarding each cost driver, apt research methods, and necessary project contexts. This paper's theoretical contribution is a deepening of infrastructure project cost drivers knowledge using a definition, taxonomy, and conceptual framework. The practical contribution is a

deepened awareness of the key opportunities for – and threats to – cost reduction for project teams, as well as a knowledge of those cost drivers that they actually have an influence over, i.e., to reduce their project's cost.

1 Introduction and background

Cost reduction is important for infrastructure project stakeholders. Privately funded infrastructure projects (e.g., railways, energy generation, etc.) must be delivered cost-effectively as for investors to get a return on investment and to create value for shareholders. For publicly funded infrastructure projects, a return on investment is not always possible (e.g., bridges or roads without tolls), and thus public bodies must be able to reduce costs "*to ensure that taxpayers and consumers get more for less*" (HM Treasury 2014 p. 3), i.e., value for money for the public. In the UK, for instance, the infrastructure cost initiative aimed to reduce the delivery cost of the UK's infrastructure project portfolio with a focus on pre-execution improvements (HM Treasury 2014; HM Treasury and Infrastructure UK 2010a; b). These reports highlighted several cost reduction strategies including effective governance, improved infrastructure pipeline visibility and certainty, increased front-end definition, and whole life planning, which were effectively implemented. However, for projects with greater complexity, uncertainty, and novelty, implementing these measures is extremely challenging (Loch et al. 2006).

Nuclear decommissioning projects are an example of these extremely complex projects for which existing cost reduction measures are inadequate. Particularly in the UK, cost reduction in these projects is a major ongoing issue; £135.8 billion (approx. US$169 billion) of public money is estimated to be spent to decommission the 17 historic nuclear "legacy" sites over the next 116 years, with the vast majority of this activity taking place at the Sellafield site (NDA 2020, 2021). A great deal of the complexity and uncertainty – and consequently the cost and schedule – of these projects comes from lack of planning for decommissioning when these sites were originally constructed in the mid-20th century (GOV.UK 2019), not least the requirement to deal with vast quantities of radioactive material (OECD/NEA 2016). The cost forecast has risen considerably since the Nuclear Decommissioning Authority (NDA) was established in 2005 to tackle the programme, the reasons for this being more realistic estimates and increased scope definition. However, although cost certainty is improving, cost reduction to deliver these projects remains difficult. This emphasises the need for project teams to identify innovative cost reduction processes/practices.

Popular topics in the realm of cost reduction in project/construction management literature tend to be primarily focused on reducing cost overruns or cost estimation inaccuracy, through analysing either the human-based determinants (e.g., Flyvbjerg et al. 2002; Ika et al. 2020; Love et al. 2012; Reichelt and Lyneis 1999; Torp and Klakegg 2016) or external considerations that lead to or correlate with overruns/inaccuracies, such as location (e.g., Migliaccio et al. 2013; Zhang et al. 2014). In contrast, studies with a primary focus on cost reduction are limited. The majority of these studies focus on linking organisational level processes or cost estimation tools with reduced cost. For instance, Building Information Modelling (BIM) is often cited as being positively correlated with cost reduction and control in projects (Bryde et al. 2013; Sepasgozar et al. 2022), as is prefabricated construction (e.g., Liu et al. 2022; Mostafa et al. 2020) and blockchain technology (Qian and Papadonikolaki 2021). As Olawale and Sun (2015 p. 624) acknowledge, most studies in the realm of cost and/or schedule reduction are on the quantitative models side, aiming to better their ease of use in practice. This is supported by Bilge and Yaman's (2022) recent review, which emphasised schedule and cost optimisation (i.e., models) as one of the biggest construction management research trends of the past 20 years. Indeed, these digital tool approaches to cost reduction have proven to be of considerable benefit in industry and are paramount in this sustainability conscious age (Forbes 2023). Therefore, the above deductively driven studies are used to highlight this.

Conversely, inductive studies have been conducted to identify the cost reduction actions of project teams, though they are less common. Bayraktar et al.'s (2011) multiple-case study revealed 23 factors that facilitate cost and schedule reduction, as gathered from literature, questionnaires, and interviews with project team members from five projects delivered underbudget and early. Olawale and Sun (2010) identified the top factors that impede the ability to reduce cost and subsequently produced 90 processes/practices employed by project teams to offset these, with Gharaibeh (2014) furthering this in a megaproject context by producing problems, solutions, and lessons learned in cost reduction from two megaprojects. These studies agree that front-end definition and good relationships and communication between parties are amongst the most effective cost reduction processes.

Extant cost reduction research is thus ontologically driven; it primarily answers the questions of what high-level strategies correlate with reduced costs. In contrast, identification of the project-level processes that reduce cost are far less common, having only had notable contributions from the abovementioned articles. Moreover, the questions of how project teams actively "do" cost reduction is lacking, i.e., the practices (Blomquist et al. 2010; Hällgren and Söderholm 2012). Therefore, cost reduction research has, regardless of being inductive or deductive, been focused mainly on the flow of organisational level process rather than on project-level processes and more particularly the practices where cost reduction activities actually occur.

To develop cost reduction research, a more ubiquitous emphasis on the main cost reduction opportunities/threats is required; these can be suitably understood by examining the "cost drivers". Using cost drivers as a lens through which cost reduction processes/practices can be studied can ultimately better the knowledge and implementation of those employed by project team members. Despite these benefits, the absence of sensemaking literature has ensued a lack of understanding and clarity of this subject. Early development of cost drivers research in the mid-to-late-2000s focused on improving cost estimation in building construction projects (Lowe et al. 2006; Stoy et al. 2008; Stoy and Schalcher 2007). Through the mid-2010s, perspectives ventured into other sectors, such as tunnelling (Membah and Asa 2015) and highways (Collier et al. 2016). More recently, the literature diversified, looking at normative studies on improving cost estimation (Elmousalami 2020) as well as offshore wind farm decommissioning projects (Adedipe and Shafiee 2021). Cost drivers have also been explored in grey literature published for practitioners (e.g., Efron and Read 2012; OECD/NEA 2003).

Remarkably, however, literature lacks a shared definition of cost drivers. Moreover, the cost drivers of projects are scattered across the literature since those outputted by these studies are project-specific; a classification of infrastructure project cost drivers (i.e., a "macro-level" project context) is missing. A further consequence of these omissions is that conceptual development of the topic is also absent. Therefore, adopting the integrative literature review method, the aim of this research is to critically review and synthesise existing knowledge to derive a definition, classification, and conceptualisation of infrastructure project cost drivers. Three research questions have been constructed based on "confusion spotting" and "neglect spotting" (Sandberg and Alvesson 2011):

RQ1: *What is an adequate definition for an "infrastructure project cost driver"?*

RQ2: *What are the key cost drivers of infrastructure projects?*

RQ3: *What are the different types of cost driver?*

The infrastructure project thus serves as the context for this research, and is defined as the construction, upgrade, or decommissioning of large-scale social and economic infrastructure (excluding telecommunications and IT systems due to the adequacy of associated research/knowledge (Gil and Beckman 2009)). This paper uses the infrastructure project as an umbrella term to include complex projects/programmes (i.e., system projects or array projects (Shenhar and Dvir 1996)), megaprojects (Flyvbjerg 2014), and global projects (Scott et al. 2011).

This paper is structured as follows. First the authors present their integrative review methodology. This is followed by three "findings" sections that correspond to the three research questions to define, classify, and conceptualise cost drivers. This is succeeded by a research agenda and then conclusions. There is no dedicated discussion section; instead, for the purposes of readability, the findings are interpreted within each of the three findings sections.

2 Methodology

The integrative literature review method is conceptual and inductive in nature, defined as a method that reviews, critiques, and synthesises literature on mature or emerging topics to resolve inconsistencies and provide new perspectives or frameworks (Torraco 2005, 2016). The two "options" of topic specified here, i.e., mature or emerging, are extended by Post et al. (2020), presenting seven "theory-generating avenues" based on what the review aims to do. Given that cost drivers research is both underdeveloped and lacking in clarity, this research opts for the "clarifying constructs" approach, which "*[l]ocates potential ambiguity around a construct and provides construct clarification in a way that extends theory*" (Post et al. 2020 p. 355). Integrative reviews contrast with systematic and narrative reviews, both of which are suited to topics that are rich in the literature and therefore tend to be more deductive / less conceptual (Baumeister and Leary 1997; Snyder 2019; Wong et al. 2013). The authors have used Torraco (2005, 2016) and Post et al. (2020) as the primary sources of guidance for conducting this review, though others have been used to supplement the methodology process (Callahan 2010, 2014; Elsbach and Knippenberg 2020; Rocco and Plakhotnik 2009; Snyder 2019; Whittemore and

Knafl 2005). Fig. 1 summarises this paper's research framework, which is comprehensively outlined in this section.

2.1 Literature collection

The literature collection stage consisted of keyword searches and screening of literature. For the keyword searches (conducted in November 2021 but continually checked until submission using weekly search alerts for all search strings highlighted in this section) and the subsequent screening, this was performed in two separate stages: (1) cost driver "explicit" phrases and (2) cost driver "synonym" phrases.

First, the cost driver explicit keyword search utilised Scopus, Web of Science (WoS), Google Scholar, ASCE Library, and Google. These literature databases were used to explore almost all related literature and thus adequately deepen the understanding of the field (Callahan 2010 p. 301). The Scopus search string, returning 1,032 articles, was: *TITLE-ABS-KEY ("cost driv*" OR "driv* cost*" OR "driver* of cost*" OR "driver* for cost*" AND (*project* OR infrastructure OR construction OR decommission*))*. WoS's *TS* function was then used in case any key cost driver explicit articles were not on the Scopus database, which returned 2,236 articles using the same search string as on Scopus (although irrelevant medicine-based subject areas were excluded from the string). Google Scholar and the ASCE Library were used but only to ensure major academic work was not omitted. Google was used to identify grey literature, entailing backwards searching. The authors also conducted searches on relevant institutional websites' databases (i.e., PMI, APM, IPA, OECD, World Bank, GOV.UK, CIOB, RICS, RIBA, CIMA, DOE, ACA, and AIQS) and reviewed accessible guidance documents; the nature of an emerging topic calls for including any material that could be of use (Whittemore and Knafl 2005), in this case being practitioner material. To initially filter out different subject areas (e.g., chemistry, nursing, or software), experiment-based papers, and irrelevant topics (most commonly activity-based costing (ABC), referring to repetitive business activities rather than projects), abstracts of articles returned from Scopus and WoS were read. For grey literature found through Google and the websites mentioned, the search function was used to identify mentions of cost drivers and thus to determine their relevancy.

To screen the remaining journal articles, conference papers, and grey literature, the authors followed two clear inclusion criteria that the articles must have met at least one of: (1) a definition for cost drivers (which could have been project-specific); (2) a set of outputted cost drivers (which must have been transferable, i.e., applicable across infrastructure projects). In screening for definitions, seven relevant definitions for cost drivers were identified. In screening for sets of outputted cost drivers, many articles provided cost drivers that were specific to a particular type of project (e.g., “number of lanes”, which is only applicable to a highway project (see Tong et al. 2021)), so these cost drivers were not included in the review because they were not transferable. The search for transferable cost drivers ended with a total of 20 articles, one of which also provided one of the seven identified definitions. Thus, the screening process totalled 26 cost driver explicit articles.

The second stage was the cost driver synonym keyword search; Appendix A outlines the list of synonyms, refined after initially formulating and trialling a range of possible phrases. The purpose of the synonym search was to supplement the cost driver explicit data by enriching/filling the taxonomy with cost drivers rather than conduct an exhaustive analysis. This search only used Scopus as this literature database provided sufficient relevant cost drivers data. Also, the search only included journal articles to ensure the returned synonym sources were reliable. After excluding various irrelevant phrases and subjects after undergoing continual refinement, the synonym search string (again employing *TITLE-ABS-KEY*) returned 5,228 articles. The authors only reviewed the articles with 10 or more citations, as by this point the data (i.e., outputted cost drivers) was saturated; just under 1,600 of these articles met this criterion. The authors acknowledge that this means many potentially valuable articles with under 10 citations were omitted, but (a) the data was saturated even after the first 500 articles and (b) it can be generally assumed that articles with 10 or more citations hold more value to academics than those with under 10 citations. However, as to not omit any current/recent developments, the journal articles returned by this string from 2021 onwards were also reviewed (regardless of number of citations); just under 950 articles met this criterion. To initially filter these articles, the authors read titles to determine relevance to this paper's topic then scanned abstracts where the title's relevancy was not clear.

To screen the remaining synonym articles, the sole inclusion criterion was that the articles must have a set of outputted cost drivers; this screening followed the same process as for cost driver explicit articles. Subsequently, 49 cost driver synonym articles met this criterion and were included in the review. Thus, as per Table 1, 75 relevant documents were identified in total to answer the three research questions. The authors combined RQ2 and RQ3 in this table since the taxonomy of cost drivers is used to construct the conceptual framework; though they address two different gaps in knowledge, the same articles apply to answering both RQ2 and RQ3.

2.2 Critical analysis and synthesis

After literature collection are the critical analysis and synthesis stages (Fig. 1). Critical analysis entails "*carefully examining the main ideas and relationships of an issue and providing a critique of existing literature*" (Torraco 2005 p. 361). Synthesis describes the technique used to present/integrate the critiqued literature (Post et al. 2020; Torraco 2016). This section describes how literature was critically analysed and synthesised throughout the following sections of the paper.

In the "defining" section, the authors first critically analysed existing literature to present a critique of what cost drivers are and are not in the context of infrastructure projects, organised into two "propositions". Then the authors critiqued existing cost driver definitions and extracted their key themes. By incorporating the propositions and acknowledging the key themes of existing definitions, the authors concluded this section by deriving a novel definition, thereby addressing RQ1.

In the "classifying" section, the authors addressed RQ2 by identifying the cost drivers outputted by the relevant explicit and synonym articles and synthesising these into a two-level taxonomy. The taxonomy classes the cost drivers into "level 1 cost drivers" and "level 2 cost drivers". The construction of the taxonomy began with identifying the level 2 cost drivers; these are the cost drivers that are specifically stated in the literature, so the titles of each of these (or at least similar phrases) can be found in each of the corresponding sources. The level 1 cost drivers describe the key cost drivers of infrastructure projects; the names of the level 1 cost drivers were deduced by the authors to succinctly describe the sets of linked level 2 cost drivers. This process was iterative in that the groups and titles were continually refined throughout the construction of the taxonomy. The two columns after these highlight the sources (explicit and synonym) that provided these level 2 cost drivers. In the subsection following the taxonomy, the authors interpret the inconsistencies and differences between the explicit and synonym sources regarding their outputted cost drivers.

In the "conceptualising" section, the second synthesis method used is a conceptual framework, presented as a two-by-two matrix classification of cost driver types (addressing RQ3). The dimensions and quadrants were derived through a critical analysis of the cost drivers in the taxonomy. They were inspired by asking by asking the question: "can anything be done about the cost driver (i.e., to reduce its associated cost)?" Placing this question in the context of the project team, i.e., the group "*of owner, individual contractors, and contractor personnel that develop and manage projects*" (Merrow 2011 p. 342), two characteristics emerged: they have the ability to (1) control and/or (2) define (i.e., in planning) certain cost drivers, which led to the conception of the four mutually exclusive quadrants. To ensure the matrix was internally valid, the authors iteratively amended the dimensions and types by inputting each cost driver.

The final synthesis method forms the penultimate section: a research agenda. This is typical when presenting a classification or conceptual framework (Post et al. 2020 p. 367), but the topic requires attention regardless. The authors determined these research avenues by taking stock of the gaps in existing cost drivers/reduction research and then incorporating and interpreting this paper's findings.

3 Towards defining cost drivers

3.1 Making sense of cost drivers: What are(n't) they?

By way of introducing the topic of cost drivers, the authors distinguish what cost drivers are and are not in the broad context of infrastructure projects. These distinctions are organised into the following two propositions.

Proposition 1: Cost drivers can have a direct or indirect impact on a project's cost. There is a dichotomy in how researchers view cost drivers (excluding synonym articles): those who observe direct cost impacts (e.g., ACE 2010; Wang and Horner 2007) and those who observe the cost impact of infrastructure project characteristics (e.g., OECD/NEA 2003; Stoy and Schalcher 2007). The former group consider the high-cost areas of the bill of quantities (BoQ) to provide cost drivers, whereas the latter describe features – physical or otherwise – of the project that cause the project to be costly. Hence, cost drivers can be respectively classed as *direct* and *indirect* (Efron and Read 2012; ETI 2018), though this should not be confused with direct and indirect *cost* (see Venkataraman and Pinto 2008). Indirect cost drivers have an indirect relationship with cost incursions, in that they cause intervening variables (which can be another indirect cost driver or a different direct/indirect impact on cost) and direct cost drivers to incur cost, creating a "causal mechanism" of cost drivers; these relationships are illustrated in Fig. 2.

Proposition 2: Cost drivers are not the same as cost overrun drivers, but cost overrun drivers that have a substantial impact on actual cost are cost drivers. The authors differentiate cost drivers from cost overrun drivers. Flyvbjerg et al. (2018) note that the drivers of cost overrun come under *root* causes and *causes*. The former entails human bias or psychological or political impacts which leads to inaccurate cost and time estimation (Flyvbjerg 2006). These are not cost drivers because they significantly affect budget accuracy rather than actual cost. In contrast, the latter describes factors such as scope changes (Love et al. 2016) and client competence (Akinci and Fischer 1998), which can be considered cost drivers since they have a strong influence on total actual cost.

3.2 Defining infrastructure project cost drivers

This section deduces a novel definition of cost drivers for infrastructure projects based on critiquing existing definitions in literature, as shown in Table 2.

Remarkably, there are only two articles in infrastructure project literature that define cost drivers (Ekung et al. 2021; Wang and Horner 2007). Ekung et al.'s (2021) definition is more transferable in research due to its general terminology, whereas Wang and Horner's (2007) is more pragmatic, proposing the “mean value theorem” which uses the BoQ to determine cost drivers. Definitions are mainly given by practitioner institutions (Australian Government 2018; DOE 2018; ETI 2018; GAO 2020; RICS 2015). Australian Government (2018) and DOE (2018) provide similar definitions, both focusing on major factors in the cost estimate, though DOE's (2018) extends this with reference to “sensitivity” (i.e., sensitivity analysis) to stress how a slight change in a cost driver’s magnitude can cause significant cost impacts. However, sensitivity analysis is less appropriate for determining indirect cost drivers as their cost is difficult to quantify. Therefore, this part of DOE's (2018) definition is not generalisable. The ETI's (2018) list-style definition has more general phrasing and some practical insights but is more towards a list of cost driver parameters than a definition. GAO (2020) makes reference to cost drivers affecting the cost estimate but provides more detail on what a cost driver is rather than only what it does. Lastly, RICS (2015) provides a definition that is succinct but vague; a “thing” that “causes” cost is not particularly specific and is thus unhelpful for this research.

Considering the points from these two sections, several key themes of infrastructure project cost drivers are worth emphasising. First, there must be a differentiation between direct and indirect cost drivers because this dichotomy reflects their relationship with actual cost, which is important for both researchers and practitioners; this is highlighted in Proposition 1, but is currently lacking in existing definitions. Second, Proposition 2 highlights how cost drivers can also refer to cost overrun drivers (e.g., rework), contradicting the notion put forward by some practitioner definitions that it relates solely to the estimate. Third, cost drivers have a significant influence on a project’s cost, as agreed by existing definitions. Fourth, the definitions suggest that cost drivers have multiple “forms” (e.g., characteristic, estimate element / cost model input, etc.), with the additional distinction of it increasing or decreasing cost. To this end, the following definition proposed by the authors addresses RQ1 by succinctly integrating these key concepts:

Cost drivers of an infrastructure project are the considerations that do or can directly or indirectly have a substantial positive or negative influence on the project’s total actual cost.

4 Towards classifying cost drivers

4.1 Taxonomy of infrastructure project cost drivers

To answer RQ2, the taxonomy of infrastructure project cost drivers (Table 3) highlights the 14 level 1 cost drivers, presented in order of most common in literature: Project team cohesiveness; Contract and procurement; Rework and additional work; Materials; Labour; Uncertainty and complexity; Socio-political stakeholders; Schedule; Regulations; Economy; Size of infrastructure and/or its components; Equipment and plant; Corruption and conflict; Health & safety.

Although these cost drivers are applicable across infrastructure projects, they must be prioritised on a case-by-case basis. Exemplifying *materials*, this is a more fundamental cost driver on construction projects rather than decommissioning projects. However, some nuclear decommissioning projects, for instance, entail the construction of waste storage facilities, so materials can be a cost driver in decommissioning (LaGuardia and Murphy 2012) even if the relative impact is greater on construction projects. Similarly, *uncertainty and complexity* is likely to have a higher relative cost impact on megaprojects compared to smaller projects, but is included since all infrastructure projects have a varying range of uncertainty and/or complexity (Loch et al. 2006; Remington and Pollack 2007).

4.2 Interpreting the divide between explicit and synonym sources

As seen in the taxonomy, cost driver explicit sources mainly recognised *materials* (specifically total direct cost), *labour*, *schedule* (specifically the total duration), *regulations*, and *size of infrastructure and/or its components* as the fundamental level 1 cost drivers. In contrast, cost driver synonym sources have considerable focus on *project team cohesiveness*, *contract and procurement*, and *rework and additional work*, also acknowledging *materials* (specifically inflation and shortages), *uncertainty and complexity*, *schedule* (specifically delays), and *economy* (specifically inflation). *Equipment and plant*, *corruption and conflict*, and *health & safety* had negligible comparisons.

These findings can be interpreted to justify the different perspectives. Cost driver explicit sources tend to focus on the planned/measurable totals of the project that strongly influence the overall project cost, which could be considered the "traditional" view. Cost driver synonym sources, however, tend to focus on the unplanned/hard-to-measure hindrances of the project that can cause a substantial deviation from the forecasted variables; this is due to synonym phrases commonly being derivatives of cost overrun drivers. Regardless, all of these totals and hindrances are cost drivers because they significantly influence actual cost, consistent with Propositions 1 and 2. Therefore, because the cost drivers body of knowledge has not been adequately defined or conceptualised by others, the high-cost hindrances identified in cost driver synonym sources could be considered cost drivers alongside the measurable totals. This is a forward-looking view of cost drivers since it widens the set of cost drivers to be considered.

Further interpretation of the divide reveals that the focus on planned/measurable totals from cost driver explicit sources is a result of the common use of regression or sensitivity analysis. These methods neglect any hard-to-measure aspects like many of the hindrances (e.g., competence) due to their quantitative nature and focus on cost estimation accuracy. This makes for an incomplete set of outputted cost drivers that will continually arise without the aid of inductive methods (as evident in Lowe et al. 2006; Stoy et al. 2008; Xiong and Xia 2014). In contrast, researchers that did not use (only) mathematical models outputted a more comprehensive, broad set of cost drivers, meaning the traditional view has hindered the ability for cost driver explicit research to be progressed. This paper's taxonomy should therefore be utilised by cost drivers researchers straying from these traditions.

4.3 Relationships between cost drivers

Fig. 3 contextualises the relationships between the cost drivers in the taxonomy. This develops the causal mechanism of direct and indirect cost drivers by exemplifying three routes that the cost drivers in the taxonomy can take to incur/affect costs. Along the top path, cost is incurred due to an indirect cost driver impacting an intervening variable. Along the middle path, cost is incurred stemming from an indirect cost driver, which results in an intervening variable that impacts a direct cost driver. Along the bottom path, cost is incurred due to an indirect cost driver impacting a direct cost driver.

5 Towards conceptualising cost drivers

To address RQ3, this section presents a conceptual framework: a control/definition matrix of cost driver types (Fig. 4).

For the control dimension, if the cost driver's actual cost impact is under the control of the project team, it is classed as "controllable", otherwise it is "uncontrollable". In other words, for the former, the project team itself has the ability to reduce (or increase) the cost / cost impact associated with the cost driver. This idea of cost drivers control is distinguished explicitly by some (ACE 2010; ETI 2018; Shane et al. 2009), and is in part supported by others that have classified cost drivers under internal and/or external factors (Derakhshanalavijeh and Teixeira 2017; Enshassi et al. 2009; Membah and Asa 2015).

For the definition dimension, if a cost driver's occurrence or impact is able to be defined by the project team, i.e., in planning/front-end stages, it is "defined", otherwise it is "undefined". Discussion of defined/undefined cost drivers in planning is not explicit in the literature, though there is a rich body of knowledge highlighting that poor planning by the project team is a key contributor to errors (e.g., Love and Matthews 2022) and, thus, rework and additional work (e.g., Love et al. 2017).

For added clarity, the authors have defined the four different types of cost driver as follows, also highlighting how the ability to reduce the cost associated with each type lessens:

1. Flexible (FL) cost drivers are able to have their actual cost impact controlled by the project team and they are defined in planning. The project team has a direct influence in these, so their actual cost reduction is the most accessible of the four types. For *uncertainty and complexity*, however, the actual cost impact is *indirectly* reducible; the authors refer to "known unknowns", where risk management is able to mitigate the specific effects of this cost driver (Ramasesh and Browning 2014), thus making it flexible.
2. Error-induced (E) cost drivers stem from lack of definition by the project team. Better front-end definition could reduce their occurrence or severity.
3. Fixed (FI) cost drivers are defined by the project team but the project team cannot reduce their cost impact; it is "fixed in place".

4. Unforeseeable (U) cost drivers are not controllable by the project team and, omitting contingencies, are not defined in planning. Their cost is therefore the most challenging for the project team to address. Some of these cost drivers are still on the "known unknowns" spectrum as the project team are aware that they (will) impact actual cost and so conventional risk management can apply (Ramasesh and Browning 2014 p. 191). For others, it is impossible to control or even be aware of them impacting actual cost, akin to that of "unknown unknowns" (Loch et al. 2006; Ramasesh and Browning 2014). Although unknown unknowns take greater effect on projects with a higher degree of novelty (again emphasising a case-by-case assessment of cost drivers), project teams can respond to unknown unknowns by establishing a culture of continual and flexible adjustment / adaptability in planning (Loch et al. 2006; Orr and Levitt 2011) and testing multiple solutions simultaneously to identify the appropriate response (Loch et al. 2006).

The matrix's dimensions and types were conceived based on the cost drivers from the taxonomy. This research would therefore be incomplete if each cost driver in the taxonomy was not assigned a type, so Table 4 is presented. Some FL, E, and FI cost drivers in the table have also been assigned a U. For the FL/U and E/U cost drivers, this accounts for the fact that projects are guaranteed to entail circumstances that cannot be defined and are out of the project team's control (Kim et al. 2020; Love and Matthews 2022), which can be due to, e.g., supply chain issues, existing conditions, weather, or stakeholder influence. For the FI/U cost driver, *exchange rates*, it refers to the defined (at the time of planning) but fluctuating nature of exchange rates.

6 Research agenda

6.1 Reduce the actual cost of controllable cost drivers in planning

The cost reduction of each controllable cost driver (i.e., flexible or error-induced) can take place in either the planning stages or execution stage of projects. Cost reduction research has more value if contextualising the former since all of the controllable cost drivers' actual cost is more significantly reduced with good front-end definition rather than good execution (Merrow 2011). This could be termed "reducing actual cost in planning" going forward; "reducing the cost estimate" can be misleading in the topic of cost reduction due to its association with reducing estimate inaccuracy rather than outright reduction of the estimate.

Still, there are several valuable avenues of research with an execution stage focus. More development is required here in regard to *project team cohesiveness*, *labour*, and *health & safety* – *rework and additional work* is already a well-developed field of research for both execution and planning stage contexts (e.g., Love 2002; Love et al. 2017, 2021). Existing research has refrained from answering how the cost associated with these cost drivers can be reduced. A research question relating to *project team cohesiveness* and *labour* could consider how, in the cases where poor competence/collaboration of project team members or competence/productivity of the labour workforce may be unavoidable in the execution stage, how can costs be controlled? For *health & safety*, it is surprising that research on mental wellbeing is an area that is considerably lacking in project management to this day (Li et al. 2022; Morris 2022), let alone its relationship with cost reduction. Researchers must particularly strive to identify what is (not) done by project team members and/or organisations to ensure cost associated with mental health/wellbeing is controlled, acknowledging that health & safety assurance is arguably the most important duty for infrastructure project teams. Noteworthy, this research stream applies to the planning stage as well as execution.

There are eight cost drivers that can have their associated actual cost reduced in planning and require further research: *project team cohesiveness*, *contract and procurement*, *materials*, *labour*, *uncertainty and complexity*, *socio-political stakeholders*, *schedule*, and *equipment and plant*. Research streams related to these cost drivers are now presented.

There are similarities between *project team cohesiveness* and *labour*; selecting competent, productive, and collaborative personnel is a significantly important part of planning and cost reduction since, as Merrow (2011) emphasises, people do projects. The question for researchers is: how is the optimal balance of personnel cost and achieving project objectives determined when selecting project team members and/or labour? Researchers asking this can take inspiration from the work on cost-schedule trade-offs (Bayraktar et al. 2011), i.e., by focusing on "cost-competence" trade-offs.

Contract and procurement researchers generally agree that incentive mechanisms and partnering/alliances have a positive correlation with (cost) performance as compared to non-relational contracts (e.g., Meng and Gallagher 2012; Suprapto et al. 2016) when done correctly (Gil 2009). However, as Morris (2022) posits, more clarity is required on how procurement strategies are formed in the ever-evolving project setting. Cost certainty between owner and contractor in contract and procurement strategies is relatively understood, but how are contract or procurement strategies selected in terms of ensuring costs are as low/controllable as can be for a particular project?

Materials and *equipment and plant* are similar cost drivers in that they are strongly influenced by supply chain management. The substantial complexity associated with coordinating the supply chain can be alleviated with systems integrators / integrated teams, known to benefit cost (Davies et al. 2009; Davies and Mackenzie 2014), but it remains an under-researched area (Denicol et al. 2020; Morris 2022). Researchers could examine tacit knowledge gained by project team members in their cost-efficient selection of materials or equipment and plant. This places a necessary focus on the people that manage projects and can advance knowledge management and project-as-practice research (Cicmil et al. 2006; van der Hoorn and Whitty 2019; Morris 2022).

Uncertainty and complexity, directly linked with risk and its management, is a cost driver that continues to be highly researched in project management. However, with risk management continuing to receive inadequate investment in the front-end (Morris 2022) and ambiguity surrounding uncertainty and complexity (Padalkar and Gopinath 2016), researchers should consider why this is the case and focus on what project teams do in planning to sufficiently define projects whilst controlling/optimising the associated costs.

The importance of *socio-political stakeholders* as a cost driver cannot be underestimated in planning. Social and political groups have the power to terminate projects (Invernizzi et al. 2017b; Juarez Cornelio et al. 2021), not least cause delays (Locatelli et al. 2017a), therefore assessing the influence of and gaining support from these parties is paramount. This cost driver has not been fully explored; researchers have tended towards examining engagement processes with socio-political stakeholders that positively correlate with cost, with much to be learnt on the micro level, e.g., engagement practices with stakeholders in planning (Burger et al. 2019) to reduce cost.

Schedule is a cost driver influenced by duration and delays. Reducing/optimising the project duration using models such as the critical path method falls under a mature area of project management knowledge (Turner et al. 2013), requiring less attention in the present day as compared to the softer, people-dependent areas. This is the case for delays, which are in many cases traced back to planning stage errors of the project team (Larsen et al. 2016; Love and Matthews 2022). Delays have already been studied to mitigate their occurrence and impact (Grant et al. 2006; Han et al. 2009), but their prevailing influence on cost in complex projects again necessitates a deeper knowledge of risk management (Morris 2022; Sanchez-Cazorla et al. 2016).

As a caveat to accompany all of these research avenues, researchers have a duty to identify cost reduction solutions that are socially and environmentally responsible, i.e., they do not fall into the "dark side" of project management such as modern slavery (Alzoubi et al. 2023) and corruption (Locatelli et al. 2017b).

6.2 Adopt more exploratory and inductive methods in cost drivers research

The authors strongly encourage the use of more inductive approaches to identify and investigate a wider range of cost drivers. As has been highlighted, regression and sensitivity analysis are commonly associated with the planned/measurable totals mindset of cost drivers (e.g., Ofori-Boadu 2015) rather than incorporating the unplanned/hard-to-measure hindrances that have a strong influence on actual cost (e.g., Yang et al. 2011). Therefore, the authors recommend inductively establishing a stronger knowledge base of cost drivers, as agreed by some users of regression models highlighted in this paper (Stoy et al. 2008; Stoy and Schalcher 2007). The richness of results from studies using interviews with project team members (Efron and Read 2012; Zhao et al. 2017) and qualitative data extracted from project documents (Adedipe and Shafiee 2021; Kwok et al. 2010) confirm this recommendation. These do not have to be standalone methods, however; the authors equally encourage the use of multiple methods to output a richer set of cost drivers for a given case project (Elmousalami 2020).

The authors also found that the rigour of existing methods of synthesis used in cost driver explicit sources is lacking. Unlike this paper's taxonomy and conceptual framework, researchers have tended towards basic methods of presenting findings that lack novelty and a detailed consideration of how their findings can be used, which makes for unstimulating discussion and thus limited development of the area. Future research should give more attention to stimulating data synthesis methods not only to extend academic knowledge but to consider what project team members can actually use from cost drivers research, narrowing the divide between academia and practice.

Together with the proposed research avenues from the previous subsection, researchers should take inspiration from single or multiple case studies that take a deep look into the project setting, its actors, interactions within the project team, and the range of planning and management considerations that were or were not adequately addressed (e.g., Davies et al. 2016; Davies and Mackenzie 2014) to study actual cost reduction. This could be studied with the aim of benchmarking – i.e., the identification and implementation of exemplar practices of others to self-improve (Anand and Kodali 2008) – to compare and contrast practice across multiple projects (Invernizzi et al. 2017a, 2018). Moreover, taking a project-as-practice approach can provide insightful findings about what project team members actually do to reduce cost, particularly if researchers perform observation of meetings and/or day-to-day activities (Çıdık and Bowler 2022; Hällgren and Söderholm 2010; O'Leary and Williams 2013).

6.3 Expand the research context of cost drivers

The authors encourage researchers to diversify the setting in which cost drivers are studied. There have been valuable contributions across a variety of project contexts, but the literature lacks a focus on two key complex project settings in which an understanding of cost drivers/reduction is essential:

1. *Megaprojects*. Just one journal publication by Kwok et al. (2010) that briefly looked into megaproject cost drivers was identified; given that their study is now over 10 years old and is specific to one case, cost drivers (explicitly termed) in megaprojects is an almost untouched topic in academic literature. Megaproject costs have been commonly studied in relation to how complexity (Brady and Davies 2014; Davies and Mackenzie 2014; Kardes et al. 2013) and governance (Gil and Fu 2021; Locatelli et al. 2014; Turner 2022) influence cost. However,

seldom addressed is what project teams actively do to reduce the huge costs of megaprojects as opposed to using the aforementioned subjects to explain poor cost management.

2. *Decommissioning projects*. The authors found that published literature on decommissioning project cost drivers is lacking, compared to cost overruns which has seen recent developments in a nuclear context (Invernizzi et al. 2019, 2020b; a). Some have derived decommissioning-specific cost drivers (Kaiser 2017; Raimi et al. 2021), but this paper has only included Adedipe and Shafiee (2021) since their outputted set of cost drivers included two that were generalisable. Therefore, the authors urge researchers to develop the decommissioning cost drivers database, not only for the purpose of contributing to research but for the sake of tackling these essential and extremely complex "back-end" projects. A case in point is the biggest project (i.e., most expensive, long, and complex) in the UK and possibly Europe: the Sellafield nuclear decommissioning megaproject (Locatelli 2021).

7 Conclusions

In an infrastructure project context, the cost drivers body of knowledge is significantly underdeveloped; this has limited the developments in cost reduction research. Using a rigorous integrative review methodology, the authors critically reviewed and synthesised existing cost drivers literature to fill the main preliminary gaps and resolve inconsistencies in this field, with the specific aim to define, classify, and conceptualise the cost drivers of infrastructure projects. First, the authors deduced an accurate, complete definition of cost drivers that is applicable across infrastructure projects. Second, the authors presented a taxonomy of the 14 key cost drivers of infrastructure projects, which integrates those scattered across literature into one classification system that is applicable across projects. Third, the authors proposed a two-by-two matrix of cost driver types that distinguishes the ability to control and define (i.e., plan) cost drivers. Lastly, the authors' research agenda proposes prioritising the study of controllable cost drivers, utilising exploratory and inductive methods, and considering complex project contexts. In summary, this paper's theoretical contribution is a deepening of infrastructure project cost drivers knowledge using a definition, taxonomy, and conceptual framework. This work is for use by researchers wishing to further the study of cost drivers and cost-reducing processes and practices used by project teams.

The practical contribution of this paper is twofold. It is first a comprehensive summary of the key opportunities for – and threats to – cost reduction for project team members actually "doing" cost reduction. Second, it is a deepened awareness of the cost drivers whose cost project team members can actually reduce, i.e., controllable cost drivers. Going forward, both public bodies and private organisations aiming to reduce the cost of infrastructure projects should put more emphasis on benchmarking project teams members' effective cost reduction practices associated with the controllable cost drivers. This is particularly important in high-cost, complex, and uncertain project environments such as UK nuclear decommissioning projects (GOV.UK 2019). Despite this paper's value to project teams, the primary audience is not cost estimators as they may find greater benefit in utilising the most up-to-date cost estimation models that have already been developed/tested as well as studied extensively in cost reduction literature (Olawale and Sun 2015).

As a general recommendation for researchers, the authors encourage a more explicit use of the term cost drivers to generate a broader and deeper understanding in infrastructure project management research, having identified only 14 journal publications providing transferable cost drivers. The authors also encourage developing cost drivers separate from a budget related focus. Budget adherence topics have dominated infrastructure project literature, and consequently almost all cost driver studies focus on how they can reduce estimate inaccuracy rather than reduce actual cost. The body of knowledge already provides strategies to reduce estimate inaccuracy (Abanda et al. 2017; Flyvbjerg 2006; Torp and Klakegg 2016), whereas reducing actual cost requires a more in-depth understanding of project team practice.

There are three main limitations to this paper that can be addressed if this paper's findings are applied in empirical settings. First, the taxonomy can be applied in a case study of a specific project, with the opportunity to supplement and develop the taxonomy with empirical primary data and thus customise it for said project (see, e.g., Padala et al. 2020). Similarly, the matrix can be used in an empirical setting to understand its application in specific infrastructure project cases, with the ability to "plot" the project-specific cost drivers. Lastly, cost drivers from a case project could be inputted into the causal mechanism to map the relationships between the project's direct and indirect cost drivers.

Appendix A – Cost driver synonyms for the Scopus search

Cost overrun*; Cost and time overrun*; Cost performance; Cost and time performance; Cost* reduc*; Reduc* cost*; Reduc* actual cost*; Cost* increas*; Increase* cost*; High cost*; Large cost*; Cost categor*; Cost group*; Affect* cost; Cost effect; Impact* cost; Cost impact; Influenc* cost; Cost influenc*; Cost component*; Component of cost*; Cost factor*; Cost uncertainty factor*; Factor* of cost; Cost element*; Element* cost; Cost significant; Cost item*; Item* cost; Key cost*; Major cost*; Cost determinant*; Determinant of cost*.

Data availability statement

All data, models, and code generated or used during the study appear in the submitted article.

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Figures (captions)

Fig. 1. This paper's integrative review research framework

Fig. 2. The causal mechanism of direct and indirect cost drivers

Fig. 3. Three examples of the causal mechanism of direct and indirect cost drivers

Fig. 4. Control/definition conceptual framework of cost driver types

Tables

Table 1. Number and types of cost driver explicit and synonym documents in this review

Document type	Explicit			Synonyms
	RQ1	RQ2, RQ3	All	RQ2, RQ3
Journal article	2	12	0	49
Conference paper	0	1	0	–
Grey literature	4	6	1	–
Total	6	19	1	49
	75			

Table 2. Academic and practitioner definitions for cost drivers

Source	Type/stage	Cost drivers definition	Theme(s)
Ekung et al. (2021 p. 134)	Sustainable buildings	"*Cost drivers refer to constraints affecting the cost performance of SB [sustainable buildings] projects.*"	Constraints; affect; cost performance.
Wang and Horner (2007 p. 1270)	Road maintenance	"*[T]he cost drivers of a set of data are those significant items whose values exceed the average of the set of data…*"	Set of data; significant items; exceed average.
Australian Government (2018 p. 128)	(Non-specific)	"*A major input to an estimate at a summary level.*"	Major input; estimate; summary level.
DOE (2018 p. 75)	(Non-specific)	"*A "cost driver" is a major estimate element whose sensitivity significantly impacts TPC [total project cost].*"	Major estimate element; sensitivity; significant impact.

ETI (2018 p. 7)	Nuclear plant construction	"*The team settled on a definition for cost drivers as: Increasing or decreasing the cost of the project; Representing one of the processes critical to plant completion or "realisation;" Having factual and/or measurable indicators; Associated with at least one of the principal actors in plant completion or "realisation;" and Collectively explaining most of the cost variation among plants.*"	Increase or decrease cost; critical; indicators; principal actor; cost variation.
GAO (2020 p. 430)	(Non-specific)	"*A system, [programme] characteristic, or cost model input which affects the system or [programme] cost estimate*."	System / programme characteristic / input; affect; cost estimate.
RICS (2015 p. 19)	(Non-specific)	"*[T]hings or events that cause costs*."	Things/events; cause costs.

Table 3. Taxonomy of infrastructure project cost drivers

Level 1 cost drivers	Level 2 cost drivers	Cost driver explicit	Cost driver synonym
Project team cohesiveness	Client/owner competence	Efron and Read (2012); ETI (2018); Ingersoll et al. (2020); ACA (2014)	Chen et al. (2016); Koushki et al. (2005); Johnson and Babu (2020); Ramabodu and Verster (2013); Manley and Chen (2016); Mahmud et al. (2021); Akinci and Fischer (1998); Dissanayaka and Kumaraswamy (1999); Shane et al. (2009)
	Contractor competence		Koushki et al. (2005); Aje et al. (2009); Rahman et al. (2013); Annamalaisami and Kuppuswamy (2021); Derakhshanalavijeh and Teixeira (2017)
	Project manager competence and leadership		Ammeter and Dukerich (2002); Sinesilassie et al. (2018); Sunindijo (2015); Shane et al. (2009)
	Project team communication		Yang et al. (2011); Ling and Tran (2012); Sinesilassie et al. (2018)
	Subcontractor competence		Olawale and Sun (2010); Akinci and Fischer (1998)
	Consultant competence		Larsen et al. (2016); Derakhshanalavijeh and Teixeira (2017)
Contract and procurement	Procurement method	Efron and Read (2012); LaGuardia and Murphy (2012); ACA (2014)	Chen et al. (2016); Raisbeck et al. (2010); Johnson and Babu (2020); De Marco and Narbaev (2021); Chasey et al. (2012); Chritamara et al. (2001); Shane et al. (2009)
	Contract/scope disputes, management, and definition		Cheng (2014); Mansfield et al. (1994); Okpala and Aniekwu (1988); Mitropoulos and Howell (2001); Oladapo (2007);

Level 1 cost drivers	Level 2 cost drivers	Cost driver explicit	Cost driver synonym
			Sinesilassie et al. (2018); Venkateswaran and Murugasan (2017); Ramabodu and Verster (2013); Shane et al. (2009)
	Contract/payment method		Chen et al. (2016); Mansfield et al. (1994); Okpala and Aniekwu (1988); Meng and Gallagher (2012); Akinci and Fischer (1998); Dissanayaka and Kumaraswamy (1999)
Rework and additional work	Scope changes stemming from planning errors		Love and Li (2000); Mansfield et al. (1994); Koushki et al. (2005); Olawale and Sun (2010); Hsieh et al. (2004); Love et al. (2012); Yap et al. (2017); Oladapo (2007); Johnson and Babu (2020); Ramabodu and Verster (2013); Annamalaisami and Kuppuswamy (2021); Enshassi and Ayyash (2014); Josephson et al. (2002); Derakhshanalavijeh and Teixeira (2017); Shane et al. (2009)
	Scope changes stemming from client requirements		Love and Li (2000); Oladapo (2007); Ramabodu and Verster (2013); Mahmud et al. (2021); Shane et al. (2009)
	Execution errors		Love and Li (2000); Josephson et al. (2002)
Materials	Materials (direct cost)	Efron and Read (2012); ETI (2018); ACE (2010); CIDB (2017); Ingersoll et al. (2020); LaGuardia and Murphy (2012); ACA (2014)	Goh and Yang (2014)
	Material cost inflation/fluctuation		Kaming et al. (1997); Enshassi et al. (2009); Rahman et al. (2013); Annamalaisami and Kuppuswamy (2021)
	Material shortages		Mansfield et al. (1994); Okpala and Aniekwu (1988); Rahman et al. (2013)
	Supply chain logistics	Adedipe and Shafiee (2021)	Koushki et al. (2005)
Labour	Labour (direct cost)	Efron and Read (2012); ETI (2018); ACE (2010); OECD/NEA (2003); Ingersoll et al. (2020); LaGuardia and Murphy (2012); ACA (2014)	
	Competency (and shortage of skill)	ETI (2018); Ingersoll et al. (2020)	Karimi et al. (2018); Derakhshanalavijeh and Teixeira (2017)

Level 1 cost drivers	Level 2 cost drivers	Cost driver explicit	Cost driver synonym
	Productivity	ETI (2018); CIDB (2017); Ingersoll et al. (2020)	Mahamid (2018)
	Training costs	ETI (2018); Ingersoll et al. (2020)	
Uncertainty and complexity	Uncertainties / unforeseen events	Efron and Read (2012); OECD/NEA (2003); Membah and Asa (2015); ACA (2014)	Cheng (2014); Olawale and Sun (2010); Akinci and Fischer (1998); Oladapo (2007); Shane et al. (2009)
	General project complexities	Membah and Asa (2015)	Kaming et al. (1997); Olawale and Sun (2010); Mirza and Ehsan (2017); Zhao et al. (2021); Dissanayaka and Kumaraswamy (1999); Shane et al. (2009)
Socio-political stakeholders	Social (stakeholder) requirements/influence	CIDB (2017); OECD/NEA (2003); Zhao et al. (2017)	Venkateswaran and Murugasan (2017); Mahmud et al. (2021); Shane et al. (2009)
	Political requirements/issues	OECD/NEA (2003)	Enshassi and Ayyash (2014); Mahmud et al. (2021); Akinci and Fischer (1998)
Schedule	Duration	Lowe et al. (2006); Stoy et al. (2008); Stoy and Schalcher (2007); Xiong and Xia (2014); Adedipe and Shafiee (2021)	Flyvbjerg et al. (2004); Olawale and Sun (2010)
	Delays		Mansfield et al. (1994); Enshassi et al. (2009); Annamalaisami and Kuppuswamy (2021); Mahmud et al. (2021)
	Government/public support	Efron and Read (2012); ACA (2014)	
Regulations	Regulatory compliance	ACE (2010); OECD/NEA (2003); Efron and Read (2012); Adedipe and Shafiee (2021); Zhao et al. (2017); ACA (2014)	
	Country-specific regulatory factors	ETI (2018); Ingersoll et al. (2020)	
	Legal compliance	ACE (2010)	Venkateswaran and Murugasan (2017)
Economy	Inflation/fluctuation		Mansfield et al. (1994); Enshassi et al. (2009); Akinci and Fischer (1998); Derakhshanalavijeh and Teixeira (2017); Shane et al. (2009)
	Continental economy	Ofori-Boadu (2015)	Akinci and Fischer (1998)
	Region	Stoy et al. (2008)	
	Exchange rates	Heptonstall et al. (2012)	
Size of infrastructure	Site/floor area	Stoy et al. (2008); Lowe et al. (2006);	

Level 1 cost drivers	Level 2 cost drivers	Cost driver explicit	Cost driver synonym
and/or its components		Ofori-Boadu (2015); Xiong and Xia (2014)	
	Number of units on site	OECD/NEA (2003)	
Equipment and plant	Equipment/plant (direct cost)	Efron and Read (2012); ETI (2018); Ingersoll et al. (2020); ACA (2014)	Goh and Yang (2014)
	Lack of availability and downtime equipment costs		Vorster and De La Garza (1990)
Corruption and conflict	Corruption	Collier et al. (2016)	Locatelli et al. (2017)
	Conflict (country-level)	Collier et al. (2016)	
Health & safety	Accident-related costs		Pellicer et al. (2014); Goh and Yang (2014)
	Accident prevention		Pellicer et al. (2014)

Table 4. Taxonomy of (level 2) cost driver types

Level 1 cost drivers	Level 2 cost drivers	Cost driver type
Project team cohesiveness	Client/owner competence	FL
	Contractor competence	FL
	Project manager competence and leadership	FL
	Project team communication	FL
	Subcontractor competence	FL
	Consultant competence	FL
Contract and procurement	Contract/scope disputes, management, and definition	FL
	Procurement method	FL
	Contract/payment method	FL
Rework and additional work	Scope changes stemming from planning errors	E
	Scope changes stemming from client requirements	E
	Execution errors	E
Materials	Materials (direct cost)	FL
	Material cost inflation/fluctuation	U
	Material shortages	U
	Supply chain logistics	FL/U
Labour	Labour (direct cost)	FL
	Competency (and shortage of skill)	FL
	Productivity	FL
	Training costs	FL
Uncertainty and complexity	Uncertainties / unforeseen events	FL/U
	General project complexities	FL/U
Socio-political stakeholders	Social (stakeholder) requirements/influence	FL/U
	Political requirements/issues	FL/U
	Government/public support	FL/U
Schedule	Duration	FL
	Delays	E/U
Regulations	Regulatory compliance	FI
	Country-specific regulatory factors	FI
	Legal compliance	FI
Economy	Inflation/fluctuation	U

Level 1 cost drivers	Level 2 cost drivers	Cost driver type
	Continental economy	U
	Region	FI
	Exchange rates	FI/U
Size of infrastructure and/or its components	Site/floor area (e.g., GFA, GIFA, GEFA)	FI
	Number of units on site	FI
Equipment and plant	Equipment/plant (direct cost)	FL
	Lack of availability and downtime equipment costs	FL/U
Corruption and conflict	Corruption	U
	Conflict (country-level)	U
Health & safety	Accident-related costs	E/U
	Accident prevention	FL