Applying value management when it seems that there is no value to be managed: the case of nuclear decommissioning

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Abstract

The vast majority of project management literature relating to infrastructure focuses on the project lifecycle up to commissioning and handover. Conversely, little attention has been paid to the end-of-life of infrastructure, i.e. when decommissioning begins. Infrastructure decommissioning projects are long and complex projects, involving an extensive network of stakeholders. Moreover, their budgets can reach hundreds of billions of Euros and, for many of these projects, keep increasing. Since decommissioning projects do not generate direct revenues, they are often considered an expensive nuisance with limited value linked to their delivery. This paper explores the use of Value Management (VM), examining the constraints of decommissioning projects and the requirements for successful implementation of VM, focusing on the nuclear industry due to its techno-socio-economic relevance. Findings derived from the application of content analysis on semi-structured interviews with experienced decommissioning practitioners include suggestions on how to implement VM, ultimately contributing to increase the knowledge on how deliver decommissioning projects with better performance.

Keywords

Value Management; Infrastructure end-of-life; Nuclear Decommissioning; Megaproject; Social Challenges.

Highlights

-Project management literature has paid limited attention to decommissioning

-Decommissioning projects present an array of new project management challenges

-This paper examines the requirements for successful VM in nuclear decommissioning

-A multidisciplinary VM team play a key role in nuclear decommissioning

-An experienced VM leader and an open project delivery environment with no ‘pre-conceived’ options are key to success

1. Introduction

The majority of project management research has investigated the planning, design and delivery of construction projects and megaprojects (Pitsis et al. 2018; Locatelli et al. 2017; Lindhart & Larsen 2016; Tripathi & Jha 2018), and only limited and recent attention has been given to the end-of-life of infrastructure (Invernizzi et al. 2018a). Decommissioning, dismantling and removal refer to the end-of-life of infrastructure and to the process of withdrawing it from service, "clean" it and deconstructing it. For instance, in the nuclear industry, decommissioning is defined as *"all the administrative and technical actions taken to allow the removal of some or all the regulatory controls from a facility […]"* (IAEA 2006, P.31-32). For the sake of synthesis and simplicity, in this paper, the authors will use the word "decommissioning" to embrace all the terms highlighted above.

Infrastructure decommissioning projects and programmes can be long, complex, and reach costs of billions of Euros, particularly for oil & gas and nuclear facilities (Oil&Gas UK 2017b; NDA 2017b). As an example, in the UK's North Sea, the decommissioning cost estimates reach a staggering £60bn (Oil and Gas Authority 2017), while the estimates for decommissioning the UK nuclear legacy are at £229 billion (NDA 2018).

Moreover, decommissioning projects involve an extensive network of stakeholders, including: the client(s), contractors and subcontractors, the managing organization, the government, regulators, employees and the local community (Perko et al. 2017; Love 2012; IAEA 2009; IAEA 2008). Moreover, the number of completed decommissioning projects are extremely small compared to the number of facilities that have actually been built. For instance, globally, more than 500 nuclear power plants have been built, but only 16 have been fully decommissioned (OECD/NEA 2016). Similarly, 470 offshore oil & gas installations (HM Government 2013) have been built in the North Sea, but only "*around 10% of oil and gas platforms installed across the North Sea have been decommissioned and less than 5% of pipelines*" (Oil&Gas UK 2017, p.12). Additionally, several other types of complex infrastructure (such as chemical plants and large dams, as well as low carbon energy infrastructure such as wind farms) are now coming to the end of their useful operational life and will soon need to be decommissioned.

Chemical plants need to be properly decommissioned to avoid the risk of leakages into the environment, and to free land that can be reused, which is becoming a pressing issue especially in densely populated countries such as in Western Europe; dams need to be decommissioned because the concrete that make up their structures is degrading, and this combined with the pressure from the soil accumulated in the dam during the operational life of the infrastructure may pose an unacceptable risk.

These decommissioning projects have common characteristics that differentiate them from more traditional construction endeavours. At the completion of these projects (Invernizzi et al. 2017; Invernizzi et al. 2019):

- there is no or little cash in-flow;
- no revenue generating assets are created;
- no "landmark infrastructure" is built, but instead the site is often left with "nothing" and its use remains restricted for several years;
- there is no "red ribbon" to cut for politicians
- jobs are often lost.

These characteristics pose severe socio-economic challenges as many of the traditional incentives to deliver projects effectively and efficiently are simply not there.

Moreover, the infrastructure decommissioning is often perceived as "dull" and uninspiring projects aimed at getting rid of and dispose of infrastructure that was once valuable. The reality, however, is dramatically different: decommissioning projects can be complex projects that encompass several interrelated valuable activities, such as hazard reduction, safety and security guarantees, site remediation and restoration (OECD/NEA 2014b; Laraia 2012). More specifically, decommissioning not only allows the safe and secure handing of hazardous material, but also to free space on an licenced nuclear site which could then be utilised for new nuclear. Additionally, under the umbrella-term of "decommissioning", construction projects such as the building of facilities for handling, treating and storing of waste may be required. Considerable R&D may also have to be carried out to ensure that the best technologies are developed and the best possible solutions are implemented in decommissioning projects (OECD/NEA 2014a). Nevertheless, despite the decommissioning industry being rich of valuable projects, how to "value manage" end-of-life of infrastructure is still remarkably under-investigated. Even with the challenges associated with decommissioning, the effort that decommissioning projects require, and the limited current knowledge on how to manage these projects, the majority of academic papers on decommissioning simply take a "hard science" perspective (investigating chemical, physical, radiological aspects), and how to actually address the project management challenges of decommissioning projects (in order to deliver valuable projects) seem to be largely disregarded by academics[1].

Value Management (VM) is a philosophy and management style to enhance stakeholders' decision making which is operationalised through a series of studies during the project life cycle (Kelly et al. 2015). VM is able to reconcile differences in views between key stakeholders, promoting early debate in the process of selection and delivery of the best solution, and it is particularly useful when dealing with long and complex projects (Kelly et al. 2015). Male et al. (2007) describe VM as a team-based, process-driven methodology that uses function analysis to examine and deliver a product, service or project in the best possible way, combining whole life performance and cost, without compromising quality. Function analysis "*is argued to be the only distinguishing characteristics of value management from other philosophies or approaches*" (Male et al. 2007, p.109). However, even if VM can support the planning and delivery of decommissioning projects, this topic also seems to be overlooked by the academic community[2].

[1] The search in Scopus of academic papers on the topic of nuclear decommissioning reveals 445 papers (as in November 2018), but only two papers have been published in "project management journals", i.e. one in the International Journal of Project Management and one in the International Journal of Managing Projects in Business (exact query in Scopus: "nuclear decommissioning").

[2] The search in Scopus of academic papers on the topic of value management in projects (as in November 2018) reveals 341 papers (exact query in Scopus: "value management" AND "project" AND NOT "earned"). The search is limited to "decommissioning projects", does not show a single publically available result (exact query in Scopus: "value management" AND "project" AND "decommissioning" AND NOT "earned").

This paper fills this knowledge gap by exploring the potential role of VM in decommissioning. More specifically, this paper answers the following research questions:

- what does “value” mean in the context of decommissioning?
- What are the constraints that affect decommissioning projects that can be addressed with VM?
- What are the requirements for a successful implementation of VM in decommissioning projects?

Addressing these research questions ultimately supports the development of knowledge on how deliver decommissioning projects with improved performance.

This exploratory research focuses on the nuclear decommissioning industry, due to its economic relevance, the urgency to deal efficiently with radioactive material arising from the decommissioning activities, and the ready availability of information (e.g. reports published by international organizations such as the International Atomic Energy Agency, (IAEA 2016a; IAEA 2011), the OECD/Nuclear Energy Agency (OECD/NEA 2016; OECD/NEA 2012), etc.).

Moreover, the urgency to investigate decommissioning is due to the fast-growing number of nuclear facilities that are approaching their end-of-life and will soon need to be decommissioned, as well as the costs that this will involve[3]. Since the vast majority of nuclear facilities in Europe are owned by their respective Governments, this burden is on the tax payers’ shoulders. Therefore, how to “value manage” these projects and improve the ratio of “benefits vs costs” in nuclear decommissioning projects is a critical and pressing issue.

To achieve the above-mentioned research objectives, section 2 explores the literature on value and VM, and reviews the requirements for the successful implementation of VM on construction. Section 3 explains the selection of the focus of this research, also describing the data collection and analysis.

[3] World Nuclear Association official website: http://www.world-nuclear.org/press/briefings/decommissioning-costs-in-context.aspx [Accessed August 21, 2018]

Section 4 presents the research findings, which are then discussed in section 0. Section 6 highlights the limitations and provides suggestions for future research, and section 7 concludes the paper.

2. Theoretical Background on Value and Value Management

2.1. The Complexity of Defining “Value”

Defining what value is can be troublesome as “*value is a subjective term and is manifested in different ways such as attitude, belief, desire, preference, need and criteria*” (Leung & Liu 2001, p.11). Value also has a dynamic nature which changes and evolves over time (Aliakbarlou et al. 2017). Thyssen et al. (2010) discuss value both in objective and subjective terms, also differentiating between intrinsic and extrinsic value. Cha & O’Connor (2005) argue that there is no single definition of value, as value is an abstract concept in nature. In the realm of projects, discussions about value deal with outputs (at the end of the project), outcome (some months after the project), and impact (years after the project) that a project delivered according to different stakeholders, levels and timescales (Turner & Zolin 2012; Zwikael & Smyrk 2012; Davis 2014).

This brief review highlights that agreeing what value is for construction projects is subjective and is often an open question that is difficult to answer. Moreover, when dealing with infrastructure end-of-life, answering the question “what is value?” is even harder than when dealing with construction projects in general. Indeed, for instance, for nuclear decommissioning projects, “value” is derived from the interplay of moral, ethical, social, economic and environmental aspects, underpinning the need to ultimately restore the nuclear site, which often has a very restricted use.

In the VM literature, value is often defined through the ration between functional performance the and the cost of resources (eg. (Hayles et al. 2010)), or the relationship between benefits and costs (Laursen & Svejvig 2016). Luo et al. (2011, p.1003) quoting (Green 1992) argue that VM is concerned with defining “*what ‘value’ means to a client within a particular project context by bringing the project stakeholders together and producing a clear statement of the project's objectives*”. This highlights that “value” in construction industry projects can potentially be described through an agreed statement.

2.2. The Value Management Study

VM is a robust mechanism to balance societal, environmental and economic aspects as well as to assist decision-making with the aim to maximise the functional value of a project and eliminating unnecessary costs (Abidin & Pasquire 2007). VM supports key stakeholders, such as the client(s), the main contractor(s) and the project owner, in considering the challenges surrounding the specific project they are involved in. This includes agreeing on a mission statement to be used as a benchmark for future decision making (utilising function analysis) and analysing all the options available to the project team, considering the political, social, economic and environmental impacts (Hayles et al. 2010, p.45). Even if the terms "VM", "value engineering" "value analysis" are sometimes used interchangeably (Cha & O'Connor 2005; Fong et al. 2001), some authors differentiate between these terms, arguing that "value analysis" and "value engineering" have been developed to optimise projects and processes, while VM focuses on the overall achievement of "value" (Laursen & Svejvig 2016).

A VM study can be split into three main phases (Lin et al. 2011):

1. A preparation phase, also called "orientation and diagnostic phase" (Male et al. 2007);
2. A workshop phase, where normally selected stakeholders will gather, discuss and ultimately produce a report and an action plan to ensure solutions are implemented. This phase can be divided into six sub-phases: information, function analysis, creativity, evaluation, development, and presentation (Hwang et al. 2015; Lin et al. 2011);
3. A post-workshop phase (sometimes called the "implementation" phase) in which the actions decided upon in the workshop phase will be delivered (Lin et al. 2011).

Several management processes exist to apply the knowledge required to the effectively manage projects, being a process a "*set of interrelated actions and activities performed to create a pre-specified product, service, or result*" (PMBOK 2013, p.47). In the construction industry, several VM processes have been identified, 44 of which have been categorized by Cha & O'Connor (2005) according to their context of application. Remarkably, none of the VM processes of the ones presented by (Cha & O'Connor 2005) refers specifically to the end-of-life of a project and to decommissioning projects. This shows, once again, the lack of attention posed on decommissioning, as well as the need to investigate which of the categorized VM processes are applicable to decommissioning projects as well.

2.3. The Requirements for Successful Value Management in Construction Projects

Kelly et al. (2015, p. 28) list the prerequisites to ensure the smooth running of a VM study. These include:

- Agreement to participate by all parties involved in the study;
- Senior management support for the VM;
- An experienced and independent VM study leader;
- An appropriate team skill mix;
- An isolated workshop environment.

Other authors have elaborated on this list. For example, Hwang et al. (2015, p.5) classify 11 "success factors" of a VM study, including communication and interaction among participants, clear and unambiguous objectives of VM, and education on VM. Shen & Liu (2003), identify 23 critical success factors and grouped them into factors that are relevant for (i) the preparation phase, (ii) the VM workshop, (iii) the implementation of the generated proposals and (iv) other supporting factors. The four factors that showed the highest ranking were:

- Client support and active participation;
- Clear objectives of the VM study;
- Multidisciplinary composition of the VM team, which "*can be regarded as the most crucial requirement for the VM team*" (Shen & Liu 2003, p.489);
- A qualified VM facilitator;

Table 1 provides a summary of the requirements for successful implementation of VM, as highlighted by academics investigating the construction industry. However, the literature also highlights the difficulties surrounding how to measure the performance of VM studies (see for example (Lin & Shen 2007)).

Requirement for successful implementation of VM in the construction industry	
Overall consensus on the VM study and approach	- Agreement to participate to by all parties invited to the value study (Kelly et al. 2015, p.28) - Senior management support (Kelly et al. 2015, p.28) - Top management commitment and support (Hwang et al. 2015, p.5) - Good involvement of project stakeholders (Hwang et al. 2015, p.5) - Support from government sector (Hwang et al. 2015, p.5) - Education on VM (Hwang et al. 2015, p.5) - Communication and interaction among participants (Hwang et al. 2015, p.5) - Commitment of the stakeholders involved in the VM study (Male et al. 2007, p.108) - Participation and interaction (Shen et al. 2004, p.211) - Client support and active participation (Shen & Liu 2003, p.487) - Management support and approval (Fong et al. 2001, p.312)
VM team	- Appropriate team skill mix (Kelly et al. 2015, p.28) - The presence of client decision taker (Kelly et al. 2015, p.28) - Appropriate resource allocation (Hwang et al. 2015, p.5) - Clear responsibilities and roles (Hwang et al. 2015, p.5) - Having experienced participants with decision making authorities "*who can engage constructively then and there*" (Thyssen et al. 2010, p.28) - Multidisciplinary composition of the VM team (Shen & Liu 2003, p.487) - Project team formation (Fong et al. 2001)
VM study leader	- An experienced and independent value study leader (Kelly et al. 2015, p.28) - The way in which the total process is facilitated (Male et al. 2007, p.108) - Qualified VM facilitator (Shen & Liu 2003, p.487) - facilitator's efficiency in gathering information (Fong et al. 2001)
VM objective(s)	- Clear and unambiguous objectives of VM (Hwang et al. 2015, p.5) - Clear objectives of the VM study (Shen & Liu 2003, p.487) - VM enables the participants to set their goals (especially for critical tasks) and derive suitable solutions to fulfil the clients' requirement (Leung et al. 2002, p.68)
VM environment and time	- An isolated workshop environment (Kelly et al. 2015, p.28) - Sufficient time to conduct the evaluation analysis, as "ideas produced in the creative phase require extensive consultations and in-depth investigations", which is time-consuming (Shen et al. 2004, p.212).
Other requirements of the VM study	- Appropriate risk allocation and management (Hwang et al. 2015, p.5) - Innovation and critical thinking (Hwang et al. 2015, p.5) - Appropriate value job plan (Hwang et al. 2015, p.5) - The methodology employed (Male et al. 2007) p.108 - Budget setting (Fong et al. 2001, p.312) - Solution generated within the time limit (number of ideas and number of feasible ideas, cost or value of the ideas) (Fong et al. 2001, p.312) - etc.

Table 1. Requirements for successful implementation of VM studies in the construction industry

2.4. Value Management in Decommissioning Projects

The lack of academic publications relating to VM in decommissioning (see note in section 1) might be due to the widespread belief that there is limited value associated with decommissioning activities and that decommissioning is simply about dismantling and dealing with waste. Not only it is more difficult to define what the value of a decommissioning project is, but often there is also a lack of clarity about what is regarded as an actual "asset" and what is regarded as "waste". For example, assets can be defined as *"possessions of value, both real and financial",* and real assets include *"land, buildigns or machinery owned"* (Black 2003, p.15). So, considering a building on a nuclear site that is not in use anymore, is this building considered an asset (as it could provide the benefits to store nuclear material or equipment) or is it simply a legacy that needs to be dismantled? And again: is the land where the building is located an asset or a liability (as it might be contaminated and might require further work before being re-used)? Similar is the case of spent fuel, which consists of fuel that can be re-used (after special and expensive treatment) for future nuclear-related operations. Is this an asset or is it waste that needs to be disposed of? These are only a few of the many examples of ongoing debates within the industry where the line between what constitutes an asset and what constitutes waste is blurry. Ultimately, the definition of value of an asset in the decommissioning industry embraces several interrelated aspects, such as health and safety, security, environmental aspects, etc., hence its value is not merely defined through its financial value.

This leads to further difficulties concerning how to "value manage" a decommissioning project.

3. Method

3.1. Selection of the unit of analysis

This paper focuses on the case of value managing the nuclear decommissioning of Sellafield[4] (in the UK) due to a number of reasons. First of all, the UK has to deal with the largest European nuclear legacy together with the associated decommissioning challenges (NDA 2017b; Öko-Institut 2013), and Sellafield is the largest UK (and European) nuclear site undergoing decommissioning, both regarding the physical land that it occupies and the techno-socio-economic effort that it requires. Indeed, Sellafield hosts around 1,400 buildings, of which 240 are nuclear facilities (NAO 2015), concentrated on a 6 km^2 site (NDA 2017b), and its decommissioning plan incorporate several interrelated activities including reprocessing spent fuel from nuclear reactors, retrieving and packaging waste from existing storage facilities, treating radioactive waste, transferring waste to repositories and disposal facilities, demolishing buildings, and clearing the final site (NAO 2018, p.31). Hence, Sellafield is an exemplary case to investigate.

Secondly, Sellafield's decommissioning is estimated to take some 120 years and more than £160 billion to decommission Sellafield (i.e. around 70% of the total estimates of decommissioning the whole UK nuclear legacy, currently estimated at £229 billion (NDA 2018). These figures stimulate debate not only on the overall costs of this endeavour, but also on project temporality (Brookes et al. 2017). In fact, Sellafield's decommissioning taking more than 120 years, overturn the classical dichotomy of project management of projects being "temporary" and the organisations delivering the projects being "permanent" (with 120 years the project will be luckily to outlive the organisations). Hence, Sellafield is an representative case to research VM in decommissioning, as actions undertaken to ensure that Sellafield decommissioning is managed to deliver value have an impact that extend in a long time period and affecting a number of stakeholders.

[4] For a more detailed description of Sellafield, please refer to Sellafield's official website: https://www.gov.uk/government/organisations/sellafield-ltd [Accessed August 22, 2018], and to the official publications by the UK national Audit Office (e.g.(NAO 2018)) and the UK Nuclear Decommissioning Authority (e.g. (NDA 2017a))

Thirdly, Sellafield is owned by the UK Nuclear Decommissioning Authority (NDA), which is a non-departmental public body created through the Energy Act in 2004 (UK Government 2004). In 2016, the NDA published “the NDA value framework” (NDA 2016). This document is a reference providing guidelines for value managing decommissioning projects, and its publication shows the NDA’s understanding on the need to focus on the delivery of value to stakeholders, in terms of a number of interrelated subjects (including health and safety, security, environment, etc.). Therefore, being the NDA the owner and directly involved with Sellafield’s decommissioning, the decision to focus on Sellafield is reasonable.

Lastly, pragmatically, the authors have over the years built a network of stakeholders from Sellafield Ltd, the NDA, other UK government-owned and operated nuclear services technology providers and key Sellafield contractors, who are willing to collaborate in the development of the current research and were willing to be interviewed as part of the data collection process.

In summary, the decommissioning of Sellafield is highly complex, time consuming, extremely difficult to manage, and it involves a multitude of stakeholders. Consequently, the whole decommissioning of this site could be regarded as a “troll” project. i.e. as a creature that is difficult to tame and control (as defined by Klakegg et al. (2016, p.283)), and is therefore an exemplary case to focus on.

The analysis of Sellafield’s decommissioning is performed using interview surveys with experienced practitioners. The data collection and analysis is explained in the following sections.

3.2. Data collection

This research started with a preliminary literature review and non-structured discussion with decommissioning experts to identify the extent to which VM has been applied in the nuclear decommissioning industry. This was followed by a systematic review of the literature on VM in construction projects, and the selection of the method to collect and analyse primary data.

The collection of primary data was performed using semi-structured interviews (DiCicco-bloom & Crabtree 2006) involving participants selected through purposive sampling (Palinkas et al. 2015).

Interviewees were selected among senior employees of Sellafield Ltd (i.e. the organization managing Sellafield site), of the NDA (i.e. the organization that owns the site), of the Nuclear National Laboratory, as well as of key Sellafield contractors. A total of 26 interviews were conducted between January 2018 and March 2018, corresponding to a total of 27 participants, as two participants preferred to be interviewed at the same time. Twenty-four interviewees have more than 10 years of experience in the industry. Eleven interviewees are employed by Sellafield Ltd, five by the NDA, seven by the Nuclear National Laboratory, while four interviewees are major Sellafield contractors. The suggested length of each interview was 30 minutes, but 2 interviews lasted almost an hour, which was due to the eagerness of some of the interviewees to provide more detailed answers. On average, each interview lasted 25 minutes.

The data collection followed a two-step process. First of all, five preliminary interviews were conducted with two key stakeholders from Sellafield Ltd, one from the NDA and two interviewees from major contractors to gain a more detailed understanding of the research context. The following questions were used as a basis for the dialogue:

- How would you define “value” in the context of decommissioning projects?
- How would you define “value management” in the context of decommissioning projects?
- According to your experience, what are the major constraints and bottlenecks that affect the performance of decommissioning projects?
- What do you think are the most relevant drivers and barriers to the implementation of value management in decommissioning projects?
- Can you describe an example of a decommissioning project where value management was implemented and has been successful and one example in which value management was implemented, but it was not successful?

Following the first five interviews and a preliminary analysis of the information collected, the authors performed 21 additional interviews, also adding the following questions to the questionnaire:

- Which stakeholders are (usually) involved in value management studies?

- How is the performance of a value management study assessed?
- How is the "NDA value framework" implemented in practice?

The questionnaire was sent to the respondents at the same time as the invitation to participate in the research. The respondents were not required to answer the questions in a written form, but they were given the possibility to read the questions in advance and gather relevant information. In this way, the interviewees were also able to have time to decide if they wanted to participate in the research or not. All the interviewees were granted anonymization.

3.3. Data analysis

After permission for recording was granted, the interviews were recorded, and the conversation transcribed. Then, the transcribed material was systematically analysed through content analysis (Hsieh & Shannon 2005; Dixon-Woods et al. 2005).

Content analysis is "*a research method for subjective interpretation of the content of text data through the systematic classification process of coding and identifying themes or patterns*" (Hsieh & Shannon 2005, p.1278). Advantages of content analysis include the fact that it is transparent, unobstructive and flexible, as it can be applied to a variety of information (Bryman and Bell 2007, p.318). Qualitative content analysis aims to preserve the advantages of quantitative content analysis by applying, at the same time, a more qualitative text interpretation (Kohlbacher 2006).

Of the three main approaches of content analysis (i.e. the conventional one, the directed one and the summative one (Hsieh & Shannon 2005)), the conventional approach is used in this research as pre-existing theories are limited. Coding is achieved through an iterative and mostly inductive process of analysing the information, following (DeCuir-gu & Mcculloch 2011; Elo & Kyngäs 2008; Mclellan-Lemal & Macqueen 2003). Hence, the transcribed material was reviewed, and a first impression noted. Then, relevant pieces of the transcript was labelled to allow a preliminary coding. Discussion with colleague followed, and the coding was iteratively finalized.

Table 2 summarizes the example of how the code ultimately named of "Unknowns and uncertainties about the site conditions and consequent need of (additional) characterization[5]" was derived. As exemplified in Table 2, the knowledge of the interviewee and transcriber (i.e. one of the authors) was fundamental to understand the relationship underlying the fact that the so-called "unknowns" hinder the site condition, and the fact this is directly related to the need of additional analysis of the site before proceeding with a more detailed planning how to proceed with the decommissioning.

<table>
<tr><th>Extracts from the interviews</th><th>Preliminary coding and identification of sub category</th><th>Final coding</th></tr>
<tr><td>-"Knowing what you got in in the first instance! We are a very risk adverse organization […]. Sellafield has a complex range of buildings, from the ones that stopped operating in the late fifties, to those that stopped operating later this year, the level of knowledge of those facilities...is low!"

-"Lack of information of what the problem is, physical constraints in terms of the ability to get in/look at the building, quite a lot of conservatism, quite frequently, about selection of technology, but also understanding which safety cases you are going to put together."

-"Not knowing because the records were not absolutely precise or...there were no records at all!"</td><td>Unknowns and uncertainties about the site conditions</td><td rowspan="2">Unknowns and uncertainties about the site conditions and consequent need of (additional) characterization</td></tr>
<tr><td>-"Then characterization is a problem: what are the characteristics of the site, and how to get there"

-"It's the initial characterization of the material…is one of the biggest issue we have"

-"…and if the facility was sitting idle? It might have deteriorated!"</td><td>Need of additional analysis of the condition of the site to be performed through characterization</td></tr>
</table>

Table 2. Example of the coding and abstraction process

[5] Where "characterization" in the nuclear industry refers to the determination of the nature and activity of radionuclides present in a specified place (IAEA 2006, p.18)

4. Findings

4.1. “Value” and “Value Management” in the decommissioning industry

From the interviews it emerged that a unique definition of the meaning of “value” and “VM” in decommissioning projects is not agreed upon. Ten out of 26 interviews broadly described “value” and “VM” in decommissioning as respectively the “hazard and risk reduction” and “being efficient and effective” in managing that hazard and risk reduction. However, other themes were mentioned, such as the need to meet the stakeholders current and future needs, and the need to address the topic of intergenerational justice, which refers to the fact that the benefit of past and present nuclear generations are mainly for the present generations, while the burdens of dealing with long-lasting radioactive material is transferred to future generations (Taebi et al. 2012).

Only two interviewees explicitly and clearly described VM as a structured three-phase process and/or including a systematic function analysis with the ultimate objective of agreeing on the selection of a preferred option. “Brainstorming exercise” or “optioneering meeting” were used as synonyms of VM, as these were all broadly described as meetings requiring (i) a preparation phase (where preliminary data and information are collected), (ii) a workshop phase (where different options are evaluated), and (iii) an implementation phase (where the agreed preferred option is carried forward and eventually implemented). Indeed, the usage of different terminology (“brainstorming exercise” vs. “optioneering meeting” vs. “VM intervention”) highlights that interviewees have different views on the ultimate goal of (i) collecting information, (ii) attending a meeting and (iii) discussing options.

For example, the focus of an “optioneering meeting” was described mostly as the collection of different technical solutions, and it is likely therefore that an evaluation of the actual value (in terms of benefits vs costs, and not simply of the technical benefits) would be overlooked. Additionally, naming “a VM process” using the word “meeting” suggests that VM participants are neglecting the importance of the preparation phase, which is pivotal (as it is in cost estimation (Torp & Klakegg

2016)). Moreover, the usage of different terminology may also be an indicator of a lack of clarity surrounding the objectives of VM studies.

4.2. Constraints of Decommissioning Projects and the Potential Role of VM

The interviewees emphasized a number of constraints that affect decommissioning projects. These, according to the interviewees, often hinder the delivery of such projects. Table 3 organizes the coded constraints according to their frequency of occurrence, limiting the list to the constraints that have been highlighted during at least three interviews. The potential role of VM in decommissioning as derived by the researchers' analysis of the information collected is in section 5.

Included in the findings of Table 3, is the fact that more than half of the interviewees highlighted that "unknowns and uncertainties" about the site conditions are one of the major challenges that hinders the smooth progress of decommissioning, as it requires multiple characterization campaigns (where "characterization" in the nuclear industry refers to the determination of the nature and activity of radionuclides present in a specified place (IAEA 2006, p.18)). Known unknowns and unknown unknowns have been extensively discussed in the project management literature (Ramasesh & Browning 2014, p.190). These are defined respectively as "*uncertainties of which the PM [project manager] is aware and to which the techniques of conventional risk and opportunity management can be applied*" and "*Unrecognized uncertainties of which the PM is unaware"* (Ramasesh & Browning 2014, p.190). In nuclear decommissioning, "known-unknowns" and "unknown-unknowns" are (somewhat ironically) a well-known challenge (see for example (IAEA 2016b; Öko-Institut 2013; IAEA/OCED-NEA 2017)). Unknowns and uncertainties are likely to also be a challenge in decommissioning projects outside the nuclear industry, as after decades of operation, it is likely that certain records will be difficult to find, have not been updated, and that tacit knowledge of operators of the plants have been lost (e.g. due to retirement). In this situation, VM supports a systematic and structured collection of information, and a discussion of the existing knowledge among stakeholders.

Moreover, a VM workshop provide a forum for discussion amongst stakeholders on how to best address uncertainties and lack of information.

Similarly, the second-most emphasized constraint, i.e. “social-related challenges”, e.g. in terms of “people’s mind set”, can be tackled with the help of VM. Indeed, the first step to promote change in people’s mind-set is to understand where the issues lay and how employees can be motivated, e.g. through clear objectives, incentives, etc. Thus, collaboration and buy-in can be achieved by including the key stakeholders early in the decision-making process, for example through a VM study which could both tackle social challenges at both at a “macro-level” (Invernizzi et al. 2017) and a “micro-level” (Invernizzi, et al. 2018).

Conversely, not all the constraints highlighted during the interviews can be addressed directly through VM, which is the case of the “unavailability of stable funding”, of a “reliable supply chain and suitably qualified resources”, as well as of “regulatory challenges”. However, through a structured VM discussion on the value and costs of each activity, it may be possible to optimize available resources, highlight potential skills shortages as well as regulatory constraints, and therefore guarantee better planning.

Indeed, “poor planning” has been explicitly mentioned during five interviews, and it is strictly linked with other constraints mentioned by the interviewees and listed in Table 3, e.g. the “lack of clarity in the scope definition”. Scope definition is both driven and drives decisions about characterization, and it needs to include considerations regarding the “interface between decommissioning and waste management”, in order to avoid “over-engineering” and re-work (also mentioned during five interviews).

Lastly, the following constraints have been mentioned in less than three interviews and therefore not included in Table 3. In particular, two interviewees mentioned (i) the overall difficulty to gain new technology buy-in and highlighted that (ii) the overall conservatism that is widespread in the industry, which (combined) negatively affect the possible introduction of new technologies. One interviewee raised concerns regarding the lack of thinking about decommissioning already during the design of the nuclear facilities. These challenges can only be very limitedly addressed through VM at this stage of the project.

The key takeaway from Table 3 is that the majority of the constraints highlighted by the interviewee with decommissioning practitioners can benefit from VM studies, as VM can tackle the lack of communication and limited information sharing that affect decommissioning projects. VM can also provide a forum to discuss and make explicit project scope as well as improve project planning, especially when considering the complex interfaces that exist between decommissioning projects and waste management operations.

Table 3 also shows that the majority of these constraints, although particularly relevant in decommissioning, are not unique to decommissioning projects. In fact, constraints such as the uncertainties that exist in the earlier stages of a project, social-related challenges, and the availability of stable funding, are common to construction projects in general (and especially relevant to large ones).

Conversely, some constraints are more specific to decommissioning projects, such as the challenges caused by poor knowledge management or the lack of information regarding previous operation of the infrastructure (which might have lasted decades). Lastly, some constraints are exclusive to *nuclear* decommissioning projects, such as the complex interfaces between nuclear decommissioning projects and waste management operations, and the lack of disposal routes for nuclear material and nuclear waste, which are challenges that do not affect the non-nuclear industry.

Constraints of decommissioning projects	Extracts from the interviews that highlight constraints and bottlenecks of decommissioning project	The potential role of VM in decommissioning, as derived by the researchers' analysis of the information collected from the semi-structured interviews
Unknowns and uncertainties about the site conditions and consequent need of (additional) characterization	-*"Knowing what you got in in the first instance! We are a very risk adverse organization […]. Sellafield has a complex range of buildings, from the ones that stopped operating in the late fifties, to those that stopped operating later this year, the level of knowledge of those facilities...is low!"* -*"Lack of information of what the problem is, physical constraints in terms of the ability to get in/look at the building, quite a lot of conservatism, quite frequently, about selection of technology, but also understanding which safety cases you are going to put together."* -*"Not knowing because the records were not absolutely precise or...there were no records at all!"* -*"…and if the facility was sitting idle? It might have deteriorated!"* -*"Then characterization is a problem: what are the characteristics of the site, and how to get there"* -*"It's the initial characterization of the material…is one of the biggest issue we have"*	VM can support a systematic and structured collection of information, and a discussion of the existing knowledge among stakeholders. Moreover, a VM workshop can provide a place for discussion by the stakeholders on how to address uncertainties and lack of information. Characterization refers to the determination of the nature and activity of radionuclides present in a specified place (IAEA 2017). A VM study could support the analysis of the extent of characterization that is required and how it should be progressed
Social-related challenges (e.g. people's mind-set)	-*"You need the bigger picture, to get collaboration, to get momentum...too many people do not have the bigger picture"* -*"In decommissioning, there is no motivation. Which are the drivers? The only drivers are the saving…than it is better to sit and wait!"* -*"By bottlenecks you mean constraints? I know what you mean. It is...what I would say is: the main bottlenecks in decommissioning project is the people. It's the people! And again...it's a mindset, it's a culture, it's unnecessarily constraints, it's being blanked with processes and procedures. It's people wanting to use something they want instead what they need..!"* -*"Sites are 'set in their way', 'this is how we do this'! So: it's about the mindset and the about the system. They have their system, and if you want to change it…they would not want."*	The first step to promote change in people's mind-set is to understand where the issues lay and how employees could be motivated, e.g. through clear objectives, incentives, etc. Collaboration and buy-in can be achieved by including the key stakeholders (early) in the decision-making process, i.e. through a VM study.
Unavailability of stable funding	-*"Annualized funding! It's a problem since when the NDA arrived. If you are doing really well, you have no funding to continue, until next year. This takes away all the benefits…because you have to de-mobilise the team. The team might not be ready on the first of April. Maybe they went on another project, and even the learning curve is lost. Accelerating...if the money is there!"* -*"Put all the right pots of money in place, make sure that it can actually move forward into delivery"*	VM cannot deliver an increase in funding, or more stability in terms of the funding. However, through a structured discussion on the value and costs of activities, it may be possible to optimize available resources, e.g. through systematic resource management.
Unavailability of a reliable supply chain and suitably qualified resources when needed	-*"So it's a quite narrow market! There's certain amount of place in the market, and they still have to charge a price, and whatever that price might be… that could actually end up being the price…no other options!"* -*"Even when they get a number of tenders, for example, for a project, you know, it's a small number, there is only a certain number with the capability to deliver some of these things as well"* -*"There is often difficulty in finding the right suitable qualified experienced resource to the workplace, at the time you want them to be at the workplace"*	The VM study, especially if applied early in the project life-cycle, could highlight potential skills shortages and market constraints, and could also support better planning.
Regulatory challenges	-*"I think there is almost a myth around the regulatory environment, that is used almost as an excuse"* -*"Regulatory compliance? Yes, transport regulations, waste acceptance criteria…manager that operate the plant might not understand + they don't know what are the options..such as do not generate the waste in the first place! Minimize, compact, incinerate, etc., separate high and low radioactive waste. And BAT assessment."* -*"Now, I would never forget the head of the regulator stood up in front of 200 of us, [among] regulators and Sellafield employees and he quoted a lot of the regulations […]. He says 'as far as reasonably practicable', and he went through a number of regulations that quoted 'as far as it's practicable' …and said: 'so what I find on your site is that a lot of people are trying to build that gold-plated Rolls-Royce before you can actually start retrieval…but well actually, when you are looking at the regulations, when you are looking at that, you are probably breaking the law, because you should get to it quicker, because the risk is so high! You should be getting into that quicker and finding a flexible mean of doing that"* -*" …there are bottlenecks when it comes to sanction and funding" […]* -*"We do have at the moment a lack of signing off things which holds projects up"*	According to a number of interviewees some of the regulations are not well understood, and this might cause unnecessary over-engineering. The inclusion of all the key stakeholders, and (if/when possible) regulatory representatives as well, could be critical to improving value.

Knowledge and information management	*-"From the inception of an idea, you do the same kind of things, but it's… "we want to do this", you know, "we want to do that", but nobody tend to go around what is the real value of doing it in the first place. It's almost a given that there is a demand, you know what I mean? We do not question that demand too much"* *-"We do silo-work"* *-"Everyone sees its part of the jigsaw"*	VM can support knowledge and information sharing between stakeholders involved in different projects/activities. A VM workshop is also an excellent vehicle in itself to improve communication, foster team building and collaboration.
Lack of clarity in the scope definition	*-"Communications of the benefits that we actually want, so clarity of what the scope is, those are the two major ones for me"* *-"the project management and the client have had different understanding of what the project scope should actually be..[…]* *there was a mismatch between delivery to the client and that has to be resolved"* *-"The customer does not understand what is required to get the waste off the plant to the disposal site. So, we work as intermediary! "*	One of the main benefits of a VM study is that it can provide clarity in terms of the definition of the project scope, specifically, through the use of Function Analysis.
Lack of clear waste routes and availability of storage and disposal facilities	*-"I was used to work on radioactive waste inventories and […] there is an awful number of waste streams, waste that we have across the site, that we shuffled away in corners or in facilities and we don't have a recognized route for treating them"* *-" Constraints of decommissioning? Lack of disposal routes! You cannot dismantle a Magnox now…there is no point if you don't have an ultimate destination...you don't know where to put the waste"*	VM can support a systematic and structured collection of information, and can help to highlight which are the actual challenges that hinder the progress of decommissioning.
Poor planning	*-"Better planning! More assessment of the risks. Everyone wants to start with the project…and there is a risk to miss opportunities"* *-"..and then poor planning. We do have at the moment a lack of signing off things which holds projects up, we also have difficulty in procurement, that is a bottleneck, and again, the upfront planning would be to prevent the bottle neck"*	One of the main benefits that a VM study can provide is improving project planning, by promoting discussion on the "way forward" from the conceptual stage of the projects as well as at regular intervals during the project's life cycle.
Interface between decommissioning and waste management	*-"connecting the dots between the project team and the waste management team, the decommissioning team and etc. etc. it would have had a much more aligned and cost effective solution!"* *-[discussing a construction project to enable decommissioning] "the fact that these people [radioactive waste management people] were missing was reflected by the fact that they didn't know about the packages!"*	A VM study could promote a better understanding of the interface between a decommissioning project and waste management operations.
Over-engineering	*-"The regulator are, and the procedures we have on our side, I believe, good regulations! And good procedures! It's how they are applied. They need to be applied intelligently […]. They have been written by very intelligent and clever people who when they set certain criteria in the regulations that people have to meet, they have included a degree of margin in their assessment for the regulation. So, you've already got margin built in the regulations, per se, built in by intelligent people. So, taking the regulations and putting some more extra margin and more extra margin and extra margin to the engineering side of things…they end up being a way a way over engineered compared to what the need to do. The things is they need to go down to meet the regulations and you don't have to go anything more than meet the regulation. "*	Over-engineering could be avoided if every stakeholder has a clear understanding of the inputs and outputs of each task, and the VM study can help in addressing this issue.
Lack of space on site	*-"so you have got to safely build a facility, that facility has to be ready as we tear a building down, firstly if you are taking a building down, you have to make sure that there is the space for the material"* *-"but then you have no space for decommissioning? If you de-licence, you would not have space to store your waste, because you don't have the agreement with the Environmental Agency to store where it's de-licensed..."*	The space available cannot change with a VM study, but (similar to funding), the usage of the space available could be optimized.
Contractual and procurement agreement	*-"Customers have limited understanding of the NEC3 contract. It's a construction contract. And people struggle to understand it properly. With early warnings? They get very defensive […]. Contracting options are not selected properly by the customer. So, if the customers have already an idea, they might not have considered different options."*	The discussion around which are the best contractual arrangements during a VM workshop could support better decision making.

Table 3. Constraints of decommissioning projects and how VM can tackle these constraints

4.3. Requirements for Successful Implementation of VM in Decommissioning Projects

The interviewees showed overall less congruence in answering the question regarding the requirement for successful implementation of VM in decommissioning, than when answering the questions of the constraints of decommissioning. However, as discussed below, the answers provided by the interviewees were in overall accordance with the formalized requirements from successful implementation of VM in construction presented in Table 1. This denotes that most of the requirements that have been highlighted in the literature as relevant for the successful application of VM to construction projects, are relevant for decommissioning projects as well.

For example, the successful application of VM requires that consensus regarding the need of a VM intervention is shared among all the participants. During the interviews, one interviewee explained: "*once I did a workshop in which optioneering did not get the answer that people had expected, and people would say...then we selected the wrong criteria! Because this is the wrong answer!"*. This exemplifies how participants' consent, agreement and active participation has to be reached at the early stage of the VM study and, when possible, starting with a "partnering workshop" (Thyssen et al. 2010) to elicit the stakeholders' opinions. Indeed*, "projects that set off with the best intentions can often incur set-backs when there is not a shared understanding at the outset, when the desires of one stakeholder are not reciprocated, when the environmental issues are not balanced with the economic issues or the politics are at odds with social issues"* (Hayles et al. 2010, p.49). These challenges need to be recognised to get everyone on the same page from the start, and avoid starting with a solution and then making all the data fit that solution.

Moreover, the VM process should be systematically structured, and as one interviewee explained: *"It cannot be a "free for all conversation"! People have to buy in the approach, they have to accept their role! It's important to gain agreement for the criteria to evaluate options, and also on the weight of certain factors! Everyone one has different ideas of these criteria and weights. And if the criteria are* *not well-defined, you need to find agreement! Also, having sufficient time is important. This is enabling!"*

Additionally, having a multidisciplinary composition of the VM team is particularly important for decommissioning projects, and this emerged to be particularly relevant in the nuclear industry, where the number and variety of stakeholders is high. Therefore it is important to identify the key stakeholders with appropriate decision making authority, during the various stages of the decommissioning project lifecycle. A stakeholder mapping exercise could support this selection. The need of many stakeholders participating in the workshop could considerably increase the cost of a VM study. However, compared to the overall effort of nuclear decommissioning projects (as exemplified by Sellafield case), the total cost of additional and/or more comprehensive VM studies would be negligible, and would most likely be outweighed by the additional value that VM could provide.

During this study, interviewees stressed particularly the fact that regulators should be invited to participate to VM studies, because, even if they cannot provide a definitive go/no-go answer, they can still challenge the workshop participants, stimulate critical thinking and provide a relevant contribution. Sharing his personal experience on this topic, one interviewee stated: "*I will never forget when the head of the regulator stood up in front of 200 of us, [including] regulators and Sellafield employees and he quoted a lot of the regulations […]. He said 'as far as reasonably practicable', and he went through a number of regulations that quoted 'as far as it's practicable' …and said: 'So what I find on your site is that a lot of people are trying to build that gold-plated Rolls-Royce before you can actually start retrieval…but well actually, when you are looking at the regulations, when you are looking at that, you are probably breaking the law, because you should get to it quicker, because the risk is so high! You should be getting into that quicker and finding flexible means of doing that"*. It can be therefore argued that regulators could provide a relevant contribution, even if their comments during the VM workshop are not necessarily binding. Indeed, regulators "*ask different questions, and can give their opinion, or advice. They are very active participants and they challenge the workshop! I think they can bring a lot of value!*", as one interviewee explained.

Having "externals" to the project team can also be seen as a barrier for the success of the VM study, as the participants might feel uncomfortable to present their opinions openly, which is both an individual and cultural issue of great relevance. However, it has been argued that conflict also stimulates creativity, which can ultimately support better decision making (Hayles et al. 2010). Nevertheless, as excessive conflict can be a major hindrance to the effective operation of a team (Leung et al. 2002), the VM study leader should ensure that every participant have the appropriate time and opportunity to illustrate their points of view.

The VM study leader should also ensure that the VM study is not biased and that no pre-conceived options or pre-designed objectives are imposed. This can be very challenging, as human nature is affected by several cognitive biases (Evans et al. 1993), such as the "belief bias" which is the tendency to accept arguments that are aligned with our prior knowledge, values and beliefs, while rejecting counter arguments and the "anchoring bias", which consists of the tendency to rely heavily on the initial piece of information offered. These cognitive biases might affect VM studies. For example, two interviewees highlighted some issues during VM studies. One interviewee illustrated a situation in which "*some people put some additional constraints to block some options, because they did not like some of the outcomes. This rejected a lot of valid solutions!*", while the second one stated "…*they started half though the process! They had already got rid of all of those options somehow and now they had a set of criteria that could only lead to one solution! And during the morning, I raised a question… why are you starting from that point and not this point?' And they all looked at me as if I had just strangled a small pet! Because I said what they all knew! Because they were pushing for a certain outcome!".* This situation could be avoided by an experienced VM study leader, active participation of all the team and clear processes in place. Indeed, a key factor of a successful VM study, is having a VM study leader with appropriate technical, risk management and VM experience, preferably at a senior management level in the client organisation, adopting a clear process signed off by senior management. For the nuclear industry in particular, the VM study leader should not only be familiar with the VM study, but should also have enough experience to understand the socio-techno-economic challenges that characterizes the nuclear industry.

Furthermore, the objective of a VM study does not necessarily overlap with the aim of overall decommissioning projects itself. Indeed, the aim of the VM study can refer to the clarification of the project scope (at an early stage of a project) or the selection of the most appropriate procurement system (at a later stage of a project development), which are not the ultimated objective of a decommissioning project itself.

A well-structured VM environment and appropriate timescales allocated for the VM study also plays a pivotal role. For example, one interviewee had to facilitate a one-day VM workshop where a lot of different options on how to develop a project had to be assessed, and due to (i) a lack of time and (ii) insufficient information provided by the participants, it was impossible to evaluate all the options and select a preferred one. Another highlighted *"people need time, not to make a decision in one meeting…they need time to challenge!", while another explained "the first calibration takes absolutely ages! And then you need to speed up. You need a facilitator that knows that and can reassure the group. It might take one hour to assess an option and you have 20 to assess in 4 hours. It does not mean you will fail! You have to tell them: "you are calibrating yourself, it's going to get faster". It's a group development of storming, brainstorming and forming!".* A VM study is not only made of a "workshop phase" but participants need to know that VM also include a data collection phase (during which the participants need to prepare for the workshop and assemble data to identify project constrains and potential issues that might arise), and a post-workshop implementation phase both of which require additional time

Concerning the overall VM study, VM should be implemented in the early phase of the project, where the "*early phase*" can be defined as in (Kolltveit & Grønhaug 2004, p.547), i.e., "*the process and activities that lead to, and immediately follow, the decision to undertake feasibility studies and to execute the main project"*. Moreover, VM should be implemented at regular intervals during the lifecycle of a decommissioning project, to ensure the continue delivery of "best" value.

Especially for large projects, VM should not be advisory but compulsory, and the “option to abandon” or “the option to switch to a better solution” should be examined at each stage of the project development. As Male et al. (2007, p.113) explain, VM could be used to highlight when a project need complete re-planning. For example, when a project team becomes dysfunctionala VM study may prove that it is better to abandon the project using that project team.

5. Overall Discussion

5.1. The Response to the Research Questions

The research presented in this paper posited three research questions, namely:

- What does "value" mean in the context of decommissioning?
- What are the constraints that affect decommissioning projects that can be addressed with VM?
- What are the requirements for a successful implementation of VM in decommissioning projects?

Circumspection in arriving at an overall response to research questions is vital, particularly in exploratory studies as the current one. Any assessment of the degree to which this research answers these questions must be predicated mostly upon the capabilities and limitations of the research method employed, as well as upon the research context. Indeed, the research reported in this paper involved interview surveys with a tightly scoped sample, which is constrained by the nature of the industry investigated and the consequent difficulty in having access to information.

First of all, the response to the first research question provided by the interviewees emerged to be very ambiguous. There appears to be only a limited shared understanding of what value in decommissioning means. Furthermore there is a substantive disparity in the milieu in which interviewees' responses are situated. Some responses are centred around on the processual nature of value management and therefore conceptualise value in terms of project "efficiency". Other responses seem far more aware of a wider societal dimension that shapes "value in decommissioning" and respond in terms of international justice and responsibility to future generations. When this lack of clarity of what value means in decommissioning is juxtaposed with the need for clarity in understanding the scope and objectives for the single VM study, it is very difficult to clearly see how any application of VM in a decommissioning project can guarantee project success.

Nevertheless, leveraging on the systematic colleting, coding and analysis of the constraints of decommissioning projects highlighted by the interviewees, as well as the requirements for successful implementation of VM in decommissioning (mostly derived from the literature on construction projects in section 2.3), a way to implement VM keeping in mind the ultimate aim of improving the decommissioning projects performance can been suggested. Indeed, the constraints (or “barriers”) facing decommissioning projects (i.e. the answer to the second research question) do appear to have the potential to be ameliorated to some degree by VM (albeit that the internal linking logic between the constraint and its potential to be addressed by VM is provided by the researchers and not by the interviewees). In fact, the requirements for a successful implementation of VM in decommissioning projects (i.e. the third research questions) appears to be very similar to the requirement for a more general application of VM, and evidence was found to suggest that the factors identified by previous research in this area would be as important in decommissioning projects as in other applications. In this study, however, the need for a multi-disciplinary team (and particularly including representatives from the regulatory bodies), of an experienced VM study leader, and a clear definition of the VM objective(s) were particularly emphasized.

To respond in summary to the research questions posed in this paper, whilst VM has the potential to tackle the constraints surrounding decommissioning projects, and existing theory is applicable to the process of VM in decommissioning *per se*, the current lack of shared understanding of what value means to decommissioning severely inhibits, if not prevents, the use of VM in the context of these kinds of projects. Hence, VM has potential to improve the performance of decommissioning projects, but in order to achieve its full potential, there is a need to have an overarching and shared definition of “value” for decommissioning projects.

5.2. Contributions to Theory and Practice

The research presented in this paper provides a contribution both to theory and practice.

One of the major theoretical contributions of this paper is predicated upon the context of this research, namely that of decommissioning projects. The applicability and extendibility of project theory to decommissioning projects has not been previously researched, and there is an urgent need to fill this knowledge gap not only to what concerns the nuclear industry, by also regarding the end-of-life of other energy infrastructure, given the growing importance of this type of projects, as outlined in the introduction to this paper.

The first of such contributions to theory is one of reinforcement. Indeed, the findings of existing studies that give frameworks for successful implementations of VM (captured in Table 1 of this paper) and are replicated in the findings of this paper.

The second contribution to theory is derived from the identification of the constraints (or 'barriers') on decommissioning projects identified by interviewees. These are a useful addition to considerations of using project management approaches in different project environments such as those identified by (Haji-kazemi et al. 2015) (Terlizzi et al. 2016) (Engström & Stehn 2016) in other sectors.

A third theoretical contribution of this paper lies in its attempt to increase the understanding of delivering project value. The experience of the diversity of the understanding of delivering value in projects and the movement from processual and monetary conceptualizations of value towards wider and more holistic understanding is well explored by Laursen and Svejrig (2016). The research in this paper exemplifies this movement, as the interpretations of value expressed in this research range from focussed constructs of "efficiency" through to wide-ranging interpretations involving social justice. As such, they emphasise the need for some mechanism of reconciliation in constructs of value as an *a priori* requirement for VM. Laursen and Sverjig's call for independent theory to support this mechanism may be provided by such developments as Porter and Kramer's ideas of "shared value" (Porter & Kramer 2011).

A further contribution to theory refers to the conclusion that decommissioning projects need to be framed in a system lifecycle perspective, embracing both the project phase and operations, and considering the creation of value inter (and not only intra) organizations (Artto et al. 2016; Matinheikki et al. 2016). This takes this research into the analysis of decommissioning *projects* and waste management *operations,* also including the investigation of the interdependencies between decommissioning projects and of the management of the material and waste that arise during decommissioning.

Concerning the more practical contributions, the research highlights constraints relating to nuclear decommissioning projects as well as the requirement for successful VM in such projects. Hence, the results will aid project managers in their decision making, to improve organisational VM knowledge, to establish internal procedures, or to establish how VM studies should be implemented. In fact, the practical guidance on the delivery of public value is not specific to decommissioning projects. This paper, focusing on the Sellafield in the UK, references the development of a business case, through a five-case model, i.e. the strategic case, the economic case, the commercial case, the financial case and the management case (UK Government 2015). The UK NDA tailored this guidance on decommissioning in (NDA 2015; NDA 2013). However these documents do not discuss the actual implementation of VM interventions in practical terms. This paper, by first highlighting constraints that affect decommissioning projects and by discussing the requirements for successful implementation of VM, fills this gap providing a "more practical" guidance on how to implement VM.

Consequently, the findings relating to the constraints of nuclear decommissioning projects equip project managers with a list of constraints of nuclear decommissioning projects that are likely to affect nuclear decommissioning projects around the world. Moreover, the findings relating to the requirements for successful implementation of VM in nuclear decommissioning could support VM in other decommissioning projects in other industrial sector.

6. Limitations and Future Research

There are some limitations that affect this research which should be addressed in future research.

The first one is that VM has been investigated as a "stand-alone" intervention on decommissioning projects, and future research could investigate the possible integration of existing processes with VM ones. For example, some attempts have been made to suggest how to integrate risk management with VM (e.g. (Dallas 2006)). The integration between risk management and VM processes could for example broaden the discussion around risks (traditionally focused on strictly-technical and negative risks that might affect the projects) in order to embrace non-technical and market opportunities, as these might play a pivotal role during the project development.

A second limitation of this research is related to the decision to focus on a single UK nuclear decommissioning project (i.e. on the case of Sellafield), and on the decision to interview only stakeholders contractually linked to this major decommissioning endeavour. Therefore, future research should seek the perspectives of external stakeholders.

Moreover, the number and length of the interviews could be seen as a limitation. However, the interviewees were selected among senior experts and who are able to convey quality information in a very short time and in a very efficient way (see also section 3).

Additionally, follow-up research could also scrutinize the drawbacks (if any) of implementing VM in non-nuclear decommissioning projects, e.g. investigating the end-of-life of ageing infrastructure in other industrial sectors. Benchmarking VM practices applied to other industrial sectors could also provide valuable insight on how to integrate VM with existing processes concerning the selection of the best option to pursue, since VM "*in project-based organizations represents an attempt to see beyond the immediate results and a way to bring stakeholder input into defining project and program scope"* (Martinsuo & Killen 2014, p.64).

Additionally, as in most of the literature on VM, this paper has focused primarily on the benefits of applying VM in the decommissioning industry, and limited attention has been given to the costs of VM interventions (e.g. cost and time of organizing and managing VM studies). These increased project costs (and potential lengthening of the planning phase) are deemed necessary (as there is the expectation that overall project cost will ultimately be lowered, and the schedule of the project reduced). However, future studies should focus on these as well as the comparison of expected VM costs vs the actual reduction of the overall cost of the project.

Lastly, future work could also include the collection of practical example of successful and unsuccessful implementation of VM in decommissioning, e.g. through in-depth case studies.

7. Conclusion

Nuclear decommissioning projects are complex, long, expensive, and similarly to construction projects (Locatelli 2018), they are often delivered late and over budget. Moreover, decommissioning projects involve a large number of stakeholders such as governments, regulators, managing organizations, etc., and not all of these stakeholders have the same objectives which often hinders the decision-making process and project progress. VM is a methodology which can draw together conceptual thinking on a project as well as gather stakeholders to promote information sharing and ultimately agree on an optimal project solution.

The findings of this research show that the decommissioning project constraints that have been mostly emphasized by the interviewees embrace both constraints that are common to construction projects (e.g. the availability of stable funding), and constraints that are unique to decommissioning (e.g. the uncertainties about the site condition, such as its radiological contamination), and that the majority of these constraints can be at least partially tackled through VM. VM, however, should be carefully planned in other to achieve its full potential. This research highlighted that the requirements for successful implementation of VM in the context of decommissioning reflect the ones identified by the VM literature on construction projects, but that the need for a multi-disciplinary team (and particularly including representatives from the regulatory bodies), of an experienced VM study leader, and a clear definition of the VM objective(s) are particularly relevant in decommissioning projects and, specifically, nuclear decommissioning projects. Furthermore, this research contributes to the wider aim of improving the overall performance of nuclear decommissioning projects through the appropriate selection of improvement approaches. In this respect, understanding value (and applying more formal processes of VM) has a role in improving decommissioning through its utilisation since the very beginning of the lifecycle of a nuclear programme. Hence, a holistic and societally based view of 'value' might become a requirement for future investments in the nuclear industry.

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