Design principles for successful adoption of life cycle thinking in asset management decision-making

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Abstract

While Asset Management (AM) organizations are increasingly using Life Cycle Thinking (LCT) studies to assess their long-term plans, the translation of the LCT outcomes into actionable decisions often appears to be lacking. The international industry standard on AM can aid in improving organizational sustainability and is therefore used to study fourteen LCT cases. Subsequently, several design criteria and principles are suggested, based on existing literature. Clarity about ownership is necessary in order to align the perspectives of project leaders and LCT performers. Furthermore, attention should be distributed across the analysis and subsequent action, and better-fitting management styles should be applied.

Keywords: Life Cycle Thinking, sustainable decision-making, Asset Management

Introduction

Asset Management (AM) organizations increasingly adopt Life Cycle Thinking (LCT) methodologies such as Life Cycle Assessment in order to become more sustainable. Even though LCT has thus far been a valuable analytical tool, it does not necessarily lead to more sustainable asset management. LCT projects usually require individuals from various hierarchical levels of the organization to be involved, which introduces unwanted complexities in the adoption of LCT outcomes (Holwerda et al., 2021). Therefore, this research proposes design principles that could help AM organizations to successfully adopt LCT in decision-making.

The international industry standard on Asset Management, ISO 55001 (International Organization for Standardization, 2014b) has an important function in delivering sustainability (Marlow et al., 2010) by creating alignment between the corporate strategy of a business and its asset management processes. Moreover, the benefits of AM include informed asset decisions, improved organizational sustainability, and improved effectiveness (International Organization for Standardization, 2014a). Therefore, ISO

55001 forms the starting point of this research by being the main vehicle for explaining the complexities that AM organizations experience.

This research focuses on exploring actionable solutions that stimulate LCT-based decision-making by viewing the problem, objectives, and possible solution directions through the lens of Design Science Research.

Method

This research followed the Design Science Research (DSR) approach (Peffers *et al.*, 2007). The DSR approach consists of six steps, which are iterated in order to come to a demonstrated and evaluated design artifact. This research covers the first three steps, which are illustrated in *Figure 1*.

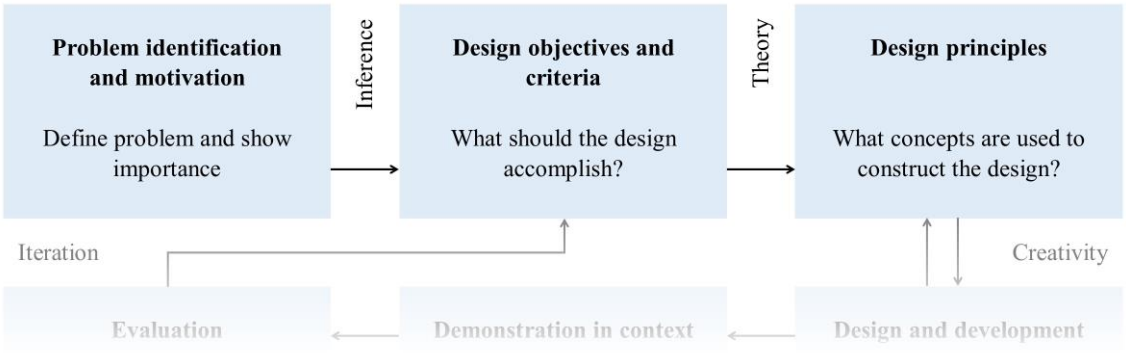

Figure 1 – Steps of the Design Science Research (DSR) methodology that were addressed in this research; adapted from (Peffers *et al.*, 2007)

Problem identification and motivation

To identify and motivate why the attention given to the adoption of LCT outcomes in decision-making seems to lag behind the attention given to the assessment itself, ISO 55001 (International Organization for Standardization, 2014b) was used as a theoretical framework. The framework was used to describe on the one hand how the LCT study was organized and on the other hand to what extent the LCT outcomes were adopted. Subsequently, the relation between these two was analyzed. Firstly, to describe how the LCT was organized, subsections 4.1 through 9.3 were translated into 21 organizational variables. These organizational variables, their definitions, and the corresponding subsections of ISO 55001 are provided in *Table 1*.

Table 1 – Variables that describe how the LCT study was organized

Organizational variables	**Definition**	**§**
Organizational context	The organizational context and its implications for the LCT study are understood.	4.1
Stakeholder expectations	The needs and expectations of stakeholders and their implications for the LCT study are understood.	4.2
Goal and scope	The goal and scope of the LCT study are aligned with the context and relevant policy.	4.3
Protocol for execution	The LCT study is performed following a predefined protocol.	4.4
Leadership and commitment	Leadership and commitment are demonstrated for the LCT study.	5.1

Policy framework	The relevant policy is available and used to provide a framework for the LCT study.	5.2
Responsibilities and authorities	Responsibilities and authorities for relevant roles are assigned and communicated.	5.3
Risks and opportunities	Actions to address risks and opportunities that potentially arise from the context are planned.	6.1
Objectives and planning	The planning to achieve LCT objectives is established and integrated with the planning of related activities.	6.2
Resources	Resources needed for the LCT study are determined and provided.	7.1
Competences	Individuals involved have the necessary competence to execute the LCT study.	7.2
Awareness	Individuals involved are aware of the LCT objectives and relevant policy.	7.3
Communication	The need for internal and external communication is determined and demonstrated.	7.4
Information requirements	The quality, availability, and alignment of information are managed.	7.5
Documentation	The LCT study is documented so that information is available and suitable for use.	7.6
Operational control	Processes, needed to meet the LCT objectives are planned, implemented, and controlled.	8.1
Management of change	Any planned changes are controlled and the unintended consequences are reviewed and mitigated.	8.2
Outsourcing	Outsourced processes and activities are controlled and knowledge and information are shared between the AM organization and the service provider.	8.3
Monitoring and evaluation	The LCT process and the performance of the other variables are evaluated and reported on.	9.1
Internal audit	Internal audits are conducted at planned intervals to determine whether the LCT objectives are met.	9.2
Management review	The LCT study is reviewed by top management at planned intervals to ensure its suitability, adequacy, and effectiveness.	9.3

Secondly, the remaining subsections of ISO 55001; subsections 10.1 through 10.3, were translated into one variable to describe to what extent the LCT outcomes were adopted. The definition that was used for this adoption variable is as follows:

> *The LCT outcomes are used to either correct or prevent negative impacts of the subject of study and these measures are continually improved through follow-up LCT studies.*

Both the organizational variables and the adoption variable were measured in fourteen retrospective LCT cases that were commissioned by Dutch AM organizations in various industries such as railway infrastructure, road and water infrastructure, manufacturing, government, and energy distribution. The LCT cases were performed between 2016 and 2023 and used various LCT methodologies: Life Cycle Assessment (LCA) (six cases); methodologies that are derived from LCA, such as Environmental Cost Indicator (ECI) and Environmental Product Declaration (EPD) (five cases); and methodologies to measure circularity, such as Material Circularity Indicator (three cases). The subjects of study ranged from the level of individual asset parts to the level of full asset portfolios. For each case, one individual involved was asked to participate in this research by indicating the maturity of the variables with respect to the LCT study. The maturity levels that participants could select from are 0) incomplete, 1) initial, 2) managed, 3) defined,

4) quantitatively managed, and 5) optimizing. Full definitions and instructions on how to use these maturity levels were adapted from the CMMI appraisal method (Information Systems Audit and Control Association, 2023).

This research aimed to analyze the relationship between the organizational variables and the adoption variable, by means of regression analysis. However, the large number of organizational variables and, moreover, the multicollinearity between them, would cause the regression coefficients to be unstable and difficult to interpret. Therefore, SPSS was used to perform a principal component analysis (PCA) in order to reduce the dimensionality of the organizational variables, as illustrated in *Figure 2*. An oblique rotation method (direct oblimin) was selected, because of the ordinality of the data. The PCA resulted in six distinctly different underlying factors that describe the variance in how the LCT cases were organized. Based on the pattern matrix and on the authors' expert opinions, names were given to the underlying factors (A through F). These factors were subsequently used as independent variables in the regression analysis.

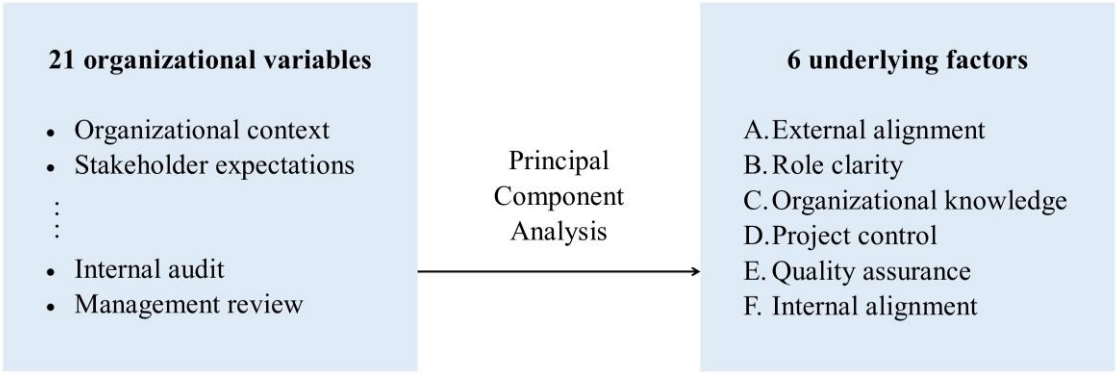

Figure 2 – Principal Component Analysis to reduce the dimensionality of the data

With the independent and dependent variables defined, regression analysis could be performed. However, no clear patterns could be identified in the regression coefficients when analyzing the data of all fourteen cases. Therefore, several cross-sections of the data were made and interesting differences were found between the data that originated from project leaders on the one hand (seven out of fourteen participants) and from LCT performers on the other hand (seven out of fourteen participants). Calculating the regression coefficients between the factors and the dependent variable for both perspectives separately helped to identify and motivate the complexities regarding the adoption of LCT outcomes.

Design criteria and principles

The complexities that AM organizations experience in their sustainable decision-making were identified and understood in previous step. Based on this, design criteria were formulated. These design criteria were the starting point for a focused literature study, in which existing methodologies were reviewed. From these methodologies, principles were selected that could contribute to the focus areas indicated by the aforementioned underlying variables and thereby could help meet the design objectives and criteria. From an overview of design principles, a selection of promising solution directions was made that could be used to increase the extent to which LCT studies lead to tangible sustainability improvement steps.

Problem identification and motivation

Descriptive statistics

From the descriptive statistics of the data from fourteen LCT cases, some valuable insights can be gained, despite the small sample size. The data shows that the LCT maturity varies largely between the participating cases as well as between the variables, as illustrated in *Figure 3*. The variance between the cases covers the full maturity scale, but overall, the medians tend to be on the lower half, which means that the participating AM organizations have only just started gaining maturity with regard to organizing an LCT study. When looking at the variance between variables, noteworthy is the relatively low maturity for the evaluation-related variables and the adoption variable. This is in line with preceding research, which indicated that the adoption of LCT outcomes in AM decision-making introduces some unwanted complexities (Holwerda *et al.*, 2021). This allows for further identification and motivation of LCT adoption complexities.

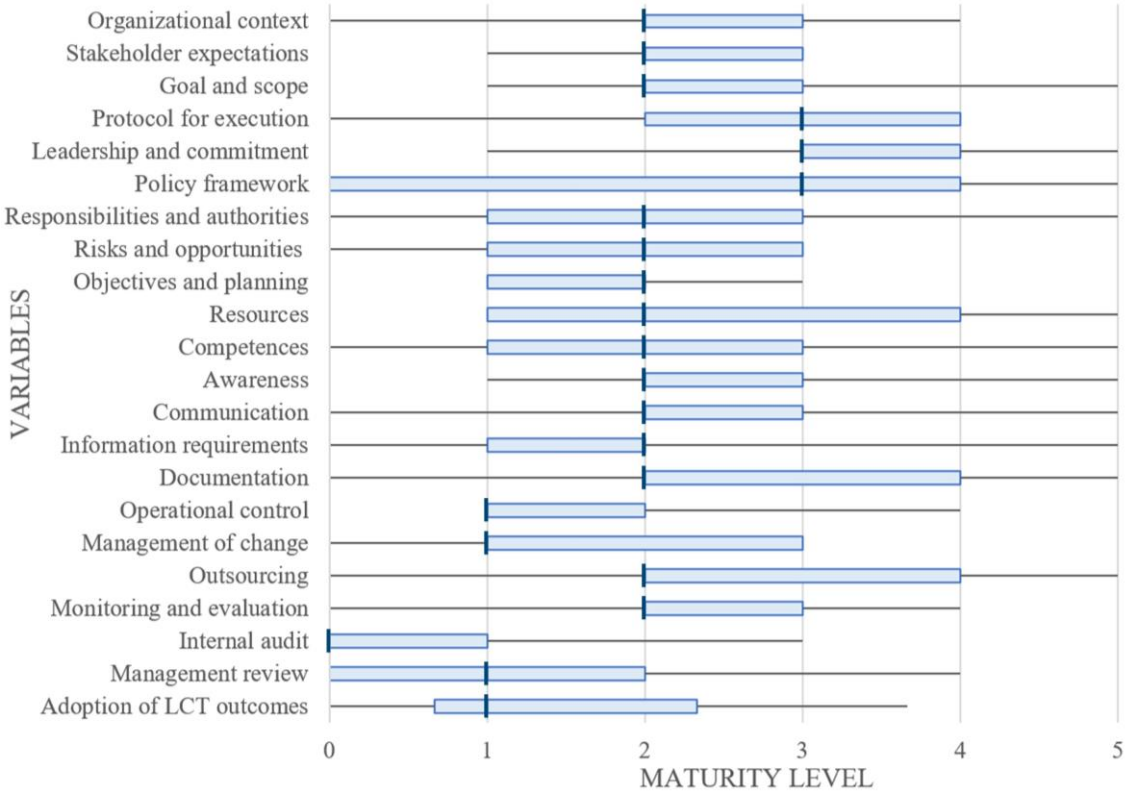

Figure 3 – Descriptive statistics of the maturity levels of the variables (quartiles 0 through 4)

Underlying factors

The variance between the cases and variables can best be described by six distinctly different factors. *Table 2* shows the pattern matrix of the principal component analysis. The names that were given to the underlying factors (A through F) are provided in the last row of the table.

Table 2 – Loadings of the variables on the underlying factors (A through F)

Variables	**A**	**B**	**C**	**D**	**E**	**F**
Leadership and commitment	0.831	0.165	0.273	-0.175	-0.100	-0.065
Documentation	0.725	0.112	-0.284	0.459	0.018	0.110
Stakeholder expectations	0.714	-0.455	-0.118	0.154	0.013	0.322

Monitoring and evaluation	0.543	0.129	0.406	-0.183	0.282	-0.332
Risks and opportunities	0.535	-0.036	0.426	0.362	-0.172	-0.331
Goal and scope	0.509	-0.038	0.121	0.214	0.202	0.395
Management of change	0.488	-0.422	0.055	0.299	0.224	0.326
Management review	0.092	0.804	-0.095	-0.207	-0.143	0.204
Responsibilities and authorities	0.051	0.757	0.095	0.461	0.281	0.096
Awareness	0.122	-0.015	0.916	-0.160	-0.095	0.189
Competences	-0.182	0.319	0.871	0.097	-0.204	0.039
Policy framework	0.129	-0.364	0.752	0.081	-0.045	-0.043
Outsourcing	0.028	-0.153	0.649	0.209	0.477	0.096
Resources	0.062	0.063	0.012	0.956	-0.097	0.038
Protocol for execution	-0.043	-0.072	-0.012	0.946	0.040	-0.007
Internal audit	-0.067	0.022	-0.239	-0.133	0.927	-0.050
Objectives and planning	0.020	0.308	0.119	0.249	0.390	0.390
Information requirements	-0.077	0.240	0.026	0.000	-0.182	0.928
Communication	-0.078	-0.143	0.196	0.087	0.277	0.796
Organizational context	0.355	0.244	-0.126	-0.334	0.032	0.550
Operational control	0.248	0.029	0.161	0.358	-0.040	0.547
Underlying factors	**External alignment**	**Ownership**	**Organizational knowledge**	**Project control**	**Quality assurance**	**Internal alignment**

Design criteria

The influence of each of these factors on the adoption of LCT outcomes varies largely when comparing the perspective of project leaders to the perspective of LCT performers, as illustrated in . Three underlying factors can describe the variance in the adoption of LCT outcomes very well. The relationship between these factors and the adoption of LCT outcomes and how this led to the definition of design criteria will be discussed below.

First of all, a strong relationship was found between ‘ownership’ and the adoption of LCT outcomes. Moreover, the perspectives of project leaders and LCT performers on this relationship are strongly divergent. LCT performers may feel ownership during the assessment itself and may not be aware of adoption barriers that potentially arise from the decision context. These barriers suddenly become visible to them when project leaders or higher management review the LCT outcomes. Project leaders need to review what impact can be made with the LCT study and how this impact can be achieved in order to take ownership during decision-making. This shared ownership complicates the transfer of LCT outcomes from the assessment to the decision-making process. This led to the definition of the first design criterium:

1. *The design should acknowledge and align the different perspectives and needs between project leaders and LCT performers in order to optimize shared ownership.*

Secondly, exploiting ‘organizational knowledge’ strongly impacts the adoption of LCT outcomes from the perspective of LCT performers. Project leaders depend on the expertise of LCT performers with respect to the subject of study and LCT in general in

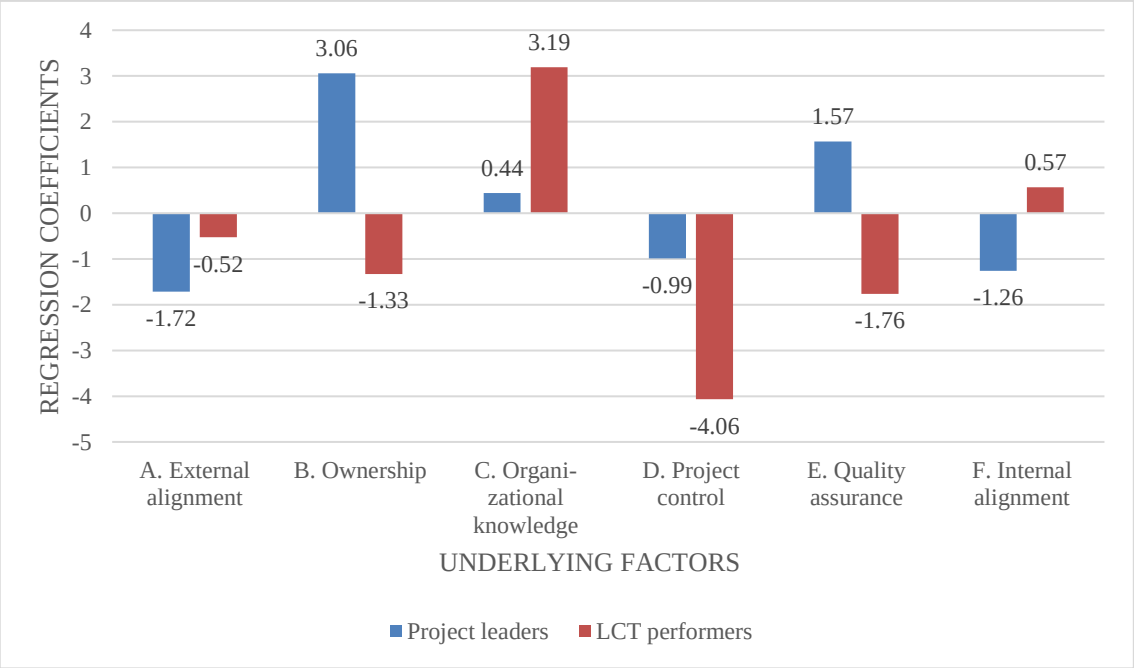

Figure 4 – Influence of underlying factors on the effectiveness of LCT, from the perspective of project leaders versus LCT performers

order for them to generate LCT outcomes. This expertise can originate from the competencies within the organization itself or from outsourcing to service providers. LCT performers, however, need guidance in the form of a policy framework in order to make the right assumptions and decisions during the assessment and thereby to come to LCT outcomes that are aligned with organizational policy. As the data shows, project leaders do not recognize this need for guidance, while they are in the position to provide it and it clearly increases the adoptability of LCT outcomes. Therefore, the second design criterium is as follows:

2. *The design should encourage project leaders and LCT performers to share and seek alignment of organizational knowledge, ranging from strategic to tactical to operational level.*

Thirdly, 'project control' explains the variance in the adoption of LCT outcomes very well, but surprisingly, the relation is negative. This means that the more a project is controlled, for example through the provision of resources and a protocol for execution, the less likely the LCT outcomes are successfully adopted in decision-making. A possible explanation for this is that AM organizations try to control the LCT process too much and consequently ran out of resources needed for the final steps of an LCT project. The tendency to overlook the evaluation is also slightly reflected in the perspective of LCT performers on the influence of factor E, 'quality assurance'. Therefore, a third design criterium is defined:

3. *The design should help manage the distribution of attention between the assessment itself and the adoption of outcomes.*

Another explanation for the influence of project control may be that an LCT study is not easily controlled by measures such as standardized protocols because LCT requires trust in the expertise of LCT performers and has to handle a high degree of uncertainty (e.g. difficulties in gathering the right input data, choices to be made about the use and analysis of the data). The negative influence is mostly perceived by LCT performers, which potentially indicates that tight control does not allow them to flexibly deal with the challenges and to collaborate with colleagues and departments whenever necessary. This

limits the awareness about the LCT study, which may complicate the adoption of LCT outcomes. This led to the definition of a fourth design criterium:

4. *The design should elicit management styles that match the different types of complexities faced.*

The other three underlying factors do not influence the adoption of LCT outcomes strongly enough to be further discussed or translated into design criteria.

Design principles

Literature was researched to borrow various design principles from existing methodologies in order to address the above-defined design criteria.

A principle that can be used to form the basis of the design is the Deming cycle, which prescribes that in order to achieve continual improvement four activities should be iterated, namely: plan, do, check, and act. Even though AM organizations are used to operating in line with the Deming cycle, the data shows that during LCT activities they mostly pay attention to 'plan' and 'do', while the 'check' appears to be difficult and the 'act' is often even lacking. Therefore, the Deming Cycle is selected as a design principle to shift the focus from merely the assessment itself to the adoption as well. Gemechu et al researched how the Deming cycle could be implemented during Life Cycle Management activities and prescribe eight practical steps (2015), which are provided in *Table 3*. Similarly, the Organisation for Economic Co-operation and Development (OECD) provides eight practical steps as guidance on sustainability impact assessments (2010), which also match the Deming cycle very well. Both can be used as inspiration for putting the Deming cycle to practice during LCT activities and, more specifically the last few steps can be used to consciously pay attention to the adoption of outcomes (design criterium 3).

Table 3 – Comparison between the Deming cycle and other frameworks

Deming cycle	(Gemechu *et al.*, 2015)	(Organization for Economic Co-operation and Development, 2010)
Plan	1. Set policies – set goals and determine the ambition level	1. Screening the proposal: deciding whether an LCT is needed
	2. Organize – get engagement and participation	2. Scoping the assessment: deciding the extent of the assessment to be conducted
	3. Survey – overview of where the organization is and wants to be	3. Selecting tools or methodologies to match the scoping
	4. Set goals – select areas where the efforts will be directed, determine goals, and make an action plan	4. Ensuring stakeholder participation: deciding on the role of stakeholders
Do	5. Make environmental and social improvements – put the plan into action	5. Analysing the economic, environmental, and social impacts
	6. Report – document the efforts and their results	
Check	7. Evaluate and revise – evaluate the experience and revise policies and organizational structures as needed	6. Identifying synergies, conflicts, and trade-offs across these impacts
Act	8. Take it to the next level – set up new goals and actions, more detailed studies, etc.	7. Proposing mitigating measures to optimize positive outcomes
		8. Presenting the results and options to policymakers

The challenge of shared ownership can be addressed by step four of the OECD framework OECD: deciding on the role of stakeholders (2010). Additionally, the RASCI matrix is a well-known tool among AM organizations and could be used for this purpose. Gemechu stresses the importance of cross-functional teams in step two and names some crucial success factors for such teams, such as a common frame of reference, empowerment, and support from senior management (2015). Even though cross-functional teams will contribute to the collaboration needed for LCT, it does not fully address the different perspectives and needs between project leaders and LCT performers. Goedkoop et al. recognize a disconnect between both roles and questions if they speak a different language (2015). To tackle this chasm, they suggest five steps, among which *finding a shared language*. To address the shared ownership (design criterium 1), this five-step approach could be used, in combination with the RASCI-matrix and cross-functional teams.

When reviewing the literature on aligning organizational knowledge, many methodologies are similar to or based on the organizational alignment model (Tosti, 2007), which prescribes translating a mission into goals, goals into objectives, objectives into activities, and activities into results. Even though such a translation of organizational knowledge is necessary, the model only addresses the top-down translation. As Goedkoop et al. argue, LCT performers mostly use a bottom-up approach instead and struggle to connect the LCT outcomes to the organizational goals that were translated top-down by the project leaders (Goedkoop *et al.*, 2015). In order to allow organizational knowledge to be shared and aligned in two directions the Line of Sight could be used as a design principle. It is a well-established term in the field of AM that represents the bilateral connection between strategic AM goals and operational activities. Furthermore, (Gemechu *et al.*, 2015) and (Organization for Economic Co-operation and Development, 2010) could again offer guidance in addressing design criterium 2.

Finally, literature was researched in order to address the fourth design criterium. The research data shows that the use of planning and control mechanisms (factor D: prerequisites) is not an effective response to the complexities experienced regarding the adoption of LCT outcomes. Maylor and Turner suggest that the nature of the complexity should be determinative of the type of response to this complexity (2017). The complexities that AM organizations experience in their sustainable decision-making tend to be socio-political or emergent in nature, rather than structural. Other complexity responses, such as *relationship development* and *flexibility* may therefore be a better fit for some of the complexities experienced. Hence, the work of Maylor and Turner could be used as a design principle to address the fourth design criterium.

Conclusion and discussion

AM organizations are experiencing complexities in the adoption of outcomes of LCT studies. This research revealed several underlying factors that can explain these complexities. First of all, the perspectives of project leaders and LCT performers on how an LCT study should be organized in order to come to adoptable outcomes differ, while both roles are crucial for the effective use of LCT. Secondly, organizational knowledge, such as expertise and policy documents contributes to the successful adoption of LCT outcomes in AM decision-making. However, the knowledge is often distributed over various stakeholders and not automatically exchanged or aligned between project leaders and LCT performers. Lastly, a focus on project control appeared to be an ineffective way to address the complexities experienced during an LCT study, possibly because LCT requires trust in the expertise of the LCT performers and the process has to handle a high degree of uncertainty. It may be interesting to explore if project control can be focused more on the actual use of the LCT outcomes in decision-making processes.

In order to improve the effectiveness of LCT studies, four design criteria were defined, based on the above-mentioned underlying factors. A literature review led to various design principles, borrowed from existing methodologies. First of all, the distinction being made between the analysis and decision-making phases could be used to consciously distribute attention between the assessment itself and the adoption of outcomes. Finding a shared language may help to better align organizational knowledge in LCT projects and thereby improve the collaboration between project leaders and LCT performers. Furthermore, addressing the complexities using a matching management style may help AM organizations to better manage these complexities and thereby to ease the adoption of LCT outcomes in decision-making.

This research addressed the first three steps of DSR, which led to various design principles that could be used to improve the effectiveness of LCT studies. Future research is recommended to design and evaluate solutions based on the proposed principles. With regard to the limitations of this explorative study, future studies should focus on the verification of our results in larger sample sizes and the possible inclusion of national differences. As such this research provides a starting point for designing a solution to improve the adoption of LCT outcomes in AM decision-making.

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