Design framework for transitioning from linear to circular in the construction industry: focussing on the installed base

T.A.J.C. (Tim) van Pelt *, supervised by: S. (Silu) Bhochhibhoya, A.G. (André) Dorée

Department of Construction Management and Engineering, Faculty of Engineering Technology, University of Twente, P.O. Box 217, 7500AE Enschede (NL)

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A B S T R A C T

The construction industry, based on a linear production model, is the most resource intensive sector in the world and thereby responsible for depleting the global resources of the planet Earth. The Circular Economy (CE) is considered to be a solution that should reduce these negative environmental impacts. To date, most academic and grey literature on CE primarily assumes that designs are created from a blank sheet, as if one would start from scratch. However, considering the built environment, there already is an installed base as a starting point (i.e. present infrastructure). Hence, in improving the level of circularity in the construction industry, researchers overlooked a field of high potential; namely the residual value of the installed base. As such, this paper focusses on identifying the aspects ought to be available in order to optimise the circular value of currently existing bridges and viaducts when (re)designing for maintenance & replacement tasks. Using Design Science Research, the results of a literature study, multiple interviews and a design workshop led to an established design-framework. This framework is validated by a management team and thereafter verified in a case study with the help of design engineers. The main results that derive from this study are that reliable data as input for design trade-offs is crucial in order to provide transparency and guidance in decisions during the design process. Moreover, a wider inventory of available an releasing assets in the region would facilitate supply and demand streams for reused components. Deeper cooperation and involvement of multiple partners in the supply chain and proper client-contractor-owner conversations on expectations can further stimulate the shift towards a CE in the construction industry. Thus, when improving CE in the construction industry, a key element lies in optimising the circularity of the built environment by fully utilising its residual value.

1 INTRODUCTION

Due to a growing global population and human welfare, our planet has to withstand an increasing amount of stress on its overall system (United Nations, 2015; IMSA Amsterdam and Circle Economy, 2013). According to the World Wide Fund for Nature (2010), due to this excessive exploitation, the world population will need almost 3 planets in 2050. Hence, the key challenge for the future will be to meet the demand of the consumers within the limits of planet Earth.

Although our economy is continuously evolving and proceeding, it has always been based on the one fundamental sequence of a ‘take-make-dispose’ pattern (Ellen MacArthur Foundation, 2013), better known as a linear economy. This model of linear production creates a stream of redundancy in terms of excessive use of materials, inefficient supply chains, end-of-life waste, deterioration of ecological systems and massive energy consumption. In short, the linear production model depletes the global commodities of planet Earth.

To encounter this trend of exhausting and deteriorating the earth’s resources, in 1987 the concept of sustainable development is proposed by the World Commission on Environment and Development. Since then, sustainability concerns have been increasingly incorporated into both the agendas of policymakers and the strategies of companies (Geissdoerfer *et al.*, 2017). One development within sustainability is the concept of the *Circular Economy (CE)*, referring to an industrial economy that is restorative by intention; aims to rely on renewable energy; minimises, tracks, and eliminates the use of toxic chemicals; and eradicates waste through careful design (Ellen MacArthur Foundation, 2013). The circular economy is gaining more and more attention all over the world, indicated by the steep increase in the number of publications on CE, reaching a more than tenfold growth in the last 10 years (Geissdoerfer *et al.*, 2017). Despite the major attention for CE, concrete practice of the topic in construction projects is still marginal (Adams *et al.*, 2017).

Zooming further in on the construction industry, Iacovidou et al. (2017) pointed out that the sector is a bulk consumer of raw materials and energy, making it the most resource intensive sector in the world. Additionally, the construction industry in general is unfortunately based on a linear production model as well. Therefore, a paradigm shift in this industry is essential to discontinue the growing depletion. The concept of CE is considered to be a solution that should reduce these negative environmental impacts within the construction industry.

Hence, on a global scale policy makers are incorporating CE goals into their policy documents (Swiss Academy of

* Corresponding author.
E-mail address: timvanpelt11@gmail.com (T. van Pelt).

Engieering Sciences, 2014; World Economic Forum, 2014). As for the Netherlands, in 2016 they developed a 'Government-wide Programme Circular Economy' in which they defined that *"the ambition of the cabinet is to fully realise a circular economy in 2050"*. Building on this statement, Rijkswaterstaat, the executive agency of the Dutch Ministry of Infrastructure, is even more progressive and has spoken out the ambition to work circular already in 2030.

The Dutch infrastructure counts for more than 40.000 bridges and viaducts, many of those infrastructural assets arising shortly after the second world war, when the Netherlands were in reconstruction, in the '50s and '60s of the last century. With a total estimated value of around 350 billion euro and high intensity usage, TNO (2014) emphasises that the status of these assets is crucial for the Dutch economy. Experts state that the 'old-school' approach of demolishing the current structure and build a complete new one, is simply not sufficient due to a lack in financial resources and manpower (Sanders, 2016). Therefore, Rijkswaterstaat has established the 'Maintenance & Replacement task', to deal with the increasing amount of traffic and heavier road freight. The objective of this task is to prioritise projects and 'upgrade' dozens of infrastructural assets in the upcoming decennia for the purpose of realising expansion and making them futureproof. For this task, Rijkswaterstaat is increasing the budget with more than €200 million per year, making it one of the largest maintenance tasks ever (Van Wijck, 2018). Furthermore, Rijkswaterstaat is eager on incorporating CE in the upcoming Maintenance & Replacement task.

In the emerging literature on CE, *design* has been recognised as a catalyst to move away from the traditional linear model towards a more circular economy (Moreno *et al.*, 2016; Institution of Civil Engineers, 2012). However, to date, most academic and grey literature on CE has been on designing new short- and medium-lived consumer products in a circular manner (Benton, Coats and Hazell, 2015; Pollard *et al.*, 2016). Moreover, these studies primarily assume that designs are created from a blank sheet, as if one would start from scratch. However, considering the built environment, there already is an installed base as a starting point (i.e. present infrastructure) and therefore 'greenfield thinking' is not fully applicable. Hence, while focussing on improving the level of circularity in the construction industry, researchers overlooked a field of high potential; *namely the residual value of the installed base*.

Combining this observation with the maintenance task of Rijkswaterstaat and her ambition to transition from a linear economy to a circular one, the opportunity for improving the level of circularity in the Dutch construction industry, is in optimising the circular (residual) value of the present infrastructure during (re)design assignments.

Currently however, an investigation has not yet been made into the necessary elements required to stimulate this transition towards a circular infrastructural sector. Therefore, this article aims to identify elements that can facilitate the transition from linear design to circular design in the Dutch construction industry. More specifically, this paper's objective is on identifying the *aspects* ought to be available in order to optimise the circular value of currently existing bridges and viaducts when (re)designing for maintenance & replacement tasks. The final goal is to outline a 'design framework' in which these essential aspects are composed.

The structure of the paper is as follows: first the project strategy is given and thereafter the research method plus the findings are depicted. Subsequently, the synthesis of the findings is presented and the design framework is outlined. Finally, after a discussion of the research and its results, conclusions are established.

2 RESEARCH STRATEGY

In the previous section, the research gap is illustrated and the objective of the article is given. To embark on this research project, the current section provides the strategy that is established for this project.

Johannesson and Perjons (2014) defined a *research strategy* as an overall plan providing high-level support for conducting a research study. Such a strategy needs to be complemented with *research methods* that can guide the research work on a more detailed level. Research methods describe how to collect and analyse data during the research (e.g. through interviews, observation or focus groups). Thus, a research strategy offers high-level guidance, while a research method can be seen as a technique or tool for performing a specific research task. Further elaboration on the research methods used in this project is given in section 3.

The research strategy used in this project is based on Design Science Research (DSR). According to Van Aken et al. (2016), "DSR is a domain-independent research strategy focused on developing knowledge on generic actions, processes and systems to address field problems or to exploit promising opportunities. It aims at improvements based on a thorough understanding of these problems or opportunities." DSR utilises an iterative approach of analysing the problem, designing a solution and developing it further in cycles of testing and redesign. Considering the objective of this research, defining a design framework, DSR is regarded as a suitable project strategy. Furthermore, this research focuses on the development of the design framework and thereafter testing and redefining it (see Johannesson and Perjons (2014) '*Development- and Evaluation-Focused DSR'*), therefore consisting of two phases, a 'development phase' and a 'testing & refining phase'. These phases are described in the following subsections as well as they are depicted in Figure 1.

The development phase is established to collect relevant data that can function as input for the development of the design framework. For this purpose, several data collection methods are used. A (*I.*) literature study, a (*II.*) design workshop and (*III.*) interviews were conducted in order to reveal aspects that may be able to optimise the circular value of present infrastructure. Furthermore, these steps were used to obtain a holistic viewpoint on characteristics concerning the construction industry, the built environment and (circular) design processes. Moreover, the design workshop and the interviews created further insight in (circular) design procedures. This data helps understanding why certain kind of trade-offs and decisions are made during the design phases and what type of input-aspects are needed for those decisions. Combining the three methods of the development phase, an initial draft design framework is the result.

The testing & refining phase is established to test the first draft and thereafter, by utilising the provided feedback, refine

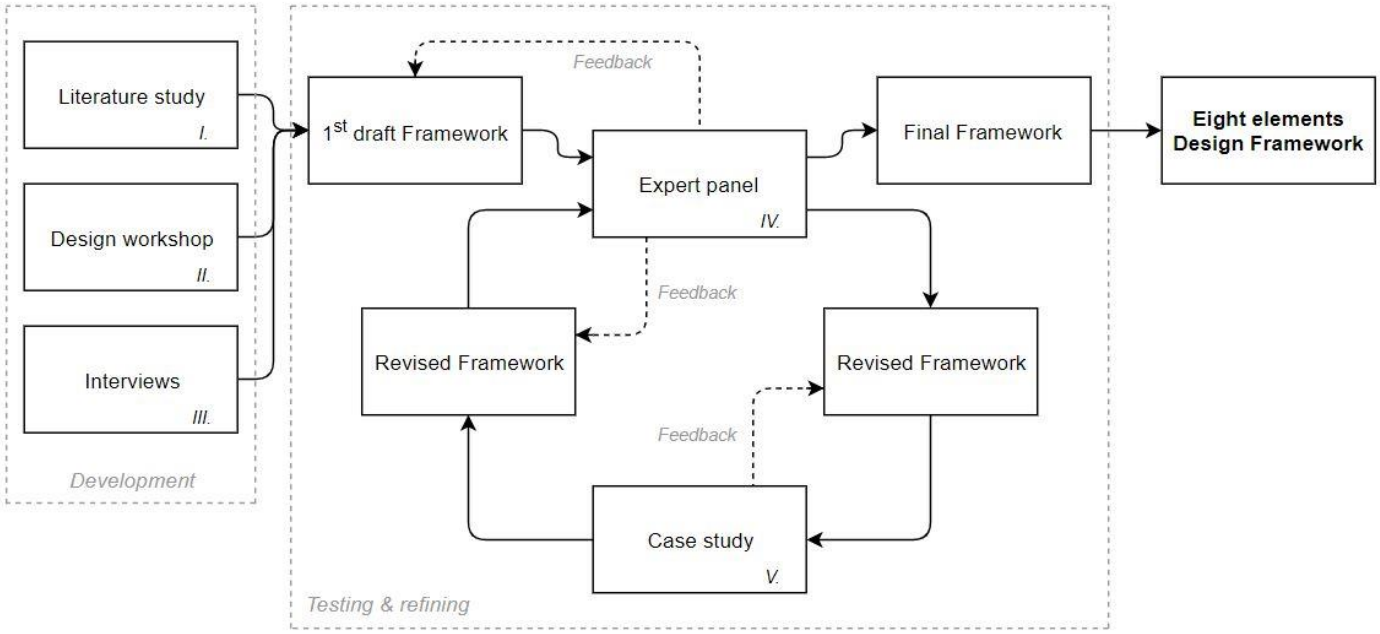

Figure 1. Research design

the framework. For this phase, two different methods were used. First, an (*IV.*) expert panel was consulted to validate the framework for completeness and correctness. Utilising the feedback from the expert panel, the design framework was slightly altered. Hereafter, the refined version was tested in a (*V.*) case study to check the functioning of the framework in a realistic case context.

As is outlined above, the DSR strategy combines multiple research methods and can therefore be called a *mixed methods approach* (Johannesson and Perjons, 2014). The mixed methods approach is related to the principle of triangulation, which is about viewing the same phenomenon from different perspectives. By conducting these steps, data triangulation is obtained and therefore validity of the research is increased (Verschuren and Doorewaard, 2015).

3 METHOD & FINDINGS

To work towards the research goal, several different methodological techniques were deployed. The combination of these techniques produced the research design of this project as is illustrated in Figure 1. In this section, deeper elaboration on the research methods is given. Furthermore, after an explanation of the research method, the findings that occurred during that research step are described.

3.1 Literature study

To date, most academic and grey literature on CE has focused primarily on the development of new business models, with some of the latter studies addressing design strategies for a CE, specifically in the area of resource cycles and design for product life extension (Moreno *et al.*, 2016). However, most researches focus on industrial product design instead of designing for construction industry. Hence, limited research is done on the application of circular economy principles in the built environment and literature on this topic is scarce. Nevertheless, some articles and reports were found relevant and cover the specific topic. Furthermore, by conducting some cross sectorial research, several additional tools and approaches could be adopted that are posed to fulfil the objective of stimulating the transition towards a CE.

One of the aspects addressed commonly in research, is managing Construction & Demolition Waste (CDW), one of the major areas where circularity can be improved. It is commonly known that the construction sector is a bulk consumer of raw materials and energy. In fact, the Dutch constructions sector is for more than 90% depending on raw materials such as iron, aluminium, copper, sand, clay, limestone and wood, together accounting for an about 260 million tons in 2010 (ABN AMRO and Circle Economy, 2014). The same resource is also stating that from this 260 million tons of raw materials, 23 million tons ended up as waste, which is responsible for 37% of the total waste stream in the Netherlands. To encounter this and improving the management of CDW, a Waste Management Plan (WMP) can be introduced. According to Gálvez-Martos *et al.* (2018), such a plan can forecast and record released materials arising during the construction phase and create insight in potential ‘second life’ options, thereby optimising residual value. The tool has been proven as an effective measure for the actors involved when (re)designing construction projects to improve the performance of CDW management.

One aspect that impedes successful improvement of CE, is the lack of a proper measuring tool to assess the level of circularity in products and designs (Haupt and Zschokke, 2017). As the saying “*What gets measured, gets done”* implies, such a tool is necessary in order to control and alter the aspects of circularity. One way to help this measurement is by introducing an LCA. Authors consistently encourage the use of Lifecycle Assessment (LCA) tools as key to enable producers and designers to assess the life cycle of a product and subsequently manage material choices for ecological optimisations (Hertwich, 2005; Van Nes and Cramer, 2006). This is furthermore stipulated by Haupt and Zschokke (2017), who state that an LCA is a comprehensive tool to assess the environmental impacts of products, end-of-life treatments and also economies at the level of society. A LCA is therefore a tool that is suitable to assess the environmental performance of circular products and designs but also large-scale changes, for example the movement towards a more circular economy.

According to Adams *et al.* (2017), a third aspect that can stimulate further adoption of CE in the construction industry is the integration of a holistic approach across the supply chain. A lack of this integration is identified as key challenge for implementing CE in the built environment. Rijkswaterstaat (2015) more specifically describes this approach as holistic integration of the construction chain, essential for improving the low value of many construction products at the end of life.

A last aspect that is described in literature as essential to improve the level of CE as a whole, is the change in mind-set required to obtain CE awareness with design practitioners. De los Rios and Charnley (2017) argue that this change in mind-set should be driven by environmental awareness and is required to execute both technical and strategic changes in design for CE. According to Cristoni and Tonelli (2018), for organisations participating in a CE sector, this is one of the most important elements in order to enhance the level of circularity in an industry.

In short, conducting a literature study resulted in the following design framework aspects:

(1) Waste Management Plan
Reason: - charts and documents the CDW streams
- influences the designers mind

(2) Measuring tool incl. LCA
Reason: - quantifies 'intangible' aspects
- compares alternatives in design stage

(3) Construction chain integration
Reason: - diminishes the intra-sectorial knowledge gap
- facilitates transmitting information in design stage

(4) CE awareness (mindset)
Reason: - arouses intrinsic motivation of designer
- influences the designers mind

3.2 Design workshop

After a thorough (*I.*) literature study, a (*II.*) design workshop was organised in order to create insight in the way of thinking during the process of designing a viaduct. This data is crucial in helping understand why certain kind of trade-offs and decisions are made during the design phases and what type of input-aspects are needed for those decisions.

Throughout the workshop, three design engineers (i.e. design leader, modeller and structural engineer) worked on a realistic design case of designing a viaduct. Since this assignment was an actual ongoing design project, the design team had access to all relevant drawings and specifications. The combination of a specialised design team and an ongoing project created a proper reflection of reality.

To gather data on reasoning during this workshop, a protocol analysis in the form of a Think Aloud protocol was used. The Think Aloud method provides rich verbal data about reasoning during a problem solving task. Using Think Aloud protocol analysis, investigators can identify the information that is concentrated on during problem solving and how that information is used to facilitate problem resolution. From this, inferences can be made about the reasoning processes that were used during the problem-solving (e.g. design) task (Fonteyn, Kuipers and Grobe, 1993).

During the workshop the design team was asked to walk through a realistic design case step by step and meanwhile verbally explaining the process of reasoning and decision making. The session was audiotaped and then subsequently transcribed to produce the verbal data.

As a result, an overview was captured of which steps are taken in a design process and what (data-)input is necessary for decision making. A first notable aspect was the need for asset data during the design assignment. Participants mentioned the structural performance and condition of the current asset as important input factors for assessing the reusability or recyclability of the viaduct. A second noteworthy aspect according to the participants was the essence of a Designer-Client-Owner discussion on expectations and future usability. The design engineers stipulated that all decisions made during the design phase, are depending on the client and owner. Wishes, requirements and specification can strongly fluctuate among different clients or owners. Therefore, the design outcomes are not only depending on the type of asset, but also highly related to the client and/or owner. Furthermore, in accordance with the literature study, design engineers also mentioned the importance of ***(3)*** integration in the construction chain. In short, after executing a design workshop, the following additional aspects are included in the design framework:

(5) Asset specific data on performance *
Reason: - creates insight in asset condition
- enables decision-making based on data

* Aspect partly described in development phase

(6) Designer-Client-Owner discussion on expectations
Reason: - clarifies future utilisation of the asset and area
- aligns opinions to create a joint objective

3.3 Interviews

Another aspect that is part of the development phase and serves as a basis for the design framework, is the data retrieved from (*III.*) interviews. Additional to the design workshop, these interviews helped to gain insight in what steps comprise a design process. However, hereby focusing specifically on circular design procedures.

Three key persons with substantial experience in design for sustainability and design for circularity in the construction industry were asked to clarify the specific facets in circular design processes. Moreover, they explained what in their opinion are important drivers for such a circular design assignment to succeed.

The group of interviewees consists of the design leader of the Circular Viaduct (Van Hattum en Blankevoort, 2019), an Architect/structural engineer on the field of sustainable design, and the programme manager 'Circular Economy' at Rijkswaterstaat. An unstructured interview technique was used with on forehand agreed main topics, thereby aiming on in depth conversations that result in detailed information. Consequently, these interviews provided understanding into the elements essential when (re)designing infrastructure in a circular manner. Furthermore, barriers and enablers for transitioning towards a circular construction industry were identified, which could thereafter be translated into essential aspects.

The findings of the interviews displayed significant similarities with the results of the literature study and design workshop. The interviewees addressed five essential aspects, of which four ***(2, 3, 4 & 6)*** already outlined in the previous steps. An additional aspect mentioned, targeted the essence of making use of reused components from other infrastructural assets. This aspect is based on the statement that reuse is highest forms of circularity.

(7) Reuse components of other infrastructural assets *

Reason: - utilises the highest form of circularity: reuse

* Aspect partly described in development phase

3.4 Expert panel

Combining the three elements of the development phase, an initial draft design framework could be established. From this draft on, the testing & refining phase is entered and several iterations are conducted in order to come to the final design framework.

A first iteration was realised by executing a validation session with the use of an (*IV.*) expert panel. This panel consisted of several members of a Management Team (MT) from a Dutch design company. In this session, the initial aspects of the design framework were presented and members of the MT were asked to provide critical feedback. Firstly, the MT argued on whether or not the aspects in the framework were pursuing the right research goal, namely allocating the aspects ought to be available in order to optimise the circular value of currently existing bridges and viaducts when (re)designing for maintenance & replacement tasks. Thereafter, the MT was asked to check the completeness of the proposed framework and complement where necessary.

During the expert panel session, some notable commentary was given on the proposed first draft framework. First of all, the MT established that aspect ***(7)*** was not specified enough. They agreed on the idea of reusing components from other infrastructural assets. However, in order to do so, the MT stated that a geographic-wide overview of available assets in the region was needed that could facilitate supply and demand of these components. This finding was based on own experience with current ongoing projects, in which they found such an overview to be essential in order to fine-tune the supply and demand stream. Secondly, the MT defined an eighth essential aspect, namely the possibility to have room for experiencing and innovating. In their experience, technical alterations in directives, governmental regulatory support and financial incentives are crucial when it comes to changing the traditional way of designing.

Furthermore, during the session the MT recognised the other six aspects ***(1 t/m 6)*** outlined in the previous sections. In short, utilising the feedback from the expert panel, the design framework was slightly altered:

(7) Geographic-wide overview of assets and components available for reuse **

Reason: - utilises the highest form of circularity: reuse
- facilitates supply and demand streams of components

** Aspect altered in testing & refining phase

(8) Room for experiencing & innovating

Reason: - stimulates knowledge and learning curve
- encourages the adaptation of circularity

3.5 Case study

After altering the design framework, the revised framework encountered a second iteration by conducting a verification with the use of a (*V.*) case study. Case study research is needed when empirical inquiry must examine a contemporary phenomenon in its real-life context (Yin, 1981). In this case the phenomenon can be referred to as designing for circularity.

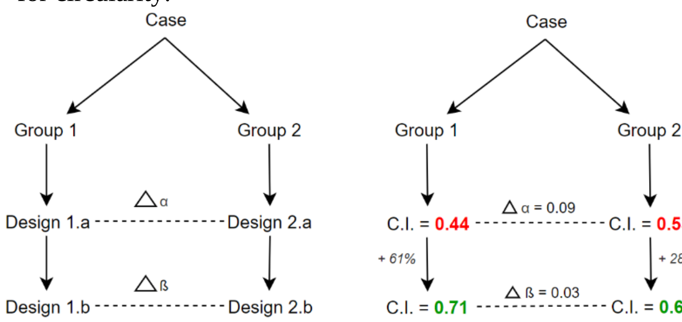

Figure 2. Left: lay-out of case study, Right: lay-out including results

The assignment covered a realistic maintenance & replacement task by redesigning a pedestrian- and cyclists viaduct, one that is also currently under reconstruction. Two separate teams (group 1 and group 2, as shown in Fig. 2) of two design engineers each were both asked to solve the same design problem, namely redesigning the viaduct in a best circular way by taking into account the provided requirements and specifications. Both design groups 1 and 2 came up with a conceptual circular design for a viaduct.

In first instance, the groups created a conceptual design without the aspects of the framework given (Design 1.a and Design 2.a). Thereafter, both groups were provided the design framework composing the essential aspects plus some additional information, and asked to create another conceptual design (Design 1.b and Design 2.b). Both sessions a. and b. lasted 60 minutes and afterwards the conceptual designs were explained and viewpoints discussed. Therefore, The result of this case study were four conceptual designs, two made without the framework-knowledge in mind and two with it the framework. Furthermore, all four designs had an attachment in which the key elements of the designs were explained by the design teams.

The goal of the case study was twofold. First and foremost, the aim was to check whether the proposed design framework addressed the right issues when designing for circularity in a real-life case. Moreover, completeness and correctness were verified by discussion with the actual design engineers. Secondly, by using a model to calculate the level of circularity of the conceptual designs before and after receiving the design framework, it could be estimated if the framework actually supports making better choices during redesign regarding the circular value of existing infrastructure.

Regarding the first goal of the case study, the session provided highly useful feedback and insights. One major finding was the fact that even without the design framework, the participants subconsciously addressed 5 out of 8 aspects ***(1 t/m 5)*** while working on the design assignment. Furthermore, when discussing the results and going through the design framework, every aspect was recognised and considered as important when optimising the circular value of the existing viaduct in the re-design task. However, both design teams stated that one aspect ***(5)*** was not providing enough information. While the designers agreed on the fact of needing more information on the concerning asset regarding structural performance and condition, extra data about the asset was found essential. This extra data should contain a breakdown of the comprising components in the asset and their interrelation and connection (i.e. de-constructability). Moreover, the exact characteristics of the materials used during construction should be made comprehensible.

(5) Asset specific data on performance, components and material characteristics **

Reason: - creates insight in asset condition
- enables decision-making based on data
- improves judgement on de-constructability

** Aspect altered in testing & refining phase

Additionally, to calculate the level of circularity, the data of the conceptual designs was translated into data suitable for using it into a circularity measuring model. This 'Bridge Circularity Indicator', established by Coenen (2019), is one of the first models to calculate the level of circularity of a bridge or viaduct. Alternate tools are mainly focusing on energy usage and CO_2 emission, making it more of a sustainability assessment rather than a circularity assessment. This model of Coenen primarily focusses on using non-scarce renewable materials and the prevention of waste by adapting the used method of construction, therefore addressing the core of circularity more appropriate. The outcome of the tool is a Circularity Indicator (C.I.), ranging from 0 (lowest level of circularity) to 1 (highest level of circularity).

After entering the conceptual design into the model, the following results were extracted (displayed in Figure 2, right). After the first design session, the C.I. of the designs 1.a and 2.a were respectively *0.44* and *0.53*. Taking into consideration the aspects of the design framework, the conceptual designs of the teams (1.b and 2.b) both showed positive changes. The C.I. of Design 1.b increased by 61% towards *0.71*. The C.I. of Design 2.b increased by 28% towards *0.68*. The difference between both teams could be explained by the difference in experience of the participating design engineers. Furthermore, since conceptual designing contains relatively less information, small changes can significantly effect the final C.I. scores. Nevertheless, considering the results of the model, is could be assumed that the design framework addresses the right aspects in order to optimise the circular value of an existing viaduct.

4 SYNTHESIS

In the previous section, the research methodology was explained and on elements of the research design was further elaborated. Furthermore, findings of the separate research steps were outlined. In this section the overall results of the research steps are synthesized into a final framework. Combining a literature study, the workshop and the interviews, all the input for the design framework is established. Using an expert panel and case study, this framework is further refined into the final eight aspects presented in this section. Each aspect is described and the origin (from which research step) is depicted in Table 1.

1. Establishing a Waste Management Plan during the design phase helps forecast and record released materials arising during the construction phase. Doing this thoroughly creates insight in the Construction & Demolition Waste (CDW) streams. With this clear, the designers mind during design is influenced and by his improved decision-making, CDW can be heavily reduced and construction materials is used multiple life cycles.
2. Realising on forehand how to steer design phases and optimise circularity levels, provides major benefits for design engineers in knowing where to focus on during the design. Simply said: "*What gets measured, gets done.*" Furthermore, such a measurement tool also illustrates results and provides feedback, making it essential for the improvement of design process. A LifeCycle Assessment (LCA) that incorporates the characteristics of circular design is proposed as a proper measuring tool that can deal with the 'End of Life' components of the bridges and viaducts.
3. When knowledge is compartmentalised, key information for design decisions cannot be properly transmitted from one chain to another in the construction chain. This results in possible loss of residual circular value of certain components, since some players in the 'value chain' have no specific knowledge of certain components. Therefore, overall integration of the construction chain is essential.
4. This fourth element is twofold. On the one hand, a solid knowledge base on circularity and its principles is obviously relevant when designing for optimal circular value. However, on the other hand, also a change of mind-set driven by environmental CE awareness is required from design practitioners. This results in even deeper detailed improvement of the level of circularity.
5. Designing is based on making trade-offs and decisions. Those decisions can only be made correctly with the right information. Therefore, to design for optimising circularity of existing bridges and viaducts, proper data is crucial. Hence, information on the concerning asset should contain data regarding structural performance and condition. Moreover, extra data should contain a breakdown of the comprising components in the asset and their interrelation and connection (i.e. de-constructability). Finally, the exact characteristics of the materials used during construction should be made comprehensible.
6. Although not specifically mentioned in the literature, one of most important aspects turned out to be the Designer-

	Design framework aspects	Literature study	Workshop	Interviews	Expert panel	Case study
1.	*Waste Management Plan*	x			x	x
2.	*Measuring tool incl. LCA*	x		x	x	x
3.	*Construction Chain integration*	x	x	x	x	x
4.	*CE awareness (mindset)*	x		x	x	x
5.	*Asset specific data on performance and material details*		x*		x	x**
6.	*Designer-Client-Owner discussion on expectations*		x	x	x	x
7.	*Geographic-wide overview of assets and components available for reuse*			x*	x**	x
8.	*Room for experiencing & innovating*				x	x

Table 1. Origin of aspects in the design framework

* Aspect partly described in development phase

** Aspect altered in testing & refining phase

Client-Owner discussion on expectations and future usability. Afterall, the level of circularity of a designed asset is always directly related to the assets future usability. Robust bridges with a supposed lifespan of 200 years in a non-dynamic area need different circularity measures than small viaducts in high dynamic regions.

7. One of the highest forms of circularity is reusing components for the same purpose as designed. However, often the circular value of components is downgraded because of the absence of potential reuse options. By creating an overview of not only the asset itself, but a wider view/inventory of available assets in the region (wider geographic unit e.g. local, regional, national), supply and demand streams for reused components can increase and this optimises the circular residual value.
8. The final aspect is the required possibility to have room for experiencing and innovating. This room can be translated to either financial incentives, technical alterations in directives or governmental regulatory support. This will stimulate companies in adopting CE in their strategy and furthermore improves the knowledge and learning curve of CE.

5 DISCUSSION

The establishment of the design framework created an in depth viewpoint on how to better utilise the built environment in circular design processes. In this section some aspects of the design framework are discussed using viewpoints of other authors in the field. Furthermore, the impact to the audience is described.

5.1 facilitating the transition from linear to circular

The results outline several essential aspects. Some of these aspects specifically underpinned by literature. However, after finalising the research, retrospectively some aspects can still be discussed utilising literature.

A first finding addressed in this research is that specific asset data is needed and a geographic-wide overview of assets and components available for reuse is essential in order to stimulate the reuse of components. A second finding highlights the use of a Waste Management Plan (WMP) to improve the performance of CDW. The reuse of components without to much downgrading can be seen as high performance CDW. Iacovidou and Purnell (2016) argue the combination of those as a design intervention that can stimulate circularity in the construction sector, by 'mining the physical infrastructure'. This statement reflects the point of utilising the built environment and is therefore in line with both the research gap as the findings in this study.

Another result of this research is that most findings might suggest that solutions for improving the transition towards a CE are rather non-technical. This is also stated by De los Rios and Charnley (2017), arguing that the majority of design for sustainability tools and guidelines disregard the bigger picture. Furthermore, they state that design efforts to increase resource sufficiency (and thereby enhancing CE) need to be further focused towards assessing intangible value and influencing client acceptance. Although this may be valid for the implementation of CE on higher policy levels, when applicating Design for Sustainability (or even more specific, Circularity) on a practical project, multiple thorough calculations should be made. Stimulating the transition towards CE can be done on a rather abstract level. However, the application of CE almost always consists of complex trade-offs considering environmental, social, technical and economical factors (Iacovidou *et al.*, 2017).

Another important note to be made is that the design framework may include, but is not limited to the outlined aspects. As pointed out by De los Rios and Charnley (2017), there is need for a balance between design-specific knowledge and transdisciplinary skills. This study attempts to identify those specific essential design input and circumstances in order to optimise the circular value of the installed base. However, another important factor in here is the presence of appropriate skills within the actors of the design process. Such a factor is only gently addressed by the fourth aspect: creating CE awareness and mindset.

5.2 Contributions

This paper contributes to the existing body of knowledge by identifying elements that can facilitate the transition from linear design to circular design in the construction industry. Contemporary research stated the importance of designing for circularity in the construction industry (Adams *et al.*, 2017), but made no effort in taking into account the present infrastructure and utilising its residual value.

Furthermore, the findings provide a better understanding of the essential steps towards implementation of CE both within national policies as well as within organisations, thereby stimulating the transition. This is underpinned by Moreno *et al.* (2016), stating that research on the practical applicability of design strategies fosters the transition towards a CE.

The social relevance of this research can be attributed to the sustainable topic 'circularity'. This theme focusses on avoiding depletion and creating resource efficiency, aspects that require a shift in thinking towards preserving the value of materials, components and products. Preserving this value can help closing the resource loops in the construction industry (Ellen MacArthur Foundation, 2013). In shifting towards this circular system, this is an essential step.

6 CONCLUSIONS AND FUTURE RESEARCH

This research presents the design framework with eight essential aspects ought to be available in order to optimise the circular value of currently existing bridges and viaducts when (re)designing for maintenance & replacement tasks.

The Circular Economy is a concept that is gaining attention all over the world. In the literature, design has been recognised as a catalyst in transitioning towards this CE. However, regarding the construction industry, practice of the topic is still marginal. Considering the infrastructure, an enormous installed base is yet present and it therefore makes sense to utilise this built environment in the shift towards a CE. Thus, this research has focused on improving the level of circularity in the construction industry, by utilising the residual value of the installed base.

By using a Design Science Research strategy, this qualitative study utilises an iterative approach of analysing the problem, designing a solution and developing it further in cycles of testing and redesign. The development phase, consisting of a literature, design workshop and interviews, has unravelled seven aspects that functioned as input for the development of the design framework. The testing & refining phase thereafter tested the proposed input, by utilising the provided feedback from an expert panel and a case study. This phase has led to an alteration of two aspects found in the development phase. Furthermore, an additional aspect was established.

Therefore, it can be concluded that the eight aspects highlighted in section 4 are essential when trying to optimise the circular value of currently existing bridges and viaducts in (re)designing for maintenance & replacement tasks.

Limitations and future research

A first limitation to be addressed lies in the novelty of circular design in construction industry. Due to this yet mostly unchartered territory, experience in the field is limited. This further resonates in the limited amount of interviews held with experts on circular design. The validity of the research would be increased if the body of knowledge on this topic was larger and more experts would have been interviewed.

Another limitation is the fact that in the verification phase, results of the case study are only checked with the use of the Bridge Circularity Indicator. This indicator primarily focusses on using non-scarce renewable materials and the prevention of waste by adapting the used method of construction. However, is does not take into account additional CO_2 emission and energy spillage in order to obtain the proposed design. Therefore, as the model was also intended to, the score should be compared with an MKI-calculation in order to give a more holistic view. Unfortunately, due to the limited amount of time in this research, this MKI-calculation was not executed.

A third limitation lies in the results obtained. Especially during the case study, involvement of the researcher was substantial and interpretation and analysis done by the researcher could be biased. This could lead to more subjective findings. Furthermore, strong participants in the group could have influenced the rest of the participants during the case study sessions, and thereby drive the discussion and feedback in a certain direction.

A first recommendation that can be made for further research on this topic, is on verifying if the addressed design framework is also applicable for other existing infrastructure rather than bridges and viaducts only. To limit down the research topic of infrastructural assets in general, this research project focussed on bridges and viaducts. First of all because this kind of asset is very common in the design portfolio of Rijkswaterstaat. A second reason for limiting it to viaducts, is the relative uncomplicated structure of the asset. Viaducts are, compared to for instances locks, far more straightforward and have less 'high-tech' components integrated in it. However, further research could establish if the proposed framework is also suitable for other infrastructure, whether or not with some slight alterations.

A second field for recommendation is to deepen the knowledge on some proposed aspects in the framework, and investigate in what way these aspects can be concrete and practically integrated in a design process. For instance, regarding aspect *5.*, how can it be made sure that this type of data is always present during redesign assignments. Moreover, reflecting on aspect *7.*, further research must reveal what is the most optimal way of creating such an inventory, keeping in mind the fact that this inventory will be a dynamic document with constant adjustments. Lastly, aspect *2.* is easier said than done. Creating a measurement tool that takes into account the characteristics of designing for circularity is far from an uncomplicated task. Integrating this into a suitable LCA definitely requires more analysis.

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