‘Total Value for Society’ Model

CREATING A DECISION MAKING TOOL FOR THE SELECTION OF BUILDING DESIGNS WITH THE HIGHEST TRUE LIFECYCLE VALUE FOR SOCIETY

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MSc Thesis In Construction Management And Engineering

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MSc. Thesis

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Creating a Decision Making Tool For The Selection Of Building Designs With The Highest True Lifecycle Value For Society

by

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Preface

This thesis report serves as the final submission for my graduation project, completed in partial fulfilment of the courses CME2001, Master Thesis Preparation, and CME2000, Master Thesis, of the master's degree in Construction Management and Engineering. The MSc program is part of the faculty of Civil Engineering and Geosciences at the Delft University of Technology.

Coming to the Netherlands, I was pleasantly surprised and impressed by the focus and importance given here to sustainability in the built environment. The level of research in sustainability aspects well reflected this. I realised however, that implementation of sustainable and circular solutions in actual construction projects still depended majorly on having a good financial business case, which was often difficult since the returns made on investments in implementing them were not apparent. In my discussions with professor Henk Jonkers, it became evident that there was a need to rationalise and justify the investment in sustainable construction materials and methods in order to promote their implementation. Thus, the starting point for my graduation project was the question – why should companies and investors invest in sustainability and circularity solutions for their projects, and do they receive tangible returns that can justify their investment? The initial research on this question led me to conceptualise a tool that could compare the value output of buildings based on not just the financial returns but also their environmental and social impact. The graduation project eventually evolved into development of a decision making tool that could compare multiple building design alternatives of the same functional equivalence, and provide an overall score based on the user's preferences of relative weights assigned to financial, environmental and social sustainability aspects, which could be used to select the design with the most 'total value for society'.

The successful completion of this thesis would not have been possible without the guidance and support of my supervisors. Firstly, I would like to thank my company supervisor, Thijs Huijsmans, for his trust and patience in my work and for always making time for my doubts and queries. I am thankful for the professional as well as moral support, and for the constructive feedback. I am grateful for my first supervisor, professor Henk Jonkers, for constantly providing me guidance and advice. Without his encouragement and assistance, it would have been challenging to complete the study. I would also like to thank professor Ruud Binnekamp for his supervision and for helping me shape my thesis, and professor Rogier Wolfert, for his counselling and constructive advice to improve the thesis and its results.

Additionally, I would like to thank the entire team at Heijmans for believing in my work and providing me with a case study to develop my model on. The thesis would not have been possible without the help and support from the company, and I am grateful for the opportunity. I would like to specially thank all the interview participants for taking time from their busy schedules and helping me with my project.

The entire journey from conceptualisation to finalising the results and writing this report has been a tumultuous one. At times, it was difficult to see a clear path ahead and of course, the covid 19 pandemic did not help. However I am happy to have been surrounded and supported by people who have provided me with strength, endurance and courage. On a personal note, I would like to thank my family, my girlfriend and my friends for always believing in me and showering me with constant love, prayers and support. Finally I would like to thank the reader for their interest in my work and I hope they enjoy reading through it!

Satvik Bhatia
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Summary

The growing need for sustainability and circularity in the construction industry has given rise to the demand for proper sustainability valorisation and evaluation methods. Investors and project owners need sound rationale for their returns on investment made into sustainability – in financial, environmental and social benefits achieved. Currently, there is a lot of research going on regarding how sustainability in the built environment can be implemented, and its benefits maximised. However, promoting sustainable building methods and the use of sustainable products and materials demands a tool that can justify the investment into them.

This thesis addresses this challenge and provides a model that can evaluate and compare the lifecycle value of material components in building designs, in order to allow investors and project owners to compare between design options and select the most optimum choice. Thus the model gives a direct relation between the investment and total returns, and acts as a guide for investors on the selection of design and material choices for the needed level of sustainability in their projects.

Termed as the “Total Value for Society” model, it evaluates and compares the true lifecycle values of construction projects that give an impression of their fitness for purpose. Through this, the model acts as a decision making tool for the project owner/ investor to pick the construction project with the most “true lifecycle value” out of multiple options of the same functional equivalence.

Therefore, if an investor is faced with a choice between various design options for, say, an office building, the true lifecycle values would be different for each option depending on the design, materials, intended lifespan, end of life operations, etcetera. The model helps the investors pick the most suitable option (of highest true lifecycle value, based on their preferences) using Multi-criteria Decision Analysis methodology.

The model follows the People-Planet-Profit ideology and aims to cover the financial, environmental and social values of the project throughout its lifecycle. The financial and environmental costs are calculated using the LCC and LCA techniques through OneClickLCA. The social value as well as the “meaningfulness” of the project are evaluated using the reference scale method suggested in the UNEP Guidelines for Social LCA. A Preference Function Modelling approach is used to arrive at the decision for the optimum option.

The following chapters introduce the current scenario of sustainability evaluation practices in the built environment. A literature study, along with survey interviews, follows to look into the current level of research, and point out the research and development gaps. The report then lays down the study objective and the development statement. A methodology is provided on how the thesis study has been performed. Based on it, a model tool is developed to analyse and compare building designs on the basis of financial, environmental and social sustainability criteria, taking their lifecycle performances and user preferences as input. The tool is applied to a test case provided by Heijmans of three variants of an office building design. The results of this model are verified and validated through stakeholder interviews. The verification, performed using Scientific Metrics software ‘Tetra’ shows that the overall scores obtained from the model are closely corroborated, and the model is able to successfully determine the most optimum and least optimum design variants for the given set of relative weights for each criteria (environmental, financial and social sustainability). A sensitivity analysis confirms the robustness of the model. The expert review performed using stakeholder interviews validates the usefulness of the model and its impact on the design selection process. The validation shows that the model’s usefulness to owners/investors, contractors and designers indeed matches with their expected uses of the model and

fulfils its needs as established by the same stakeholders earlier. Finally, the report concludes by answering to the main development statement - **The Total Value for Society Model, by comparing design options based on their lifecycle performances on financial, environmental and social sustainability aspects, and showing the most optimum option for the given preferences on the relative weights of criteria, can enable investors to evaluate and compare the true lifecycle values of construction projects, and doing so, guide their investment decisions.**

The report then lists the main limitations of the model and the thesis approach. While validation has been performed from expert reviews, intended users and stakeholders such as banks and investment firms have not been interviewed regarding the validity of the model. Moreover, the experts belong to the same organisation and there exists a chance of bias in their opinions. While the use of PSIA (Product Social Impact Assessment) methodology has been recommended for the performance of SLCA, the approach is admittedly oversimplified . Moreover, the test case is limited to the building superstructure and façade and therefore, PSIA methodology could not be applied on it. This also means that the model is not shown to provide the performances of the building variants in the use phase and the exploitation phase. Finally, the applicability of the model can only be truly validated through a pilot project.

The report also goes on to make recommendations for Heijmans and for future research and development. Heijmans is recommended to explore ways of integrating the model into their existing trade-off matrix in order to consider sustainability in designs along with expenditure, risks, quality and time. The organisation is also recommended to use the model as a base for discussions with clients and investors regarding sustainability aspects in their projects, and guide the discussions towards returns made on investments into sustainability and circularity. For future research, it is recommended to look further into the field of social sustainability and into standardisations of performance analysis and product declarations. The decision making model can also be made into a design model that is capable of designing the most optimum alternative based on user criteria and preferences. The inclusion of benefits of circular building techniques in the model, like designing for disassembly and adaptability, along with architecture, aesthetics and floor space plans should be looked into.

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List of Abbreviations

BIM	Building Information Modelling
BREEAM	Building Research Establishment Environmental Assessment Method
CDW	Construction and Demolition Waste
CE	Circular Economy
CML	Centrum voor Milieukunde Leiden
DGNB	German Sustainable Building Council
EOL	End of Lifecycle
LCA	Life Cycle Analysis
LCC	Life Cycle Costing
LEED	Leadership in Energy and Environmental Design
MCA	Multi Criteria Analysis
MKI/ECI	Milieu Kosten Indicator (Environmental Costs Indicator)
NMD	Nationale Milieu Database
PSIA	Product Social Impact Assessment
PSILCA	Product Social Impact Life Cycle Assessment
RSR	Rate of Sustainable Return
SDG	Sustainability Development Goals
SETAC	Society for Environmental Toxicology and Chemistry
SHDB	Social Hotspot Database
SLCA	Social Life Cycle Analysis
TVS	Total Value for Society
UNEP	United Nations Environment Programme

1. Introduction

The relatively new concept of circular economy has swept the world quickly. It is already a major focus of the European Union's (EU) 2030 action plan to meet the United Nation's SDG (sustainability development goals), including goal number 12, "ensuring sustainable consumption and production patterns". (Nazareth, 2019)

The world is not only facing the urgent need to shift towards more circular ways of operation, there are also huge economic and environmental benefits attached to it. According to the European Commission (2018), 'circular economy offers an opportunity to boost our economy, making it more sustainable and competitive in the long run.' This supports the argument by McKinsey and Company (2015) who have stated that a circular economy 'would allow Europe to grow resource productivity by up to 3% annually'. This is further established by The Ellen MacArthur Foundation (EMF) which states that "Shifting towards a growth within model would deliver better outcomes for the European economy and yield annual benefits of up to €1.8 trillion by 2030" (Ellen MacArthur Foundation, 2015). According to TNO (2013), expanding circular economy for all of Netherlands can lead to an annual saving of 7.3 billion euros, resulting in around 54,000 jobs (Verberne, 2016).

As for the environmental benefits, Het Groen Brein (2016) has argued that 'the initial target for the circular economy is to have a positive effect on the ecosystem and to counteract the overload and the exploitation of the environment. The circular economy has the potential to result in a reduction in emissions and use of primary raw materials.' Emissions can be heavily reduced from heavy industries; by as much as 296 million tonnes CO_2 emissions per year in the European Union (Sitra et al., 2018).

The need to turn to circularity is even more evident in the construction industry and the built environment. According to Arup and Bam (2017), the construction and demolition waste makes up 25-30% of all waste generated in the European Union. Construction and Demolition Waste (CDW) is a huge challenge for the industry because it is the largest waste stream worldwide (30-40% of total solid waste) (Jin et al., 2018; Tam and Tam, 2006). Arup and Bam (2017) state that circular business models will not only 'help businesses save on raw material costs and waste management costs' but also result in 'little or no waste to landfill, and environments will be enriched by biological nutrients reintroduced into the biosphere through composting and bio-digesters.'

The CE (Circular Economy) principle targets economic and environmental value retention. The construction industry, generating the "heaviest and most voluminous waste stream in the European Union" (European Commission, 2018) offers a high potential for its recycling and reuse. According to Ellen Macarthur Foundation (2013), 70-80% of the discarded construction materials have the potential to be applied in another application, thus retaining value.

Although circular economy is increasingly becoming a major agenda for the construction industry within Europe (Jones et al., 2018), looking at the market demand, Circular Economy (CE) is still very much in the "infancy stage" (Nazareth, 2019). As per Adams et al. (2017), the major challenges in adopting circularity in the built environment included "the complexity of buildings; the fragmented supply chain; lack of a market mechanism for recovery; lack of circular economy knowledge; lack of incentives to design for end-of life products; limited awareness across the supply chain; and lack of interest." The lack of incentives to design for end-of-life issues for construction products was seen as the single most important of these challenges (Jones et al., 2018).

From suppliers, to construction companies and contractors, to recycling companies, everyone in the industry is aware of the need for sustainability optimisation in construction. Yet, there is a lack of tools available for managers to make sustainable investment appraisal decisions (Leisen et al., 2013).

A lot of research has been done in the field of circular construction focusing on recycling. However, this potential for reuse and recycling has still not been fully realized. In the Netherlands, over 95% of the CDW is being recycled (Rijkswaterstaat, 2015). However, the majority of this is downcycled, which is not the value retention as propagated in the CE paradigm (Anastasiades et al., 2020).

There are several “Sustainability Management Tools” available, such as the lifecycle assessment, the sustainability balanced scorecard, Green shareholder value, etc. However, these tools do not meet all the four main requirements given by Leisen et al. (2013) for implementation of sustainable strategies. These requirements are: (1) tool must justify commitment of resources to a certain investment; (2) tool must be able to cover entire duration of an investment; (3) tool must target an improved performance with respect to financial, environmental and social sustainability; and (4) tool must be easy to communicate and understand.

The closest to frameworks that can guide sustainable strategies are the Sustainable Value Added Method (Figge & Hahn, 2005) (Strakova, 2015) and the Net Present Sustainable Value (Leisen et al., 2013). These integrate the social and environmental resources with the financial, using the concept of opportunity costs (and the time-value of money). However, these are value-based methods and they do not indicate whether the overall capital use is sustainable. They look at overall sustainable efficiency but don’t consider if a sustainable use of capital has been attained. Also, the opportunity costs are subjective and the RSR (rate of sustainable return) only gives the percentage by which a project exceeds (or falls short of) the minimum targeted return. The tools do not provide the value generated by separate resources as a direct comparison of their investment.

Currently, unlike the LCA and LCC, the ways to measure social impacts and the performance of SLCA are not standardised or generally agreed upon. A major reason for this is because social aspects are highly subjective and case-specific. This makes it is difficult to quantify them through a common practice and provide them a financial-value based relative weight. Moreover, the preference of the decision maker is not a property of money and therefore, attaching a shadow price to social and environmental impacts that is generally accepted is not possible.

Thus there is a need for a model that can homogenize the evaluation of such (current as well as residual) value returns of circular and sustainability practices. The model also needs to include the preferences of the decision maker (here, the investors and the project owners) in the relative weights of the financial, social and environmental performances. This model can be useful in making investment decisions and allocating resources and capital for the sustainability aspects of a construction project. One such model that has been proposed is the TVS (Total Value for Society) model. This model considers the economic value of assets, the environmental costs, the added societal values from the ecosystems created, as well as the user preferences. The TVS model would potentially lead to not only better management decisions regarding sustainable design and construction but also form the new tool to justify sustainability investments such as constructing demountable structures.

This study focuses on developing such a tool that can allow investors and project owners to compare between design alternatives and product and material components, on the basis of their lifecycle sustainability impacts while also considering their personal preferences on the relative weights given to the three sustainability aspects. Thus, the aim of the tool is to enable investors and owners to compare construction project options and pick the one with the least total cost for society. This gives rise to the following development statement and objective.

1.1 Development Statement

To enable project owners and investors to evaluate and compare the total value for society of construction projects, in order to guide the sustainable investment decisions towards projects with higher true lifecycle value.

1.2 Development Objective

To enable the evaluation and comparison of true lifetime values of constructions, including their financial and environmental costs as well as social impacts and stakeholder preferences, thereby providing a decision making tool for the project owner/ investor to choose the project with the highest true lifetime value, amongst multiple options of same functional equivalence.

Here, true cost accounting refers to accounting where the 'hidden costs' for environment, people and society are included in the balance sheets (Who Will Pay the "True Price"? | Eosta, 2019).

1.3 End Deliverables

The result to the development statement should provide a model that can be globally applied to compare between infrastructure assets of same functional equivalence, to direct the choice based on the total value (costs and benefits) for society, including economic, environmental and social values. The model's use and results should be verified and validated by the intended stakeholders. Using this model, it should be clear how the overall TVS values can affect the investment and management decisions.

1.4 Scope

The scope for the project is narrowed in order to make it possible to complete within the stipulated time without getting overly complicated while also ensuring the broad functioning of the model and its ability to justify investment decisions in implementing sustainability and circularity in construction.

The project will restrict itself to the building's first use lifecycle. It will not concern with the use of the recovered value in the second lifecycle.

The project will mainly focus on the lifecycle values of material components. This includes their economic, environmental and social value. However, the project will not concern with the energy savings and other recovery of values during the use phase.

1.5 Thesis Structure

The thesis reviews state-of-the-art assessment tools with respect to sustainability, and identifies gaps, justifying the development of the envisioned TVS model. The report introduces the model in chapter 1. Chapter 2, through literature review and stakeholder interviews, justifies the need and leads the way into forming the methodology for building the model, which is covered in chapter 3. The development of the model is covered in chapter 4 and is evaluated in chapter 5. Chapter 6 concludes the development study and gives recommendations for future research and development.

2. Literature and Development Gap

This chapter establishes the research and development gaps and through stakeholder interviews, strengthens the argument for the requirement of a Total Value for Society Model. In this section, a brief review of relevant literature is done to give a general overview of the current state of research concerning sustainability assessment methods relevant to the building sector, and shortcomings are identified.

2.1 True Cost Accounting

This study aims to evaluate the true lifecycle values of construction assets. True cost accounting is, as explained above, basically a form of accounting where the 'hidden costs' for environment, people and society are included in the balance sheets. Including their benefits in sustainable practices makes them more affordable and might make non-sustainable practices more expensive by adding the environmental and social costs. According to Investopedia, "True cost economics is most often applied to the production of commodities and represents the difference between the market price of a commodity and total societal cost of that commodity, such as how it may negatively affect the environment or public health (negative externalities). The concept also may be applied to unseen benefits—otherwise known as positive externalities" (True Cost Economics Definition, 2019). Thus, in order to truly reflect the lifetime cost and values of construction projects, it is important to consider the societal costs and environmental hidden costs along with the economic value.

A sustainable lifecycle evaluation that measures changes in society from the perspective of goods and services, must take into account the economic, environmental and social criteria in order to enable sustainable consumption and production patterns (United Nations Environment Programme, 2009). While economic and environmental criteria are easily definable, the social criteria needs better understanding.

2.2 Purpose Economy

Purpose economy, according to Aaron Hurst, author of "The Purpose Economy" book, is an economy that creates purpose for people by allowing them to develop and be a part of the community (Hurst, 2014). The theory of purpose economy states that the companies with a clear societal purpose will tend to be more successful in the long run.

"The purpose economy is one that fosters the flow of good ideas, the creation of positive and impactful services and products, and ultimately a more efficient way to spread good in the world." –(Hurst, 2014)

Thus, a purpose based economy is an economy that revolves around creation of purpose and meaning for its parties along with the goods, services and information. This focus on meaning and purpose helps purpose-driven companies sustain a substantial market share (Hurst, 2014). There is clearly a space for creating purpose where sustainability in the sense of society is concerned.

2.3 Mind Map

From the above considerations, the following mind map can be derived. 'Purpose' or fitness-for-purpose of a building involves the positive as well as negative economic, environmental and social impacts on the stakeholders. These impacts are measured in the relevant 'values' that are generated throughout the lifecycle performance of the building for the said stakeholders.

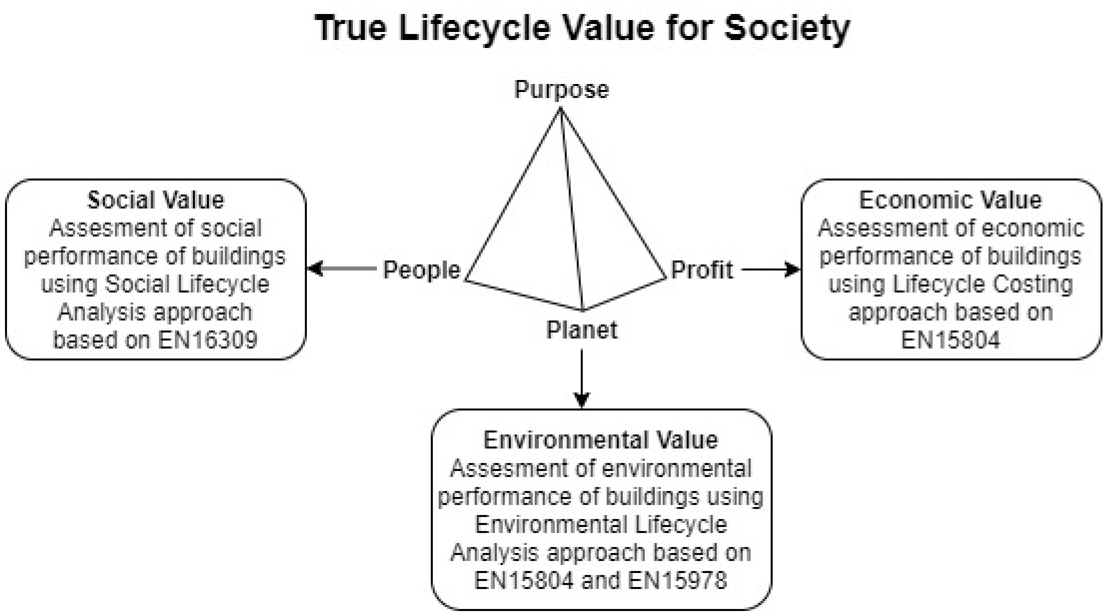


Figure 2.1 Mind Map (People-Planet-Profit ideology)

The Mind map gives a depiction of the criteria that need to be included. In order to compare the true lifecycle values for creating a purpose economy, sustainability and circularity have to be evaluated according to three main components – People (social), Profit (financial) and Planet (environmental).

There has been a lot of research about calculating and evaluating their benefits. In fact, According to Pauliuk (2018), there is an "overabundance of indicators" to measure environmental, economic and social performance. Tools such as the Life-cycle Costing and (Environmental) Life-cycle Analysis provide a fair representation of the lifecycle financial and environmental performances of building projects. Sustainability assessment and certification tools like LEED and BREEAM also provide credibility and acceptance to implemented sustainable building practices. There are also ways like the Shadow Pricing method, used by MKI/ ECI (Environmental Cost Indicators) that essentially assign financial-value based weighing factors to the "loss of economic welfare that occurs when one additional kilogram of the pollutant finds its way into the environment" (CE Delft, 2018) expressed in Euros per kg pollutant. Although this does allow comparison of environmental and social impacts, the method only provides an added cost while not reflecting the benefits gained. Moreover, these generally accepted tools and methods do not give any indication of social impacts and benefits. Thus, there exists the need for a tool that can give a clear and integrated picture of the financial, environmental and social returns that can be achieved through investment in sustainable building practices.

As per Anastasiades et al. (2020), some of the most commonly applied tools to measure sustainability are the Life Cycle Assessment (LCA) and Life cycle Costing Analysis (LCC). While the LCA calculates the environmental impact a project has during its entire lifecycle, the LCC calculates the economic impact. Corona et al. (2019) state that LCA shows a "high potential in addressing all the goals of the CE at the product and service levels" and that "LCA was found to be the most used framework to assess circular strategies". LCA is currently considered the standard approach by the industry to calculate the embodied impact of buildings (Lowres & Hobbs, 2017). Thus, to evaluate and compare the true lifecycle performances of building designs, LCA, LCC and SLCA approaches would be adopted.

European standards such as EN 15978 (environmental performance), EN 16309 (social performance) and EN 16627 (economic performance) for building level assessments support the environmental, economic and social evaluations. Through EN 15978, the building life cycle can be divided into the following life cycle phases: Production (module A), Use (module B) and end-of-life (module C). There is also a fourth life cycle stage (module D) that evaluates the environmental impacts and benefits of any potential future reuse/ recycle of building components which have been disposed of as wastes from the previous lifecycle phases (Lowres & Hobbs, 2017). However, module D is optional, and is rarely included in LCA studies because information at the product level is often missing. (Delem & Wastiels, 2019). For the consideration of above criteria, the following EN codes are of relevance.

EN15804: Sustainability of construction works - Environmental product declarations - Core rules for the product category of construction products

EN15978: Sustainability of construction works - Assessment of environmental performance of buildings - Calculation method

EN16627: Sustainability of construction works - Assessment of economic performance of buildings - Calculation methods

EN16309: Sustainability of construction works - Assessment of social performance of buildings - Calculation methodology

2.4 Lifecycle Analysis (LCA)

(Environmental) Life Cycle Assessment, or LCA, is a methodology for measuring environmental performance of products and components across their entire lifecycle. It is based on international standards (**ISO 14040** Environmental management -- Life cycle assessment -- Principles and framework, **ISO 14044** Environmental management -- Life cycle assessment -- Requirements and guidelines, and **ISO 21930** Sustainability in buildings and civil engineering works -- Core rules for environmental product declarations of construction products and services). For construction assets, the lifecycle stages are set out by ISO2903 and EN15804 as follows.

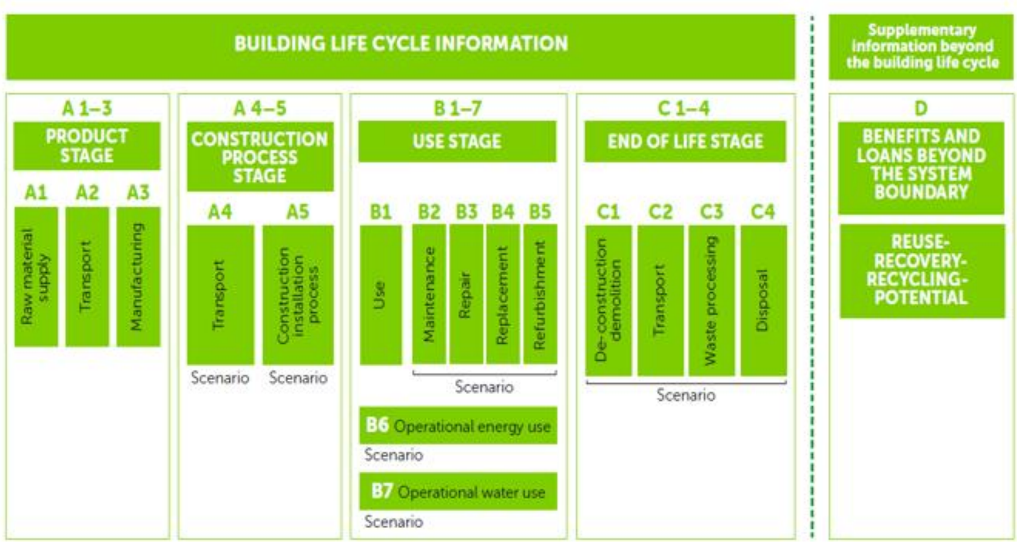


Table 2.1 Building Life Cycle Information (One Click LCA, 2020)

The LCA measures and expresses environmental performances in form of environmental impacts as normalised unit equivalents. This methodology is called characterisation. One such characterisation methodology for lifecycle impact documentation is the CML (Centrum voor Milieukunde Leiden), developed by the Institute of Environmental Sciences, Leiden University. According to Sphera (n.d.), "CML 2001 is an impact assessment method which restricts quantitative modelling to early stages in the cause-effect chain to limit uncertainties. Results are grouped in midpoint categories according to common mechanisms (e.g. climate change) or commonly accepted groupings (e.g. ecotoxicity)." The baseline method, as included in EN15804+A2, contains the following impact categories, as described in a sample report generated by OneClickLCA software:

Impact category	**Unit**	**Description**
Global warming potential (greenhouse gases)	kgCO_2 eq	Describes changes in local, regional, or global surface temperatures caused by an increased concentration of greenhouse gases in the atmosphere. Greenhouse gas emissions from fossil fuel burning has been strongly correlated with two other impact categories: acidification and smog. Often called "carbon footprint".
Acidification potential	kgSO_2 eq	Describes the acidifying effect of substances in the environment. Substances such as carbon dioxide dissolve readily in water, increasing the acidity, which contributes to global phenomena such as ocean acidification (IPCC 2014).
Eutrophication potential	kgPO_4-eq	Describes the effect of adding mineral nutrients to soil or water, which causes certain species to dominate an ecosystem, compromising the survival of other species and sometimes resulting in die-off of populations.
Ozone depletion potential	kgCFC_{11}eq	Describes the effect of substances in the atmosphere to degrade the ozone layer, which absorbs and prevents harmful solar UV rays from reaching Earth's surface.
Formation of ozone of lower atmosphere	kgC_2H_4eq	Describes the effect of substances in the atmosphere to create photochemical smog. Also known as summer smog.
Primary energy	MJ	

Table 2.2 Environmental Impact Categories (One Click LCA, 2020)

2.5 Lifecycle Costing (LCC)

LCC is a methodology to map the financial costs of assets throughout their entire lifecycle. These include the purchase prices and associated costs, the operating costs and the EOL costs. The modules for the calculation of LCC are given by EN16627, and described by a sample report by OneClickLCA as:

Pre-construction stage	Product Stage			Construction Process Stage		Use Stage							End-of-Life Stage				Benefits and loads beyond the system boundary		
Activity carried out before a development site is selected	Raw material supply	Transport	Manufacturing	Transport to building site	Installation into building	Use/application	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	Deconstruction/demolitio	Transport	Waste processing	Disposal	Reuse	Recovery	Recycling
A0	A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D	D	D

Table 2.3 Life Cycle Costing modules (One Click LCA, 2020)

These modules are also explained in the same sample report.

Life cycle module	Analysis scope
A0-A5 Pre-construction and before use stage	Costs of purchase or rental costs (costs of the site); costs of building products; costs related to the transport between factory and site; project feasibility, planning, design, engineering and construction costs, incl. permissions, commissioning and handover; site clearance and landscaping (e.g. lawn, trees, and similar within the curtilage and other external works costs; subsidies and incentives (e.g. incomes related to renewable energy)
B1-B3 Operation and maintenance costs	Building related facility management costs (e.g. regular cleaning, insurance, security, fire inspection and similar costs); repair costs; ground maintenance; redecoration
B4-B5 Replacement/refurbishment	Planned adaptation or refurbishment (incl. infrastructure, fitting out and commissioning, validation and handover); replacement of major systems and components (incl. associated design and project management)
B6 Operational energy use	Energy costs (incl. fuel and electricity for heating, cooling, power, domestic hot water and lighting, as per EPBD)
B7 Operational water use	Water related costs (e.g. rates, local charges, environmental taxes)
C1-C4 Deconstruction	Demolition costs; transport costs associated with deconstruction and disposal; fees & taxes (e.g. landfilling); waste processing costs

Table 2.4 Life Cycle Costing modules- Analysis scope (One Click LCA, 2020)

Further, for the module D (beyond the lifecycle stages), potential incomes generated from the economic value of buildings after their use, or the reuse or sale of construction assets and components at the building's end-of-life, can be calculated.

2.6 Social Lifecycle Analysis (SLCA)

The Social part of the evaluation of true value, combined with the "meaningfulness" for all major stakeholders, is going to be measured using the SLCA. SLCA, or the Social and socio-economic lifecycle analysis, looks at the current as well as potential socio-economic impacts, both positive as well as negative, of products, services and processes throughout their lifecycle (Fauzi et al., 2019). This knowledge of social impacts on major shareholders can help provide decision making support, and enable the choice of most favourable social consequences. Thus, SLCA is a management tool that draws attention to aspects of a product's life that affect the human wellbeing, and promotes the societal growth and betterment.

With the publication of the United Nations Environment Programme (UNEP) and the Society for Environmental Toxicology and Chemistry's (SETAC) UNEP/SETAC "Guidelines For Social Life Cycle Assessment Of Products" in 2009, the interest in the field has grown. However, despite that, the amount of available literature is limited, and "most published research is case-study-specific and based predominantly on qualitative or semi-qualitative data, making it difficult to infer from results to general situations" (Huertas-Valdivia et al., 2020).

The Social Impact indicators are more difficult to quantify than the environmental impact indicators. This is because the social impact categories and indicators are highly subjective in their measurement criteria and their perceived importance, and their value is variable depending upon the specific case. It must be noted here that an extensive list of indicators does not exist because their application is case-specific and depends on the goal/scope of the study (United Nations Environment Programme, 2009). Moreover, since it is challenging to find "accurate and objective proxies for social indicators", there exists no unanimity or agreement on what categories of social impact should be included and how to measure some of them (Huertas-Valdivia et al., 2020).

According to Rahla et al. (2019), "The social aspect is usually overlooked when assessing building sustainability. Measuring this dimension generally implies subjective assessment which eventually weakens the overall methodology." The social aspects of structures are not commonly considered when talking about the value of a building. These, in certain cases, may have an even higher importance to the users and stakeholders as compared to the financial and environmental costs. Moreover, even though the EN 16309 betters the understanding of social aspects, assessment of the social impact of buildings is still not performed often (Lowres & Hobbs, 2017). The social aspects may include "noise and dust created during construction stages, health and safety, security and comfort issues during the construction and use stages of the buildings or involvement of the local community" (Lowres & Hobbs, 2017).

Thus, for example, to 'measure' health and well-being, one would need to define the parameters of a healthy life and be able to measure 'happiness' with a universally applicable indicator, and that is very challenging. Due to the subjective nature of indicators and the difficulty in quantifying them, the most challenging part of SLCA is data collection and inventory. To help with this, a few institutions have created SLCA databases to evaluate the social impacts of products through their lifecycle. Two of these are (1) The Social Hotspot Database (SHDB) and (2) Product Social Impact Life Cycle Assessment Database (PSILCA). According to Huertas-Valdivia et al., "Based on PSILCA and ecoinvent, SOCA is the first database to attempt to provide complete comprehensive S-LCA, complementing environmental and cost data with social risk information" (Huertas-Valdivia et al., 2020). The limitations of such databases is that the information is collected mainly at sector/industry or country level, and thus the local data and information gets ignored.

There is a clear need for more research to understand the complexities of SLCA. Currently, there is no consensus on social indicators (Kühnen and Hahn, 2018), there are definitional challenges, limited regulations, limited availability of data and databases, and a lack of technical knowledge on the performance of SLCA (Huertas-Valdivia et al., 2020). The most commonly accepted guidelines are that of the UNEP/SETAC.

Guidelines for SLCA by UNEP/SETAC

The UNEP/SETAC guidelines provide a skeletal framework for carrying out the SLCA, and propose "a general approach based on a set of stakeholder groups, possible impact categories, subcategories and indicators". The SLCA Guidelines also "provide the necessary basis for the development of databases and the design of software that will ease the practice of S-LCA" (United Nations Environment Programme, 2009).

Since stakeholder involvement is crucial, the indicators developed for the evaluation of SLCA are phased according to the stakeholders. The main stakeholders considered for the lifecycle are: Workers, Local Community, Society, Consumers and Value Chain Actors (United Nations Environment Programme, 2009).

This framework is in line with the ISO 14040 and 14044 standards for Life Cycle Assessment and proposes classification of social impacts by stakeholder categories as well as impact categories. Within each category, "the subcategories seek to describe the overall meaning of indicators used, and the attributes or relevant social features for evaluation. The social and socioeconomic subcategories have been defined according to the best practices at international level: international instruments, Corporate Social Responsibility initiatives, the legal framework model, and literature evaluation of social impacts" (Adami Mattioda et al., 2017).

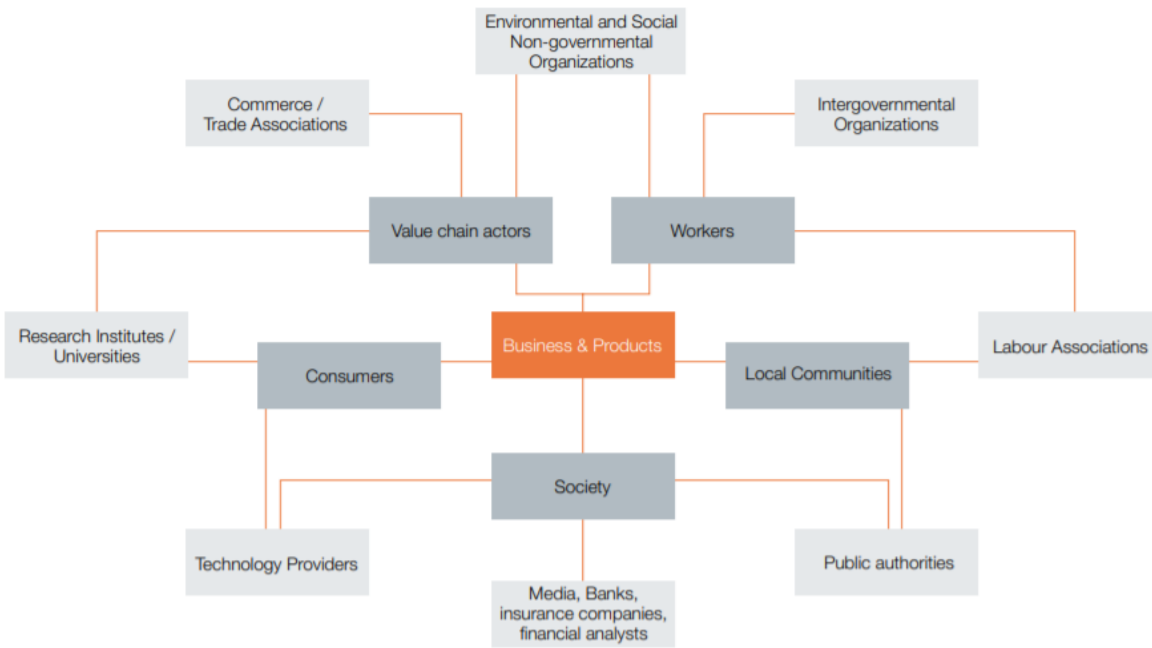


Figure 2.2 Stakeholder Diagram (United Nations Environment Programme, 2009)

Stakeholder categories	Subcategories
Stakeholder "worker"	Freedom of Association and Collective Bargaining Child Labour Fair Salary Working Hours Forced Labour Equal opportunities/Discrimination Health and Safety Social Benefits/Social Security
Stakeholder "consumer"	Health & Safety Feedback Mechanism Consumer Privacy Transparency End of life responsibility
Stakeholder "local community"	Access to material resources Access to immaterial resources Delocalization and Migration Cultural Heritage Safe & healthy living conditions Respect of indigenous rights Community engagement Local employment Secure living conditions
Stakeholder "society"	Public commitments to sustainability issues Contribution to economic development Prevention & mitigation of armed conflicts Technology development Corruption
Value chain actors* not including consumers	Fair competition Promoting social responsibility Supplier relationships Respect of intellectual property rights

Figure 2.3 Stakeholder Categories and Subcategories (United Nations Environment Programme, 2009)

2.6.1 Approaches for Social Impact Assessment

SLCA involves two main types of impact assessment approaches – the Reference Scale Approach and the Impact Pathway Approach (UNEP, 2020). The reference scale approach evaluates the social performance or social risk in the product system based on predefined reference points, while the impact pathway approach is used to evaluate or predict the potential social impact by the using causal relationship between the system and its social impacts.

Neither approach is better or worse than the other and their applicability is restricted by various factors like data availability. For simplicity and convenience of use, the TVS model focuses on the reference scale approach, but it is possible for the model to be amended for the use of the impact pathway approach.

2.7 Establishing the Need Through Stakeholder Interviews

To build upon and bridge the development gap found in literature, a series of interviews were conducted with relevant top management position holding individuals with experience in construction, built environment and real estate. The interviewees were selected based on their impact on the decision making related to building designs and project go-ahead. Semi-structured interviews were conducted and the framework for the line of questioning is provided in the Appendix A. The questions aimed to evaluate the current scenario within the construction sector and the decision making process and approach being applied by one of the top organizations in the Dutch construction industry. Further, the interviewees were asked about the various relevant factors considered when selecting between multiple design options and their opinions on the need for a model that can help with the same. Their responses can be found in Appendix B.

From the interviews, it was determined that currently, the factors being considered for selection between building designs are usually the capital and operational expenditures (CAPEX and OPEX), along with risks, time, quality, safety, and the architecture. Furthermore, factors such as affordability, product-to-market costs, and the expected returns on investment also play a major role. In terms of sustainability, certain projects have specific sustainability requirements that are needed for certifications or permits, which are used for marketing the building in a commercial way. However, these do not allow the sustainability performance comparisons between designs.

The interviewees agreed that a good financial business case is at the base of the project, and is the most important aspect. For government projects, there is a higher demand for sustainability, and it is reflected in the requirements of the project. There is also some consideration given according to the company's internal sustainability goals and policies. However, the responses showed that environmental and social aspects are only considered to a certain degree, as long as their minimum legal requirements are met.

Thus, there is a huge development gap in the analysis and measurement of value added, whether economic, environmental or social, through the sustainable building methods. As can be seen, there is a lack of incentives to invest in them and is limited to meeting the minimum requirements for a commercial business case. This is a major challenge, and it is understandable because the effects of sustainable building practices on economic, environmental and social costs & benefits are not well understood.

To help fill this development gap, the interviewees were asked to consider a potential model that could integrate the financial, environmental and social values of a building design and aid in the selection of the most optimum design. Such a model would potentially be able to compare the value addition by sustainable building materials and methods. Their responses on the potential usefulness of this hypothetical model were noted, along with their views on its potential impact on the decision making process of selecting between designs.

As can be seen from the table (appendix B), four participants felt that potentially, such a model would be useful to very useful in comparing design options. The two other participants found the concept model interesting and could see its potential benefits. The interviewees discussed several potential uses of it. These were- useful in selecting business cases, useful for comparing between building components, useful in promoting building sustainability, useful for expanding the trade-off matrix with sustainability aspects, useful in directing discussions regarding sustainability with clients and investors.

All interviewees were of the view that the tool would potentially have a positive impact on the decision making process for the selection of optimum design. The type of impact, according to them, could be- improving the business case, knowing more about the environmental and social performances of materials used, leading discussions with clients and allowing for more sustainable design options, as well as convincing clients that the chosen alternative is the more optimum one.

2.7.1 Needs of the Stakeholders

From the responses, the needs of the stakeholders can be interpreted and codified as follows:

1. The model should be able to integrate the comparison of environmental, financial and social sustainability aspects for different design options.

2. The model should be rational and follow logical reasoning, and should allow users to try and compare different relative weights for the different criteria.
3. The model should be able to provide a basis for starting discussions between investors, contractors and designers on preferred requirements as well as design considerations around real and feasible implementation of sustainability, in order to help with decision making on building designs.
4. The model should be able to help with an organization's internal goals and policies on sustainability ambitions, and contribute to improved discourse on social impacts of their projects.
5. The model should be able to help contractors and builders find and opt for more sustainable and circular opportunities by comparison of the total costs and value of projects, and fulfil client's sustainability goals.
6. The model should be able to help designers in making better sustainability choices that include the client's sustainability preferences.
7. The model should be able to add to the current decision making systems and trade-off matrices, used by the construction companies and builders, with sustainability value comparisons.

Thus, as evident from the responses, there is sufficient support for the concept model and its potential usefulness in comparing designs based on economic, environmental and social sustainability aspects. The following chapters follow the methodology and the building of this model. The validation of the model built is then performed with the same group of stakeholders and their views on its usefulness are recorded and compared with the above interpreted needs and expectations.

3. Methodology

The following chapter outlines the methodology used for this study. First, a general methodology for the thesis is given that provides the workflow. Later, the model-specific methodology is provided that takes the reader through the steps of building the model.

3.1 General Methodology

This study would take place over three phases.

Figure 3.1 General Methodology Phases

The first phase is data gathering, from available literature and through expert interviews. This phase focuses on studying the current literature to establish the fundamentals and justify the development gaps. Sustainability and its financial, environmental and social aspects, including their definitions, indicators, and ways of evaluation, are studied to provide a theoretical background. Following this, a set of stakeholder interviews are conducted to understand the current solutions for design selection, and the relevance of the model for the stakeholders, in order to further establish the industrial need for it. This has been covered in the previous chapter.

The next phase involves building a working TVS model. This model includes the criteria that evaluate the design variants, and takes the user's preferences as input for the relative weights of said criteria. It also takes as input the lifecycle performances of each variant. The model should then be able to perform a multi-criteria decision analysis and provide overall scores for each variant as output. A result dashboard is created to provide the user a more comprehensive view of the performances of the variants and a scenario analysis for various relative weights of criteria. This process is carried out with the help of a case provided by Heijmans. The case study explores three variants of a generic office building's superstructure and façade. The three variants are- a concrete frame structure with brick façade, a steel frame structure with a metal façade and a wooden frame structure with wooden façade. The lifecycle analysis of the three variants is performed to be used as input along with user preferences in the criteria weights, and the overall scores are calculated.

The last phase involves the discussion of results and output of the model, as well as the verification and validation obtained. This is performed using the 'Tetra' MCA software for preference based modelling by Scientific Metrics. The relevance of the model is also validated here using stakeholder interviews. Based on these discussions, a conclusion is arrived at, and the limitations of the model are addressed. Further, recommendations for future research & development, and scope for further improvements are provided.

3.2 Methodology for Building the Model

The methodology for the decision making tool is based on the concept of **Preference Function Modelling** where there is a single decision maker (the owner/ investor) making the choice between alternatives. There are fundamental mathematical errors in the foundations of game theory, economic theory and other social science disciplines (Barzilai, 2009) that are avoided by this method.

Barzilai also claims that construction of preference functions cannot be avoided by assuming that the payoffs are in monetary units because this implies that utility or preference of the decision maker is a property of money. In the context of mathematical modelling the distinction between objects and properties of objects is fundamental. Additionally, the mathematical operations of game theory must be performed on the preferences of the decision maker because the preferences for the outcomes matters more than the physical outcomes.

Preference modelling attempts to model the decision making process by studying the preferences of the decision maker in specific contexts and placing the alternatives accordingly on a relevant latent scale. The preference function modelling MCA is performed as per the following steps:

First, the decision maker and the alternatives to be considered are decided and the criteria upon which the decision will take place are finalized. These may have several sub criteria within them. Then, the weights, or relative importance of each (sub)criteria to the others, are defined.

For each criteria, the upper and lower references are then defined. Based on the ratings of the alternatives, the alternatives with the highest and lowest ratings form the references, and the rest of the alternatives are placed accordingly.

Finally, based on the relative rating an alternative has received for each criteria, and the weights of respective criteria, the model computes an overall score for each alternative. This thesis uses the above steps along with the weighted sum method to compute the overall scores. The computational model can be verified using the Scientific Metric's software 'Tetra', which constructs preference scales using a user's criteria weights and alternatives' ratings, and then calculates the overall scores on a scale that takes into account all these pieces of information. The software is intuitive to use and therefore has been considered for this case.

Based on the above steps, the methodology of building the model is as follows.

Figure 3.2 Methodology for building the model

1. Create a model- First, the decision maker and the alternatives to be considered are decided. Also the criteria upon which the decision will take place are finalized. These may have several sub criteria within them.

2. Define the weights for all the criteria- The weights, or relative importance of each (sub)criteria to the others, are defined.

3. Establish reference alternatives for each criterion- For each criteria, the upper and lower references are defined. This will be used in the next step to place the alternatives in accordance with these references.

4. The Decision Maker enters the ratings for each alternative with respect to each criterion.

5. "Solve"- the model computes the overall scores and gets a numerical rating of the alternatives. This is calculated based on the relative rating an alternative has received for each criteria, and the weights of said criteria.

4. Building the TVS Model

This chapter follows the steps from the methodology for building a model that can integrate the economic, environmental and social aspects of a building lifecycle, and give a holistic view of the true value provided by it. As established in chapter 2, there exists a need for a model that can allow users to compare between multiple design options, and select the one with the most value to them. Thus this 'Total Value for Society' model is a decision making tool that can compare design options on the basis of their economic, environmental and social values. The aim is to guide the decision making towards a value based approach, and enable the users to consider more sustainable design alternatives. The current approach only considers the economic values and sustainability is limited to meeting minimum requirements.

Creating the TVS model is done with the help of a case study provided by Heijmans. The created model needs to compare the variants in the case study on the basis of their true lifecycle performances, and recommend the most optimum design variant based on relative criteria weights provided by the user. The case study not only provides the design variants to be compared, but also provides a testing bed for the model and further leads to discussion of results (later in this chapter) and the model's verification and validation (in the next chapter). Thus, the case study is essential in guiding the development of the model and is explained in the next section. The following steps are followed for building the model.

1. Creating the model framework: For the project, the Decision Maker is the project owner/ investor. The criteria, from the mind map (section 2.3) are financial, environmental and social impacts. The sub criteria are naturally the impact categories for each, as given in the respective EN codes. The alternatives are the different project options from which the decision maker has to pick the one with the highest true lifetime value for him.

2. Assigning Weights: The relative importance of financial, environmental and social impact categories might vary for each project owner. Therefore, the owner should be able to set his or her own weights for each criteria. That way, the owner's preference on the importance of each criteria is also included. Thus, the user of the model needs to be assigning the weights as input.

3. The ratings of the alternatives will be taken from their lifecycle performance in each criteria. Thus, the ratings for financial criteria will be taken from the lifecycle costing performance of each alternative. Similarly, the ratings for the environmental and social criteria for each alternative will be taken from their LCA and SLCA performances.

4. Setting Reference Alternatives: The alternatives with the highest and lowest rating will be set as the reference alternatives. All other alternatives will be placed on the preference scale based on their relative ratings.

5. Solving the Model: According to the weights of each criteria and ratings of the alternative on these criteria, the model computes the overall score for the alternatives. The alternative with the highest overall score would be the one with the highest value for the owner, according to his preferences in weighing.

4.1 Creating the Model Framework

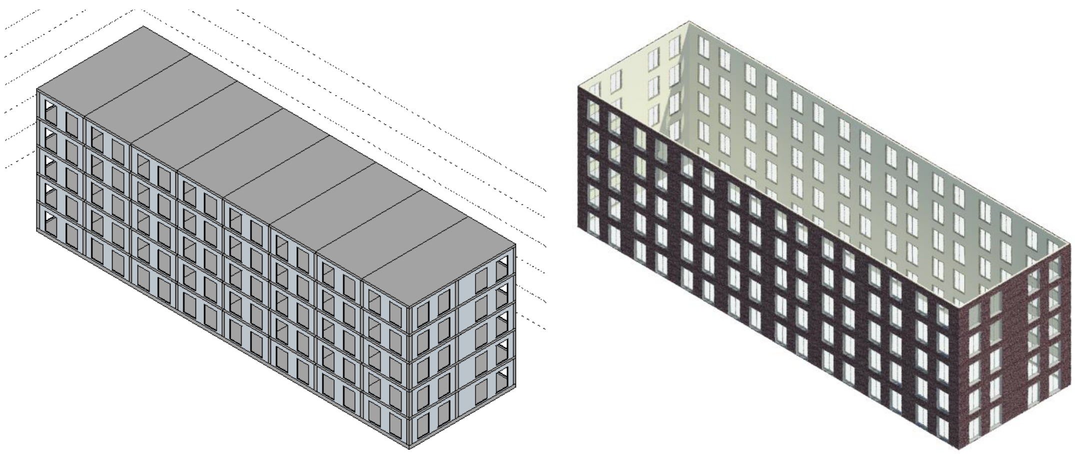
As seen in the mind map, the main criteria for the decision making tool are economic value, environmental value and social value, the performances of which are to be calculated using LCC, LCA and SLCA methods. These are referred to from their EN codes, as explained in chapter 2. The subcategories for the social and environmental aspects are the impact categories. The design alternatives the model would be comparing as a case study are provided by Heijmans. The case study is explained below.

4.1.1 Case Study

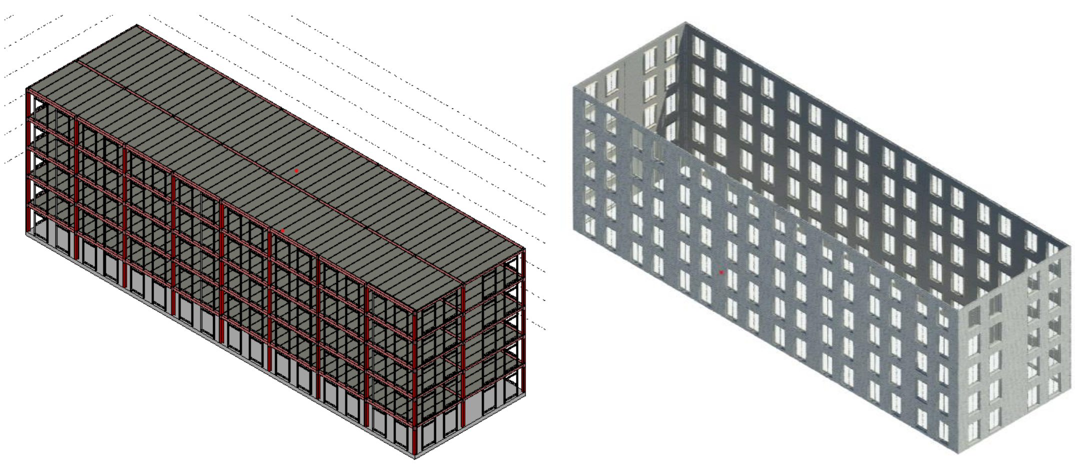
The model aims to compare building designs of the same functional equivalence. According to EN15978, a functional equivalence is “a representation of the required technical characteristics and functionalities of the building. It is the means by which the characteristics of the building are rationalised into a minimum description of the object of assessment.” Thus, for our the study, the primary functional equivalence is – An office building, with a Gross Internal Floor Area of 5000m2 and a service life of 50 years.

For ease of calculation, the scope for this case study is the building material BIM designs of the superstructure and the façade.

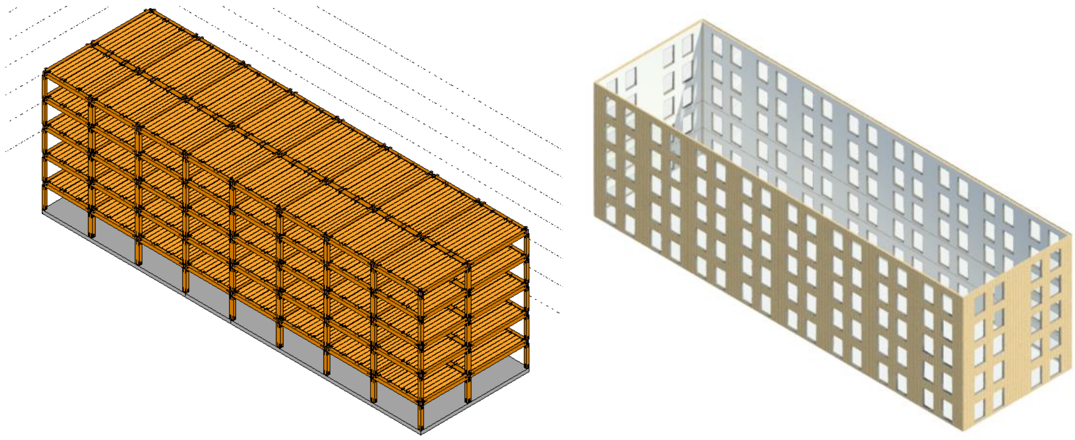
The case study consists of three variants of this functional equivalence:



a) Variant 1 – It is predominantly a concrete frame structure with a brick façade.



b) Variant 2 – It is a steel frame structure with aluminium-paladium profiled sheet façade.



c) Variant 3 – It is a timber structure with a wooden façade.

Figure 4.1 Case Study Variants (a) Variant 1, (b) Variant 2, & (c) Variant 3

4.2 Rating the Variants

The ratings of above the three variants are obtained from their lifecycle performance in each criteria and sub-criteria. For the financial and environmental lifetime performances, the software OneClickLCA by Bionova Ltd. has been used. OneClickLCA is a lifecycle metrics software for the construction industry, and it calculates the LCA and LCC performance data intuitively by taking material information directly from BIM designs. It has been chosen for its convenience and ease-of-use. However, the model does not rely on this, and the users of the model are allowed to enter their own internally calculated LCA and LCC performance data as well.

4.2.1 Lifecyle Assessment

OneClickLCA performs the LCA calculation in accordance with the National Milieu Database, which contains environmental information on products and activities. Thus, the results are consistent and verifiable (Stichting Bouwkwaliteit, 2019). The life cycle stages considered are as given in EN 15804:2012. It assesses the designs using the CML methodology and all its impact categories. All the datasets of OneClickLCA comply with EN 15804.

The LCA parameters, in order to ensure calculations with correct default values, are set in OneClickLCA as follows:

1. Service Life values for materials: This is set as being equal to the technical service life of materials, which is the life they would last for in good conditions.

2. Transportation Distance values for materials: These are the mode and distance of transport for each material from manufacturer to the site. It is set to 'European' as default for typical transport distances and modes in European construction projects.

3. Material Manufacturing Localisation: Each material used in the designs has an environmental impact that is defined by the energy profile of the country it is being manufactured in. It's default is set to the Netherlands.

4. End-of-Life Calculation Method: This is by default set to the software recommended 'material-locked' scenario which calculates the end-of-life impacts based on typical demolition and transport values along

with the use of DGNB (German Sustainable Building Council) calculation tools for the EoL impact assessment.

The LCA performance of the three case study variants by OneCLickLCA is given in Appendix D.

4.2.2 Lifecycle costing

The software performs the LCC analysis in accordance with the ISO 15686-5 & EN 16627 standards. Also, the tool claims to be “third party verified by ITB for compliancy with the following LCA standards: EN 15978, ISO 21931–1 and ISO 21929, and data requirements of ISO 14040 and EN 15804”. The datasets for LCC calculation are obtained from “Neubau Baupreise Kompakt; Statistische Baupreise für Positionen mit Kurzttexten (BKI) (2017) and Spon's Architects' and Builders' Price Book (AECOM) (2017) and include modifications for different regions related to labour costs and cost indexes” (LCC Tool, Assessment Scope and Costing Database, 2020).

The LCC parameters are set by first specifying the Cost Regionalisation, which involves selecting the project country for obtaining default project costing values of that country. This is set to the Netherlands, and on this basis, the software auto-fills the following parameters-

1. Currency and Exchange rate: Set to Euros and 1.

2. Local construction labour rates and local cost index: The regional material cost index, which indicates the variation in non-labour costs for construction, is set at 0.8. The hourly labour rates of workers and craftsmen are set at 29.2 Euros and 39.4 Euros respectively by default.

3. Discount factor and inflation: The discount rate of the cost of capital is set at 7.0% , the general inflation rate at 2%, the energy and water inflation rates are also set at 2%, and the End-of-life costs, calculated as a percentage of the total capital costs, is set at 2.5% by default.

The LCC performance of the three case study variants by OneCLickLCA is given in Appendix D.

4.2.3 Social Lifecycle Assessment

For the selection of social impact categories and their ratings for the three alternatives, this study recommends the use of the PSIA methodology as provided by the Product Social Impact Assessment 2020 Handbook. The methodology is based on the reference scale approach, as explained in chapter 2, and has been produced, along with the Handbook, in a joint effort of over 20 companies in the Roundtable for Product Social Metrics. It is a “consensus-based methodology to assess positive and negative social impacts” on four stakeholder groups: workers, local communities, small-scale entrepreneurs and users (PSIA Handbook, 2020), of which this study concerns with workers, local communities and users. The methodology is inspired from the UNEP guidelines and focuses more on the business applicability, and therefore has been recommended for this study. However, if the users of the model want to use a different approach for rating the social impact categories, they are allowed to do so as long as the ratings can be translated into reference scales.

For the performance of SLCA, two main documents will be referred: The UNEP Guidelines and Product Social Impact Assessment 2020 Handbook. The methodology for performing the SLCA has been taken from the Product Social Impact Assessment 2020 Handbook.

Methodology for SLCA:

The PSIA (Product Social Impact Assessment) method outlined in this Handbook consists of four key components: Stakeholder groups, Social topics (subcategories), Performance indicators, and Reference Scales to assess impact.

1
- **Preparation**
- Defining the requirements of the study, stakeholders to focus on, access data sources per stakeholder category

2
- **Defining Goal and Scope**
- Understanding system boundries, functional units, processes being analysed and selection of social subcategories (topics)

3
- **Hotspot Identification**
- Identifying value chain actors that have significant social impacts

4
- **Assessing Social Impacts**
- Collecting data on the decided social topics from direct and indirect sources and scoring on reference scale for each social topic

5
- **Interpretation**
- Data quality assessment and documentation

Figure 4.2 Methodology for performance of SLCA

The handbook, from the concepts of business dependencies and social impacts, recognizes the following list of 25 social topics (subcategories). More information on the social topics, the impact indicators and their data sources, and the definitions for the reference scales can be found in The Social Topics Report (Roundtable for Product Social Metrics, 2020).

Social topics for workers	Social topics for local communities
1.1 Occupational health and safety 1.2 Remuneration 1.3 Child labour 1.4 Forced labour 1.5 Discrimination 1.6 Freedom of association and collective bargaining 1.7 Work-life balance	3.1 Health and safety 3.2 Access to material and immaterial resources 3.3 Community engagement 3.4 Skill development 3.5 Contribution to economic development
Social topics for users	**Social topics for small-scale entrepreneurs**
2.1 Health and safety 2.2 Responsible communication 2.3 Privacy 2.4 Affordability 2.5 Accessability 2.6 Effectiveness and comfort	4.1 Meeting basic needs 4.2 Access to services and inputs 4.3 Women's empowerment 4.4 Child labour 4.5 Health and safety 4.6 Land rights 4.7 Fair trading relationships

Figure 4.3 Social Topics for major stakeholders (Roundtable for Product Social Metrics, 2020)

PSIA is designed to consider both positive and negative impacts of the product or service, using a 5-point Reference Scale. Each position on the scale is a performance reference point, assigned a score ranging from -2 to +2. A score of -2 is unacceptable performance and +2 is ideal performance.

- **+2** Best in class, continuous improvement
- **+1** Beyond generally acceptable situation , continuous improvement
- **0** Generally acceptable situation,
- **-1** Unacceptable situation but improving
- **-2** Unacceptable situation, no improvement

Figure 4.4 Generic scale to assess social performance (PSIA Handbook, 2020)

These Reference scale scores for each social topic can be used as the ratings for the social categories in the MCA analysis. The new version of the PSIA Handbook does not offer a quantitative assessment because "When tested and applied to multiple case studies by the Roundtable members, the quantitative method proved too difficult to apply, especially due to difficulties in getting access to the appropriate quantitative data. The case studies showed that using a strict numeric assessment leads to conclusions that were not in line with the intention of social assessments" (PSIA Handbook, 2020).

It is important to note that while the user is being asked to score the social topics on the above 5-point reference scale, it is not a preference based or subjective scoring. In fact, for each social topic, each of the 5 scores contains a definition, included in The Social Topics Report, Roundtable for Product Social Metrics (2020), and only when the definition of a score is satisfied, the scoring is provided. This makes it an objective approach to comparing social impact.

Based on the stakeholder interviews (Appendix A), for the case study considered, the following social subtopics were chosen. (Their score definitions have been taken from The Social Topics Report and modified for the case study.)

1. Occupational Health and Safety of Workers:

SOCIAL TOPICS	DESCRIPTION	SCORES DEFINTION				
		-2	-1	0	1	2
Occupational Health and Safety	The extent to which the management maintains or improves the safety and overall health status of the workers.	There is a neglect in the working conditions (culture) regarding the maintenance and promotion of occupational health and safety, which results in high accident rates and deteriorating health conditions of workers.	There is a neglect in the working conditions (culture) regarding the maintenance and promotion of occupational health and safety, which results in high accident rates and deteriorating health conditions of workers, but the company or facility has developed a corrective action plan with clear timeline for completion.	Working conditions and working culture are adequately protecting occupational health and safety, which includes that equipment, the use of personal protection equipment, the prevention of harassment are conforming to the state of the art regarding safety and exposure.	There is a management system in place to pro-actively and continuously improve the working culture, beyond an acceptable level and can show tangible results of these efforts.	The management is best in class compared to its peers on Operational Health & Safety performance.

Table 4.1 Score Definitions for Occupational Health and Safety of Workers

2. Effectiveness and Comfort of Users:

SOCIAL TOPICS	DESCRIPTION	SCORES DEFINTION				
		-2	-1	0	1	2
Efictiveness and Comfort	The extent to which the office buildings affect the efficiency and comfort of users. • Effectiveness: the degree to which something is effective: in which effective is defined as: successful, or achieving the results that you want. • Comfort: something that makes your life easy and pleasant.	The building contributes to ineffectiveness or discomfort to the users.	The building makes users less effective or comfortable compared to standard solutions.	The building does not affect the effectiveness or comfort of users compared to standard office buildings.	There is credible evidence or 3rd-party research that the office building is significantly better compared to standard office buildings on effectiveness and comfort.	There is credible evidence or 3rd-party research, that the building is the best in class compared to standard office buildings on effectiveness and comfort and is setting new standards in the office building category.

Table 4.2 Score Definitions for Effectiveness and Comfort of Users

3. Health and Safety of Users.

SOCIAL TOPICS	DESCRIPTION	SCORES DEFINTION				
		-2	-1	0	1	2
Health and Safety of users	The extent to which the office building, under defined conditions maintains or improves the health status and safety of the office users.	Any use of the building has direct negative health or safety impacts on short or long term.	The normal use of the building has negative health or safety impacts, but the management has developed a corrective action plan to improve the building in order to significantly reduce the negative impacts.	The normal use of the building does not have any significant detrimental effect on the health and safety of the user.	The management has evidence that shows how the building has been successfully designed to create a maximum contribution to health and safety of the user and that the building contributes to a better health and safety for the users.	There is solid science-based evidence that the building can contribute very significantly to a better health and safety AND it is managed in such a way that it does reach the most vulnerable groups who would benefit most from the building and it's services.

Table 4.3 Score Definitions for Health and Safety of Users

Thus the model, with all its categories and subcategories, looks like figure 4.5.

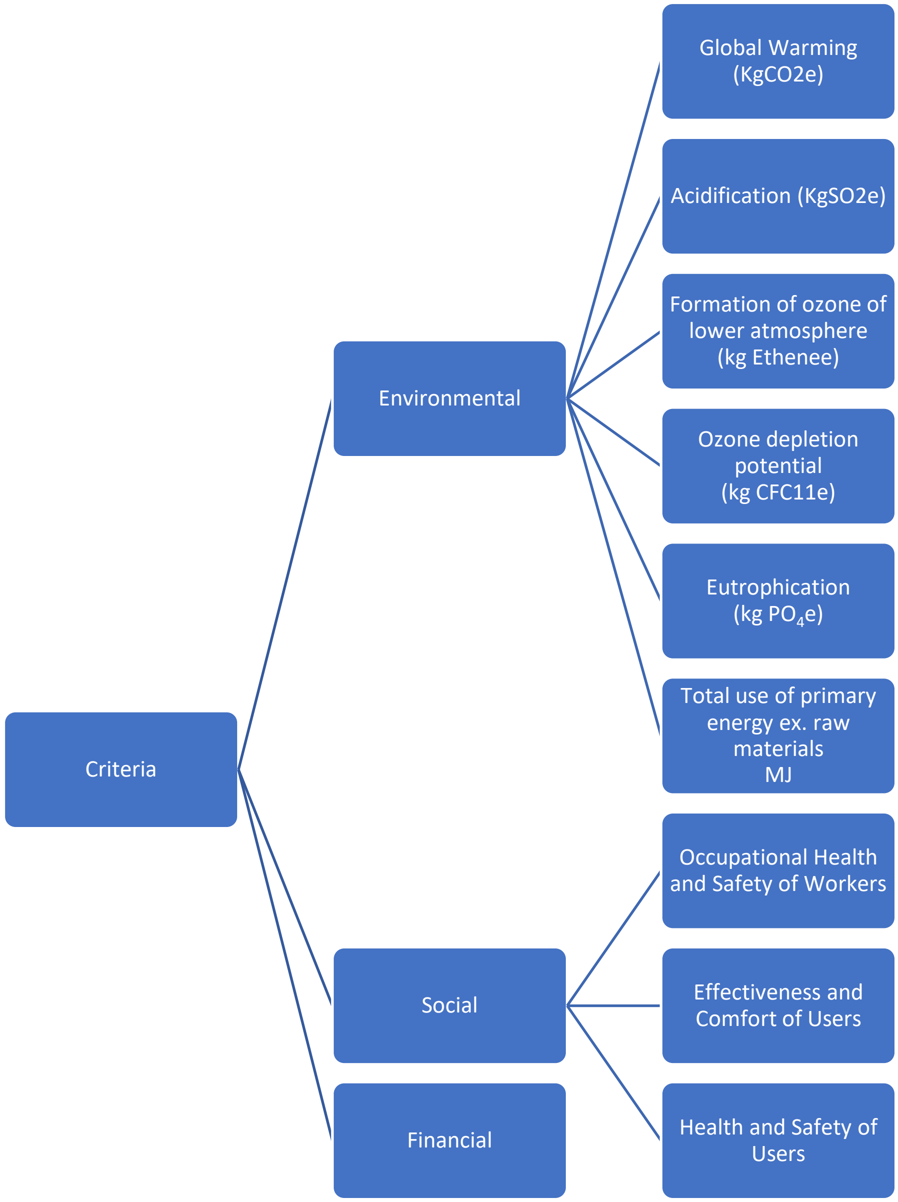


Figure 4.5 Model Criteria Framework

For the purpose of this thesis, given the limited scope, the performance of SLCA through PSIA methodology was not possible, since the study was conducted on only the basic designs of superstructure and façade. Consequently, the social impacts which depend to a large extent on the location, the stakeholders involved, the intended users and their social practices, etcetera, cannot be accounted for. Thus, for the sake of the working of the model, the ratings for the social aspects have been assumed on the basis of building material performances alone. This report does not claim to have performed an extensive SLCA performance analysis due to the above reasons, and the assumed data is only intended to showcase the working of the model.

Based on the above LCA, LCC and SLCA considerations and performances, we obtain the ratings for each category and subcategory, as shown in table 4.1.

4.3 Setting Reference Alternatives

Reference ratings, or ratings of reference alternatives, in a preference function model, provide an aid for measurement of all the alternatives. For each criteria, at least two references alternatives must be defined, on which the other alternatives are rated, in order to establish a scale. Since it is not possible to provide hypothetical reference alternatives for the best and worst LCA, LCC and SLCA performances, the model uses two out of the actual alternatives, based on the best and worst ratings. Further, in order to use the weighted sum method, there has to be a common scale for each object. Thus, for each criteria/ sub-criteria, a scale of zero to 100 is established. The alternative with the best performance in a particular subcategory gets a reference rating of 100, while another alternative that performs the worst on the same subcategory, receives a zero. All other alternatives are then relatively scaled to be placed on this zero to 100 range.

For the case study, for example, the global warming potential in terms of CO_2 equivalents is the most for the concrete variant and the least for the timber variant. Thus, the reference ratings for the concrete variant becomes zero and for the timber variant becomes 100. Following this, the rating of the third (steel) variant is translated onto this scale at a score of 11.04.

In the case of SLCA performance, as the scores are already on a 5-point scale, the translation into a score from 0 to 100 becomes easier. Moreover, as the 'best' and the 'worst' performing objects are already defined (with scores of +2 or -2 respectively), the reference ratings can be directly translated as the object with +2 is placed at 100, with +1 is placed at 75, with 0 is placed at 50, with -1 is placed at 25 and the object with a score of -2 is placed at the reference scale at 0.

The table 4.1 also shows the reference scales set out in the same way for all categories and subcategories.

4.4 Solving the Model

As described in the methodology, the weighted sum method is used on the reference scale scores of each criteria, along with the relative weights that are given by the user of the model, to calculate overall scores for each of the variants.

If we consider each of the environmental and social subcategories to have a weight of 5%, this would result in the environmental category with a 30% relative weight, the social category with a 15% relative weight, and the financial category with a relative weight of 55%. This weighing is in line with the average answers received to the question "How much weight to each aspect would you provide (from experience as well as preference)?" in the stakeholder interviews. The overall scores for the three case study variants, in this case, are also shown in the table 4.1.

Categories	Weights	Indicator	Variant_1 (concrete)	Variant_2 (steel)	Variant_3 (timber)	Variant_1	Variant_2	Variant_3
Environmental Category (LCA)	**30.00%**							
Global warming	5.00%	kg CO2e	882282.00	862,941.00	707,091.00	0	11.03995	100
Acidification	5.00%	kg SO2e	2,930.00	2,250.00	2,420.00	0	100	75
Eutrophication	5.00%	kg PO4e	336.00	329.00	444.00	93.91304	100	0
Ozone depletion potential	5.00%	kg CFC11e	0.0863	0.1310	0.0983	100	0	73.15436
Formation of ozone of lower atmosphere	5.00%	kg Ethenee	145.00	206.00	167.00	100	0	63.93443
Total use of primary energy	5.00%	MJ	7,190,000.00	10,400,000.00	10,600,000.00	100	5.865103	0
Financial Category (LCC)	**55.00%**							
Lifecycle Costs	55.00%	Euros	€ 744,529.00	€ 744,260.00	€ 1,322,902.00	99.95351	100	0
Social Category	**15.00%**							
Occupational Health and Safety of Workers	5.00%	The extent to which the management maintains or improves the safety and overall health status of the workers.	1	2	2	75	100	100
			The company has a management system in place to pro-actively and continuously improve the working culture, beyond an acceptable level and can show tangible results of these efforts.	The company is best in class compared to its peers on OHS performance	The company is best in class compared to its peers on OHS performance			
Effectiveness and Comfort of Users	5.00%	The extent to which the project affects the efficiency and comfort of users. • Effectiveness: the degree to which something is effective: Effective is successful or achieving the results that you want. • Comfort: something that makes your life easy and pleasant.	0	1	2	50	75	100
			The product or service solution performs average in terms of or does not affect the effectiveness or comfort compared to standard solutions.	There is credible evidence or 3rd-party market research that the offered product or service solution is significantly better if compared to standard solutions on effectiveness and comfort.	There is credible evidence or 3rd-party market research, that the offered product or service solution is best in class compared to standard solutions on effectiveness and comfort and is setting new standards in this productor service solution category.			
Health and Safety of Users	5.00%	The level of safety, security, and benefits to the health of its users	0	1	2	50	75	100
Total weight is 100%			The building does not have any significant detrimental effect on the health and safety of the user	There is solid science-based evidence that normal use of the building can contribute very significantly to better health and safety of its users	There is evidence that shows how the building has been successfully designed to create a maximum contribution to health and safety of the user			
					Overall Scores	**83.42008**	**78.34525**	**30.60444**

Table 4.4 The Total Value for Society Model

4.5 Results Dashboard

Table 4.1 shows the working of the built TVS model. The first column lists out the major criteria (environmental, financial and social values) as well as the sub criteria. Column 'Weights' notes the relative weights given to each criteria. These are user-defined and can be varied to get different results. Here, the user of the model can input his preferred relative weights to compare the alternatives with. Column 'Indicators' gives the unit measurements (and definitions for social aspects) for each sub criteria. The next three columns contextualize the lifecycle performances of the three variants from the case study, with their LCA, LCC and SLCA scores. These 'ratings' are required input from the user for all the alternatives being compared. They depend only on the characteristics of the variants and do not vary with preferences. The final three columns turn the ratings into reference scales by setting reference alternatives for each sub category. Using weighted sum, the model calculates the overall scores as shown. For this case study, for the relative weight distribution given above, the overall scores for the three variants are - Variant 1 (concrete) gets 83.42, Variant 2 (steel) gets 78.35 and Variant 3 (timber) gets 30.60. This means, that for the user of this model, the variant 1 provides most value while the variant 3 provides least value. Therefore, the user should go for the concrete variant.

To explain the above scores, and to provide a visual representation, the model creates a dashboard as shown in figure 4.6. The high overall score of the concrete variant can be understood by its performances in the various criteria. Out of 6 environmental subcategories, the concrete variant performs the best in Ozone Depletion Potential, Formation of Ozone of lower atmosphere, and Total use of primary energy. Moreover, for the financial category that carries the majority of the relative weight (55%), the concrete variant only scores marginally less than the steel variant. Meanwhile, the timber variant has a lifecycle cost almost twice that of the concrete variant, and so loses a lot of points in the major relative category. The carbon footprint of the timber variant is the least by a big margin, but since the global warming potential is only weighted 5%, this does not increase the score much for variant 3.

Moreover, the dashboard also showcases a scenario analysis which compares the overall scores of the variants for different relative weight scenarios, as seen on the x-axis. It considers 15 different relative weight scenarios of the main categories, while assuming that all the subcategories within them share an equal weight. The graph for the concrete variant shows that it is the best option for most cases where the relative importance given to financial and environmental aspects is higher than social. The overall scores for the steel variant peak when the financial and social aspects have higher relative weights while environmental aspects have a lower relative weight. The timber variant provides the least value in most cases and only becomes the best option when the social aspects get the majority of relative weights. It is important to note here, that these variations in overall scores of scenarios assume an equal relative weight between the subcategories within the environmental and social aspects.

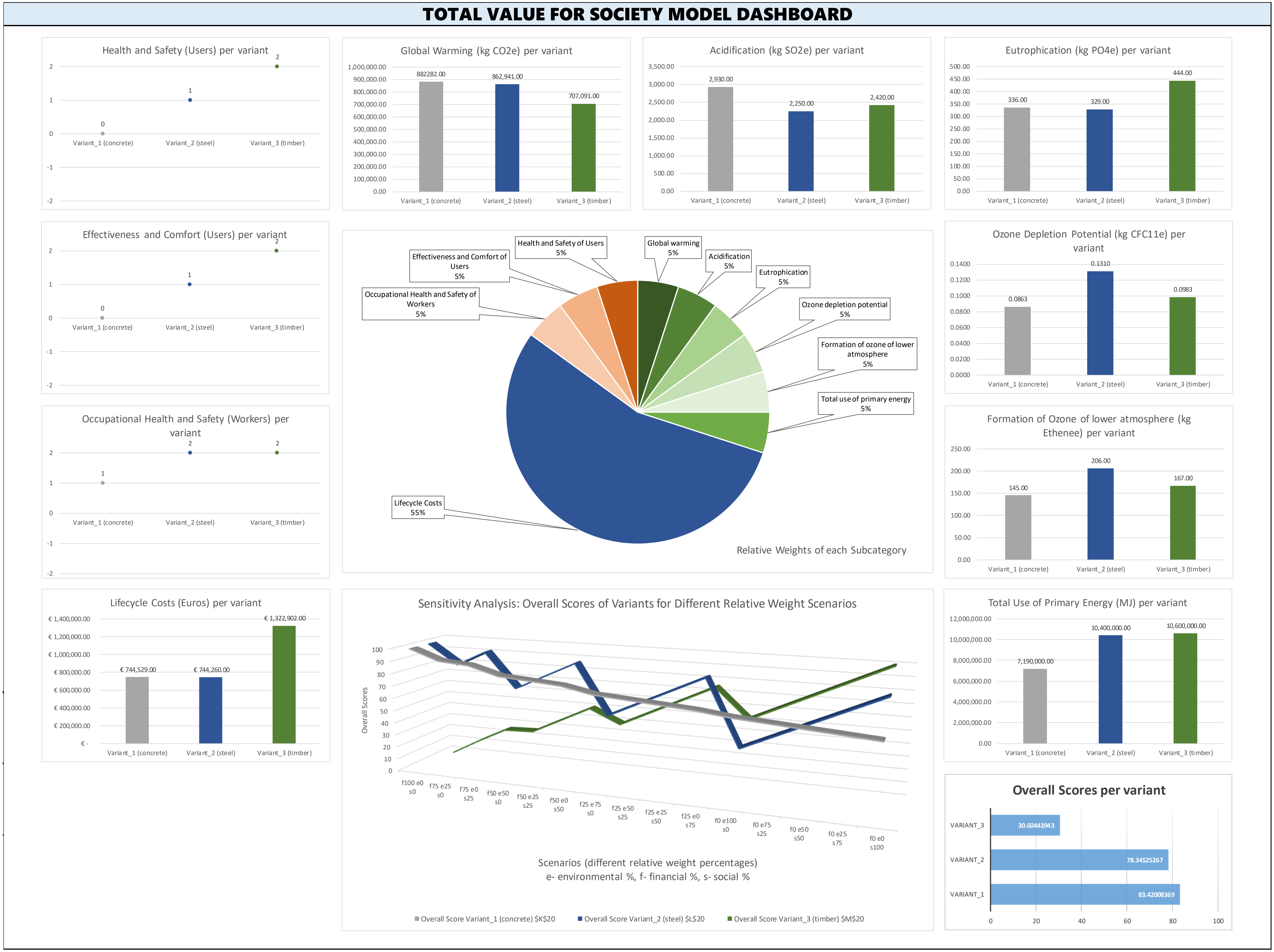


Figure 4.6 Total Value for Society Model Dashboard

5. Verification and Validation

This chapter goes over the verification of the model results as well as their validation from the intended users, done through expert reviews obtained during the part 2 of the interviews (Appendix A).

5.1 Verification

The verification is done through the comparison of the overall scores obtained for the case study in the above scenario with preference function modelling performed using Tetra, which constructs preference scales using a user's criteria weights and alternatives' ratings and then calculates the overall scores on a scale that takes into account all these pieces of information. The software is intuitive to use and therefore has been considered for this case. The criteria, weights and the alternatives' performances are recreated on the software. Tetra solves the multi-criteria problem to give the following result.

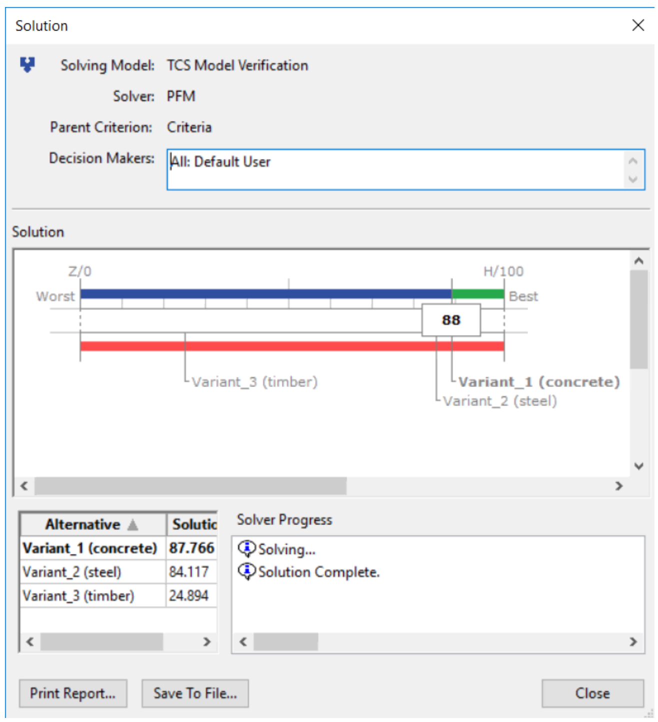


Figure 5.1 Tetra Solution for Case Study

As can be seen from the solution, the overall scores obtained for the three variants from Tetra, for the scenario where financial, environmental and social aspects have the weights 55%, 30% and 15% respectively (divided equally amongst the subcategories), are comparable to the scores obtained from the model. Tetra confirms that the best option is indeed the concrete variant for the given weights, followed by the steel variant and finally the least preferrable is the timber variant. The complete solution report by Tetra is given in Appendix E.

Relative weights scenario	Overall Scores	Variant 1 (concrete)	Variant 2 (steel)	Variant 3 (timber)
f-55%, e-30%, s-15%	From Tetra	87.766	84.117	24.894
	From the model	83.42	78.345	30.604

Table 5.1 Overall score comparison between TVS model and Tetra for case study scenario

5.1.1 Sensitivity Analysis

The overall scores of the three variants depend on the relative weights provided to the categories. For the above scenario, the overall scores of the variants from the model and from Tetra are comparable, but in order to test the robustness of the model, the verification has to be done for extreme cases as well.

From the dashboard, the following graph (figure 5.2) of the overall scores of variants for different relative weight scenarios is obtained. For further verification, and robustness check, the following three extreme and one random relative weight scenarios are taken:

- Financial – 100%, Environmental – 0%, Social – 0%
- Financial – 0%, Environmental – 100%, Social – 0%
- Financial – 0%, Environmental – 0%, Social – 100%
- Financial – 75%, Environmental – 25%, Social –0%

These scenarios, as shown in the graph below, result in different overall scores for the three variants and consequently, the most optimum and least preferrable choices also vary. For the sensitivity analysis, the overall scores obtained from the model and those obtained from Tetra for the above scenarios are compared in table 5.2. Tetra reports are presented in appendix E.

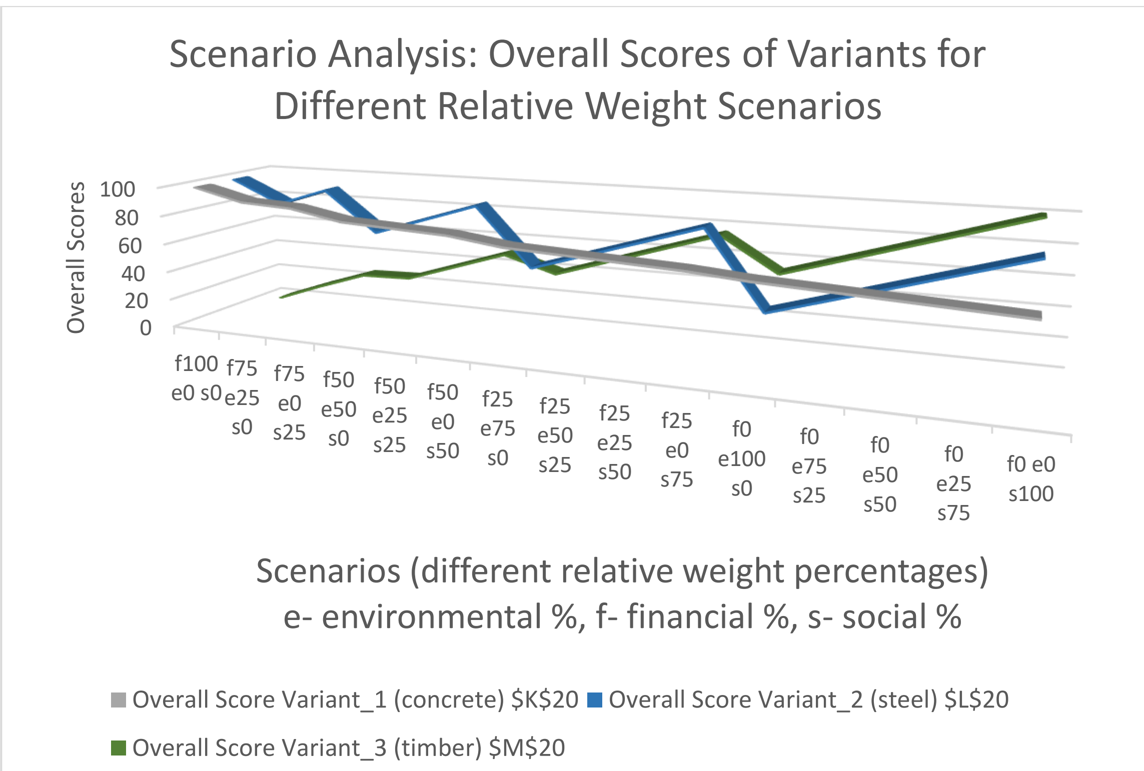


Figure 5.2 Sensitivity Analysis Graph for different relative weight scenarios

Relative weights scenario	Overall Scores	Variant_1 (Concrete)	Variant_2 (Steel)	Variant_3 (Timber)
f-100%, e-0%, s-0%	From Tetra	99.954	100	0
	From the model	99.954	100	0
f-0%, e-100%, s-0%	From Tetra	71.605	31.171	52.506
	From the model	65.652	36.151	52.015
f-0%, e-0%, s-100%	From Tetra	58.489	83.879	100
	From the model	58.333	83.333	100
f-75%, e-25%, s-0%	From Tetra	95.036	89.777	9.026
	From the model	91.378	84.038	13.004

Table 5.2 Robustness check: Comparison of overall scores of variants from the model and Tetra

As can be seen from the table, the overall scores obtained for the extreme and random cases from the model are comparable to the scores obtained from Tetra. In all cases, the choice for the most optimum variant and the least optimum variant remain the same. Thus, it can be satisfactorily stated that the model is robust in its results.

(Again, it should be noted here that when a 100% relative weight is given to the environmental category, the concrete variant receives the highest overall score. This may seem counter-intuitive but it is because all the sub-categories within environmental aspect have been assumed to carry an equal weight. Thus, even though in practice, the global warming potential of the concrete variant is too high, and is arguably of more relative importance than some of the other subcategories, it does manage to score the best in three other subcategories, thus making up for the lost points. Therefore, it is advisable for the user to individually assign the preferred relative weights to each subcategory in order to get a more accurate picture.)

5.2 Validation

The validation of the model has been performed through an expert review from the same stakeholders (interviewed to establish the need) as a part 2 of the interviews (Appendix A). The experts are from one organization and have different roles within it. All the experts are involved in the process of either designing or the development of projects. Thus, all of the experts are involved with the decision making for the go-ahead of design proposals and are potential users of the model.

During this review, the interviewees were shown the workings and the results of the built TVS model based on the case study. Then, they were asked about their views on the model and whether it fit their expectations as established in section 2.7. The responses have been tabulated in the appendix C and further discussed below.

It must be noted here that the validation is based on the model's workings & results showcased to the interviewees through the case study. The scope for the study only includes the superstructure and the façade of the design options. The BIM models do not give an impression of the performances of the variants in the use, maintenance and exploitation phases. Due to this reason, the case study does not allow the performance of SLCA. Since the social impacts have been assumed (as explained in the section 4.2.3), the case study is not suitable for illustrating how well the model supports social aspects.

Out of the experts interviewed, three are of the opinion that the model is rational and logical, and interesting in its approach to allow users to try different relative weights. Two others claim that the model methodology can be useful to start discussions with clients as well as to guide an organization's internal ambitions. Two interviewees are still concerned about the accuracy of information needed to use as input for the model, such as the social performances and product declarations by the manufacturers of building components, but agree that the model would be useful if the information is accurate. Overall, there is a general consensus that the model is mostly useful for three main stakeholders – the owners/investors, the contractors and the designers. Their responses on the usefulness for each of these stakeholders is discussed in further detail below.

5.2.1 Usefulness to the Owner/Investor

All the experts feel that the model is useful for the investors as they are the ones that set the requirements. Two experts feel that the model can help them make decisions on the choice of design based on their preferred requirements, while three others feel that the use of the model is more in starting a discussion between the investors and the contractors and providing a base for the discourse and decision making on requirements as well as design considerations. One expert feels that the model would be useful in making the discussion around circularity real and feasible. Another expert also feels that the model can contribute to discussions about the social impacts of a company or a project but expresses concern about the model needing user competence in the three aspects for its use.

5.2.2 Usefulness to the Contractors

Three experts here feel that the usefulness of the model to the contractors depends largely on the requirements of the clients. The model would be useful if the client has social and environmental sustainability requirements. One expert believes that the model could help contractors meet the local government's sustainability goals and this can provide an advantage in obtaining projects. While three experts feel that the usefulness depends also on the policies of the organisation itself, two of them agree that the model would be useful in fulfilling internal goals by helping them find and select the best opportunities in sustainability and circularity. However, one expert expressed concern over the lack of clarity and agreement on social aspects and definitions and another expert highlighted the need for testing the applicability of the model in a pilot project before it can be adopted.

5.2.3 Usefulness to Designers

Five experts are of the opinion that the model would be useful for designer to make better choices regarding design of building components by considering the client requirements as well as sustainability and circularity aspects, and one of them believes that the model would be useful when the client has a good mix of sustainability aspects and that the model could be added to their organization's trade-off matrix. However, another expert believes that for designers, the model is only a little useful to compare different projects. One expert also believes that the model can be useful internally for designers to reach the organization's sustainability goals.

5.2.4 Missing/ Potential Features

On being asked for potential improvement suggestions, the experts have the following opinions. One expert believes that there is not enough link between the scoring and definitions of social aspects, and the design alternatives. A second expert is of the view that the model is too complex for the user, and that it doesn't consider how good a contractor is. He also agrees with another expert in saying that the model currently only considers the material components but not the architectural aspects and spatial and floor planning. One expert believes that the output in technical terms does not give an intuitive feel about the impact, while another believes that right now there is a lot of emphasis on greenwashing, which can be added to the criteria. Another expert believes that it would be interesting to connect this model to an investment model or a plan, and to be able to calculate exit prices. These suggestions and opinions are noted in the next chapter under recommendations for future research and development.

5.2.5 Applicability of the Model

The expert review interviews also asked the interviewees about the applicability of the model in real projects, and whether it can be adopted in practice to optimise sustainability practices. Their responses are noted below.

Expert 1 (Design manager integrated non-residential construction projects): "It is not really useful because if you look at sustainability and in my opinion environmental impacts, then LCC, LCA or MKI (Environmental cost indicator) are more commonly used for sustainability. You have different models for environmental comparisons, and different tools for financial comparisons but those together combined with social aspects is the uniqueness and the added value of this model. "

Expert 2 (Director at Heijmans real estate): "Yeah, sustainability is a very large definition so this in my opinion seems more to use of materials, not about energy or heating or climate adaptation or so. It's a part which could contribute to a bigger theme."

Expert 3 (Senior project manager Non-Residential): "I think it's just on a scale for the clients overall, you can use this model, but I think for us from the contracts and also in the design phase process we have, it can be added to our standard trade off matrix, which already has its own finance and risk and time aspects and quality aspect. So I think if it can be combined then it's very useful."

Expert 4 (Commercial Manager at Heijmans): "How well is not the question. It's more about - your tool is to bring the contractors, the designers and the investors together, to convince each other of the necessity of circular buildings. If you ask me how well, I don't know because we have never used it. I don't have the answer because we have to put it to test. We have to have a pilot and then during this pilot you have to use this model and do the investigation and look if we can use this model, does it influence the decisions we make, Can we design based on this model?"

Expert 5 (Manager Plan Development at Heijmans): "Yes at the base of it you can, of course you have to correct the aspects, social aspects etc. But on the basis it can be a tool to give emphasis on sustainability and environmental aspects."

Expert 6 (Development manager at Heijmans real estate): "It can contribute to the discussion to make buildings more sustainable. I do think so, yeah."

From the above responses, we see that four of the six experts believe that the model indeed has applicability in contributing to a bigger theme and assisting in discussions regarding sustainability. While one expert was of the opinion that model is not really applicable because existing tools like MKI are used to measure the environmental impact, he agreed that the model has added value for integrating the different tools for financial, environmental and social performance. Lastly, one more expert felt that the applicability of the model cannot be predicted and would have to be tested in a pilot.

5.2.6 Concluding the Validation

Thus, it is evident from the discussion of expert reviews, that there is a general agreement in the responses regarding the usefulness of the created model. Compared to the needs and the expected potential uses of the model stated in section 2.7, the responses from the expert review confirm that the model indeed has use in comparing design options based on sustainability aspects. The validation responses show that all 7 listed needs, as interpreted from the previous discussions in section 2.7.1, have been met.

The responses also confirm that the model can be used by contractors for selecting business cases and directing discussions regarding sustainability with clients and investors, and by designers to compare between building components. There is a general consensus that a major positive impact of the model on the design selection process is that it can be used to guide discussions with investors and clients on environmental and social sustainability. These are in line with the expected usefulness and needs stated in chapter 2, thereby validating the model.

6. Conclusions and Recommendations

This chapter completes this thesis by concluding the development statement. It also looks at the limitations of the model and provides recommendations for the future.

6.1 Conclusions

The thesis, with the help of literature and interviews with relevant stakeholders, established the existence of the need for a model that can provide investors a way to consider investing in more sustainable options by evaluating the total costs and benefits of sustainability – financial, environmental as well as social – throughout the lifecycle of construction assets. The thesis showed that such a model does not currently exist that can integrate the evaluation and comparison of all three aspects, and help with the decision making in selecting the optimum design option. The value of such a model to the relevant stakeholders was established through a series of interviews. The responses received clearly showed that such a tool would have a positive impact on the decision making process for the most optimum design. A multi-criteria decision analysis methodology, with preference function modelling approach was used to build the model. The model was tested on a test case study with three design variants of an office building, and its results were verified from a third party software. Another set of interviews based on the results of the model was conducted to validate the model.

The development statement of the thesis was as follows:

To enable project owners and investors to evaluate and compare the total value for society of construction projects, in order to guide the sustainable investment decisions towards projects with higher true lifecycle value.

To respond to this statement, the thesis defines a clear methodology for the creation of TVS Model that can evaluate the true lifecycle values – financial, environmental and social – of design alternatives of the same functional equivalence. These alternatives are given ratings based on their lifecycle performances. The financial and environmental lifecycle performances are obtained from their LCC and LCA analysis. The social performance of the variants is more challenging to evaluate, and the thesis suggests a clear methodology of Product Social Impact Analysis to perform SLCA. The model has been intentionally made flexible and the users of the model are free to perform their own lifecycle analysis of the variants, and input them as ratings. The model also considers the user's preferences of the three aspects and takes them as input of relative weights of each criteria, to provide more flexibility. It then calculates an overall score for each variant, thus allowing the users to pick the variant with the most true lifecycle value for them. Having the option to compare design options based on their sustainable performance, the project owners and investors are enabled to consider more sustainable options and building practices. Thus, the solution to the development statement is:

The Total Value for Society Model, by comparing design options based on their lifecycle performances on financial, environmental and social sustainability aspects, and showing the most optimum option for the given preferences on the relative weights of criteria, can enable investors to evaluate and compare the true lifecycle values of construction projects, and doing so, guide their investment decisions.

6.2 Limitations

The model created through this thesis has its limitations due to the scope and current level of research.

1. The stakeholder interviews were conducted with design and planning managers of a contracting firm in the Netherlands. However, other important stakeholders and potential users of the model like banks, investment firms and local governments have not been interviewed due to scope constraints.

2. All stakeholders interviewed are from the same firm and thus, there is a possibility of a bias in the results.

3. For the performance of LCA, LCC and SLCA, the datasets used and the product declarations by the manufacturers have to be assumed to be true. Specially in the case of SLCA, the level of research is in an infancy stage and product declarations are not readily available.

4. In the recommended methodology of SLCA, working with 5-point scales is admittedly an over-simplification of the real life scenarios. Moreover the intuitive interpretation of the scale is that the references are integers and that -2 is twice as bad as -1, which may not be the case.

Further, two products or design alternatives considered using PSIA may have very similar PSIA results if produced along the same value chains, and this will make the decision making challenging.

5. The scope for the study only considers the superstructure and the façade of the design options and does not give an impression of the lifecycle performances in the use, maintenance and exploitation phases. How the results might change with their inclusion is unknown. Moreover, due to this reason, the thesis could not apply the PSIA methodology and conduct the SLCA.

Also, the case study only concerns with the difference in building materials and does not consider the building methods or process used.

6. The results of the model cannot be physically validated without actually measuring the lifecycle performances of pilot projects.

6.3 Recommendations

6.3.1 Recommendations for Heijmans

1. Heijmans is recommended to explore the integration of the TVS model with its present trade-off matrix. This would enable the organization to add the sustainability factors to the same platform as risks, quality and time.

2. The company is proposed to continue the research into the social aspects of building sustainability. The area of social impact analysis studies is still largely unexplored and the demands for social sustainability are going to increase in the near future.

3. Heijmans is also recommended to initiate discussions with clients for new projects regarding sustainability criteria and circularity implementation in the building methods. The company can use the TVS model as a base for discussing the client's sustainability needs and the potential interest in investing into sustainable construction. The model can also be used to guide the discussions towards getting returns on investment made into social and environmental sustainability.

4. The organization is also suggested to use the model and its future developments in working towards its own sustainability goals. It can do so by choosing future government projects based on the optimum value it can gain in terms of economic as well as environmental and social sustainability returns.

6.3.2 Recommendations for Future Research and Development

1. The TVS model in its current form is a decision making tool that allows comparisons between design alternatives. However, the same can be expanded into a design model that can build the most optimum design based on the user preferences. It is recommended to have further research and development conducted on building this design model, since it would make it the design process easier and more optimised.

2. There is need for further research into the social sustainability and its impact analysis methods. Currently, there is a lack of standardisation in the social impact categories and the performance of SLCA. Unlike the environmental LCA performance, there is no standard methodology. Moreover, it is difficult to quantify the social impact of products and there exists no database for social product declarations. Having such standardisations and databases will help in more accurate and consistent SLCA performances, and will better link the social performances to the designs and building materials. It will also help in selection of subcontractors and encourage positive social building practices.

3. The TVS model in its current state does not particularly include circularity and post end-of-life performances of materials. It does not include the added benefits of circular building methods such as designing for disassembly and adaptability. Such circular returns gained from post EoL treatment of material components is recommended to be looked into for the future iterations of this model.

4. The model does not factor in the architecture, aesthetics and floor use plans in building designs. This makes the selection of optimum design challenging. It is recommended for future studies to include these aspects in the next iterations.

5. The current model uses technical terms and numbers for the lifecycle performance analysis, and they do not translate intuitively into sustainability goals. The future studies should look into making it easier for the user to have a feel of the real world impact of the environmental and social performances of alternatives.

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A | Appendix A: Stakeholder Interview Questionnaire

Part 1. To Establish the Need for the Model

Introductory Questions (to capture a brief insight on current methods)

Q. How would you describe your role within the company?

Q. Can you describe the planning phase of a project in terms of design considerations?

Q. Can you describe the design phase with respect to interactions with designers and contractors, and the importance given to sustainability in design?

Q. How many design alternatives are usually considered before a design is finalised?

Q. Can you describe the process of greenlighting a project design at your company?

Transition Questions (To discuss the relevance of selecting an optimum design)

Q. What are the factors considered when selecting between multiple designs for a project?

Q. In your opinion, how much relative importance is given to financial, environmental, and social aspects when considering a design?

Q. In your opinion, how useful would be a model that can compare design options of same functional equivalences to the company, based on the above aspects?

Q. How impactful would such a model be to your decision making process of selecting the optimum design?

Main Questions (To discuss the model and its applicability)

Q. How much relevance is given to LCC and LCA while considering multiple design options?

-Are there other tools that are given more importance while considering economic and environmental impacts?

-If so, what are those tools?

Q. How is social impact currently being documented?

Q. What are your views on the PSIA methodology for qualitatively documenting the social impacts?

Q. What stakeholders are most relevant in the social impact study?

Q. What are the hotspots where major social impacts occur in a typical project?

Q. What are the most relevant social topics/subcategories that can be considered for the project?

Part 2. To Validate the Model

Q. What are your views on the PSIA methodology for qualitatively documenting the social impacts?

Q. What stakeholders are most relevant in the social impact study?

Q. What are the hotspots where major social impacts occur in a typical project?

Q. What are the most relevant social topics/subcategories that can be considered for the project?

Q. How much weight to each aspect would you provide (from experience as well as preference)

Q. Does the model result fit in line with your expectations?

Q. How would you describe the usefulness of this model in terms of selecting designs for real projects?

-To the owner/investor

-To contractors and other stakeholders

-To designers

Q. What are the problems that are not being considered by this model?

Q. For the applicability of the model, how well do you think it can be adopted to optimise sustainability in designs?

Q. Are there any other considerations that should be taken into account apart from those above?

Q. Is there anything else that you would like to share that I may have missed?

B | Appendix B: Stakeholder Interview Responses (Part 1)

The following table shows the responses of the participants received during part 1 of the stakeholder interviews and establishes the need for the model.

No.	Interviewee Position	Factors considered when selecting between multiple designs	Relative importance being given to financial, environmental, and social aspects when considering a design	Usefulness of suggested model that can compare design options of same functional equivalence	Impact of such a model on decision making process for selection of optimum design
1	Design manager integrated non-residential construction projects	Combination of CAPEX and OPEX, the architecture and looks, the risks	For government projects (for the last few years), there is always an intention for implementing sustainability and social aspects.	Would be really useful for Heijmans real estate who basically decide on the business cases of projects.	There is always one thing more important that sustainability and that is financial aspects.
			Private companies give less importance, but there are also a lot of private companies focusing on sustainability.	The tool would be useful for comparing between inner walls, façade elements, material used.	If the model could tell how much more expensive it would get for what environmental and social benefits, then that would be useful.
			For government projects, these aspects can be a part of the requirements, but also have projects where better the sustainability performance, the better rated your tender proposal.	For a design manager, it is interesting to use this tool for specific products, and see the sustainability effect for that specific part of the building If you take the whole building, it will be more relevant for a client or a real estate project developer who is responsible for the entire business case.	The tool will have impact but to what extent, that is difficult to say at this moment. It depends on the type of project and the type of client. For me, it will be a little impactful.
2	Director at Heijmans real estate	For an investor it would be interesting what value the building would have in 50 years	Financial aspects are the base for a good business case.	I think it would be useful. You want to be the makers of a healthy environment. So we have to push in that direction to make our buildings more sustainable.	I think it will be very impactful. Now decision making is more like a wild guess.
		Affordability is very important to consumers	Environmental and Social have to meet the minimum legal requirements but not much further		It will also be impactful in knowing about the material used in the building, and it's social and
3	Senior project manager Heijmans Non-Residential	CAPEX, OPEX and quality	Environmental and social sustainability are taken into consideration when the clients ask for them.	Very interesting, because also we now have the trade-off matrix and it would be wider and better, not only looking for cost, quality and time but also in terms of quality and sustainability.	Can add value to the company because we are a systems integrator.
			To satisfy the company policies on sustainability. Also to comply with regulations from the government in the building codes.	A greater possibility to get more clarity for the clients and also for us internally with our directors to get the right discussion.	We listen very clearly to the client and what they want. But we can also surprise them by looking wider than only time and quality in the debate.
4	Commercial Manager Netherlands at Heijmans	Right balance between market-issues, product-to-market, costs of location, risks-issues (zone-planning), building costs, designing costs, sustainability items, return on investment (yields).	Environmental, yes. The investors want these credits from BREEAM.	Very important, because society changes and we need to think differently about social yields.	A kind of predictable model in future, where you compare the financial and construction optimums and calculate the environmental but also the financial end of life cycle, we don't have this model.
			No calculation model for the social impact.	For residential areas it would be interesting for Municipality to have a kind of idea that if we do this what is the social impact.	I think so but what we have to do is first of all we have to understand the model first and we have to train for how we can work with it because we also have to explain it to our stakeholders, to our advisers, etc.
				Very interesting to have this tool to discuss with the investor.	
5	Manager Plan Development at Heijmans	Different aspects, for instance, circularity, they ask for an MPG (MilieuPrestatie Gebouwen - Environmental Performance of buildings).	It is hard to say which is the most important. I think they are all important. But if we do not have a financial business case then there's going to be no project. So in that case the financial is the most important.	I think it can be very, very useful.	The tender criteria are the most important. Then such a model can help us to explain to the client why the design we choose is the best design.
		It's always of course, costs, time, safety. Also depends on the tender criteria required. Often there are circularity and energy saving criteria.	For environmental aspects, the base case is what we legally have to do. Hopefully we can do more if the financial business case allows.		
6	Development manager at Heijmans real estate	To market your specific projects with a special label that can be used in a commercial way, you can address specific requirements as well regarding sustainability, circularity.	Financial is still one of the most important criteria to be met because that's the main of our existence, and if we cannot meet the financial promises we minimally need, the project is rejected.	If you can make such a comparison visual, of course that can help.	If we can advise our clients on how to add more value, I think that's another added value we can deliver and so it's an added value for our company
		Main acceptance of sustainability for a living environment is growing. So it's getting commercially more interesting to specify specific sustainable or circularity goals so you can use it in marketing your product.	We just have to meet the sustainability goals that are given in the building regulations and it's with most real estate developments, already a challenge, so that's enough for now.	With less exploitation costs, the initial investments can grow, and that's in our concern, because then we can make more money. The value rises.	It can also help convince ourselves about making those choices.
		Local requirements and building materials.	Socially we also want to contribute to a better local society and local community		

Table B.1 Stakeholder Interview Responses – Establishing the need

C | Appendix C: Stakeholder Interview Responses (Part 2)

The following table shows the responses of the expert review conducted as part 2 of the stakeholder interviews and provides the validation for the model.

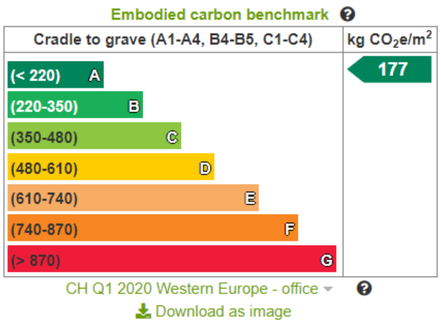
Table C.1 Stakeholder Interview Responses – Validation of the model

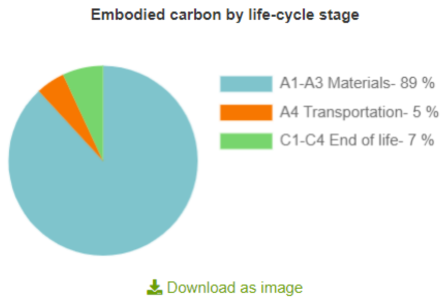
S. No.	Interviewee Position	Views on the model	Usefulness to Owner/Investor	Usefulness to Contractors	Usefulness to Designers	Missing/ Potential features
1	Design manager integrated non-residential construction projects	Usefulness of the model depends on the information provided by the manufacturers	It also depends on the policy of the company and also the requirements from the clients on different social aspects.	A little useful. Depends on the policies of the company.	A little useful. Can be useful for comparing different products.	The link between the scoring of the social aspects and the designs is not clear. Need to relate the social aspects to the technical design options.
		Will be useful but the success depends on the information you can receive from different manufacturers and subcontractors.	Really useful for the investors as they decide the requirements.		Model would not be very useful for non-residential buildings because basically the requirements for social aspects in these projects are determined by the clients.	
		Financial and environmental aspects preferred above social at the moment because we do not have a lot of social problems in the Netherlands.				
2	Director at Heijmans real estate	No such decision making tool exists at the moment. Model is interesting.	If the client is concerned about social and environmental sustainability, he would like to have the option to compare designs.	Have to test the model with real projects and look with other constructors and advisors, but would be useful for contractors.	For designers, the model would give them a lot of knowledge and help them make the right decisions. Would be very useful.	More interesting for banks and investors to give loans to models that give a certain rating.
		You have to ensure the correctness of data to use it.	Can help business to business clients and also local governments to get new work aquisitions.			Model is too complex for the user of the building.
			For Investors, it will be useful.			This model does not look at the contractor and what he is good at.
						Model's use directed at material impact. Does not consider spatial and floor planning.
3	Senior project manager Non-Residential	Model seems logical and also you can play with the weights of the criteria and and find the best alternative in each case.	It is most useful. Can compare designs from different tenders on the same criteria.	More difficult because of the definition of social impact.	When we add this model to our standard tradeoff matrix, then it can be useful.	Still need to translate the social aspects definitions for construction sector.
		Interesting to compare on social aspects.	Simple model to choose the best company/ best alternative.	When the client has these aspects in it's requirements and gives them importance, then the model is useful to show to the clients that the proposal is great for social and environmental aspects.	Will be helpful when the project goals require a good mix of the three aspects. Also can use this model to reach Heijman's organisation goals and ambitions.	The model should can also take into account the architectural aspects such as aesthetics and spatial use.
				The use of this model can help you reach the goals of more circularity. You can use it in our organization to see the best opportunities.		
4	Commercial Manager at Heijmans	Model is useful in making decisions from the point of what kind of investor or company we want to be.	Model would be helpful to have a discussion to make it real and feasible for our stakeholders and companies to see the results of choosing a model.	It gives information on how to deal with discussions about why and how decisions to develop and build circular buildings.	Designers will be happy because they all want more sustainability in their architectural designs.	Would be interesting to connect this model to an investment plan /model (income and costs and exit price.
			Really helpful. Helps in discussions about circularity.			
5	Manager Plan Development at Heijmans	The methodology to compare different aspects to get an overall outcome is useful to start a discussion. It's good to use it as a base to discuss different alternatives.	It can help the investors to make choices, but it's more to have the discussion about different elements and what's important than just to make the calculation and say that one is best.	For the contractors it is less important because the contractor is just building it. For Heijmans, environmental aspects, health are important issues and it could be useful to to make choices between different projects for selection of which projects to pursue.	For designers, it is more useful because they have to make different choices for their design and it can help them make the right choices	A lot of emphasis on, greenwashing projects- green facades, green trees and such aspects is being given in projects. That's not really in the criteria now.
6	Development manager at Heijmans real estate	Financial information is the easiest to analyse. It is very rational.	Model can contribute to discussions about social impacts of a company on society or its workers.	Contractors are mainly concerned with fulfilling requirements. So lesser use to them.	Useful for design components and for iterations.	Technical terms of environmental aspects do not intuitively translate into sustainability goals.
		Social and sustainable goals are quite subjective. You have rationalised them which is good. It can contribute to the discussion to make buildings more sustainable.	Decision makers need quite some competence to know about the three aspects to use the model.	The local governments also have sustainable goals. And if you can contribute to those goals, then it's leverage in gaining projects, and the weight of that specific aspect rises because it has to meet those local requirements specifically. In that way this can contribute specifically.	To designers, I think it would help the same way. It's about making it possible to discuss the right aspects.	Hard to get a feeling on what the real impact is (need to give a perspective to let user imagine what the numbers mean)
		I think this is quite interesting how you can just play with the numbers and get a feeling about how it's affecting our choices.	Model is useful in contributing towards starting a discussion on how to choose the requirements and priorities			the rational approach disappears when there's politics involved. You cannot rationalize and analyse it correctly.

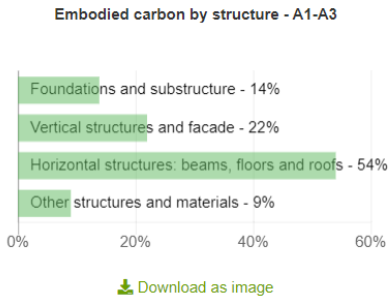
D | Appendix D: Lifecycle Performance Analysis of Case Study Variants by OneClickLCA (source: OneClickLCA)

1. LCA performance of the three variants

1.1 Variant 1 (Concrete)



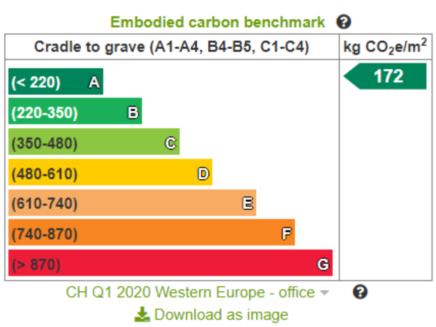


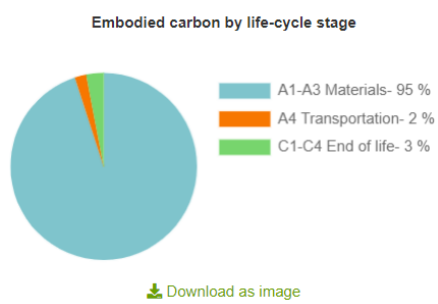


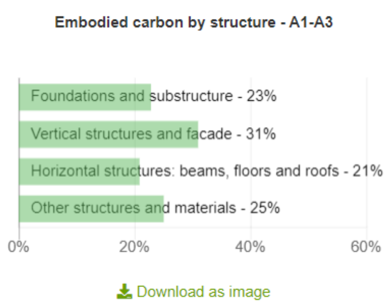
Life-cycle assessment results

	Result category	Global warming kg CO_2e	Acidification kg SO_2e	Eutrophication kg PO_4e	Ozone depletion potential kg CFC11e	Formation of ozone of lower atmosphere kg Ethenee	Total use of primary energy ex. raw materials MJ	
A1-A3	Construction Materials	7,84E5	2,68E3	2,78E2	6,91E−2	1,33E2	5,17E6	Details
A4	Transportation to site	4,03E4	6,28E1	1,29E1	6,82E−3	5,93E0	6,3E5	Details
C1-C4	Deconstruction	5,76E4	1,89E2	4,53E1	1,04E−2	5,99E0	1,39E6	Details
D	External impacts (not included in totals)	−1,42E5	−3,2E2	−9,73E1	−3,54E−3	−2,19E1	−9,4E5	Details
	Total	**8,82E5**	**2,93E3**	**3,36E2**	**8,63E−2**	**1,45E2**	**7,19E6**	
	Results per denominator							
	Gross Internal Floor Area (IPMS/RICS) 5000.0 m^2	1,76E2	5,86E−1	6,73E−2	1,73E−5	2,89E−2	1,44E3	

1.2 Variant 2 (Steel)





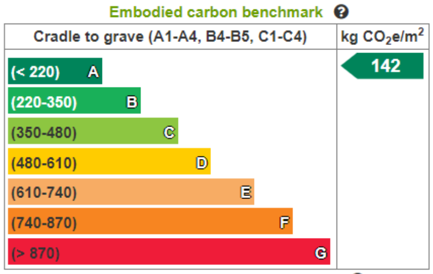


Life-cycle assessment results

	Result category	Global warming kg CO_2e ⓘ	Acidification kg SO_2e ⓘ	Eutrophication kg PO_4e ⓘ	Ozone depletion potential kg CFC11e ⓘ	Formation of ozone of lower atmosphere kg Ethenee ⓘ	Total use of primary energy ex. raw materials MJ ⓘ	
A1-A3 ⓘ	Construction Materials	8,21E5	2,12E3	2,99E2	1,23E−1	2,01E2	9,45E6	Details
A4 ⓘ	Transportation to site	1,59E4	4,56E1	9,75E0	2,89E−3	1,72E0	3,36E5	Details
C1-C4 ⓘ	Deconstruction	2,61E4	8,6E1	2,01E1	4,69E−3	2,67E0	6,31E5	Details
D ⓘ	External impacts (not included in totals)	6,5E4	4,4E2	2,69E2	6,05E−3	1,18E2	3,88E5	Details
	Total	**8,63E5**	**2,25E3**	**3,29E2**	**1,31E−1**	**2,06E2**	**1,04E7**	
	Results per denominator							
	Gross Internal Floor Area (IPMS/RICS) 5000.0 m^2	1,73E2	4,5E−1	6,57E−2	2,62E−5	4,11E−2	2,08E3	

1.3 Variant 3 (Timber)

Embodied carbon benchmark



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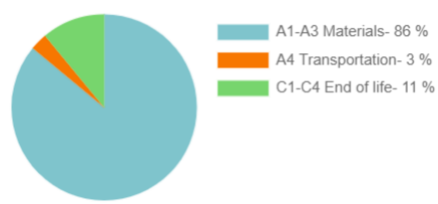
Embodied carbon by life-cycle stage



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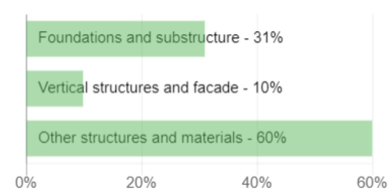
Embodied carbon by structure - A1-A3



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Life-cycle assessment results

	Result category	Global warming kg CO_2e ⓘ	Acidification kg SO_2e ⓘ	Eutrophication kg PO_4e ⓘ	Ozone depletion potential kg CFC11e ⓘ	Formation of ozone of lower atmosphere kg Ethenee ⓘ	Total use of primary energy ex. raw materials MJ ⓘ	
A1-A3 ⓘ	Construction Materials	6,1E5	2,22E3	3,95E2	9,15E−2	1,55E2	9,53E6	Details
A4 ⓘ	Transportation to site	1,86E4	5,79E1	1,24E1	3,42E−3	1,88E0	4,13E5	Details
C1-C4 ⓘ	Deconstruction	7,82E4	1,44E2	3,61E1	3,37E−3	9,99E0	6,5E5	Details
D ⓘ	External impacts (not included in totals)	2,42E5	1,93E3	6,9E2	2,56E−2	3,58E2	1,19E6	Details
	Total	**7,07E5**	**2,42E3**	**4,44E2**	**9,83E−2**	**1,67E2**	**1,06E7**	
	Results per denominator							
	Gross Internal Floor Area (IPMS/RICS) 5000.0 m^2	1,41E2	4,84E−1	8,88E−2	1,97E−5	3,34E−2	2,12E3	

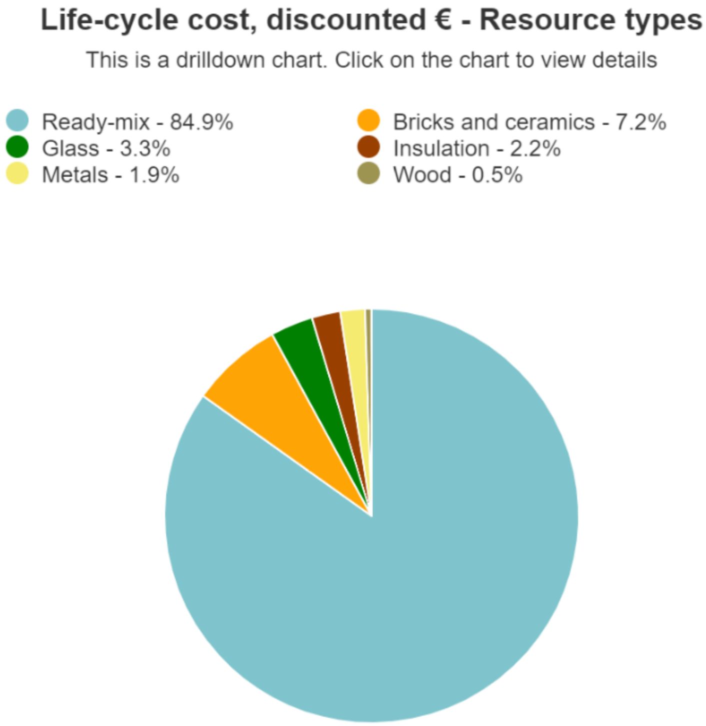
2. LCC performance of the three variants

2.1 Variant 1 (Concrete)

The life-cycle costing is carried out with One Click LCA, a life-cycle performance cloud software, in compliance with ISO 15686-5 standard while following the structure of EN 16627 standard. This LCC calculation can be used for instance in BREEAM certification process for the Life-cycle Cost Analysis credit.

Life-cycle cost as per ISO 15686-5 and EN 16627

	Result category	Life-cycle cost, discounted €	LCC, nominal (undiscounted, includes inflation) €	
A0-A5	Construction	742 909	742 909	Details
C1-C4	End of life	1 620	51 000	Details
	Total	**744 529**	**793 909**	
	Results per denominator			
	Gross Internal Floor Area (IPMS/RICS) 5000.0 m^2	149	159	

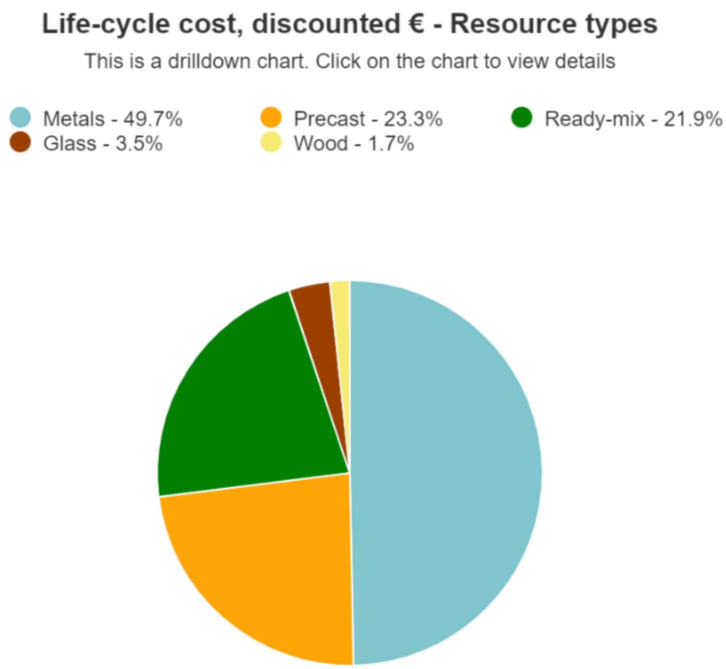


2.2 Variant 2 (Steel)

The life-cycle costing is carried out with One Click LCA, a life-cycle performance cloud software, in compliance with ISO 15686-5 standard while following the structure of EN 16627 standard. This LCC calculation can be used for instance in BREEAM certification process for the Life-cycle Cost Analysis credit.

Life-cycle cost as per ISO 15686-5 and EN 16627

	Result category	Life-cycle cost, discounted €	LCC, nominal (undiscounted, includes inflation) €	
A0-A5	Construction	742 641	742 641	Details
C1-C4	End of life	1 619	50 982	Details
	Total	**744 260**	**793 623**	
	Results per denominator			
	Gross Internal Floor Area (IPMS/RICS) 5000.0 m^2	149	159	

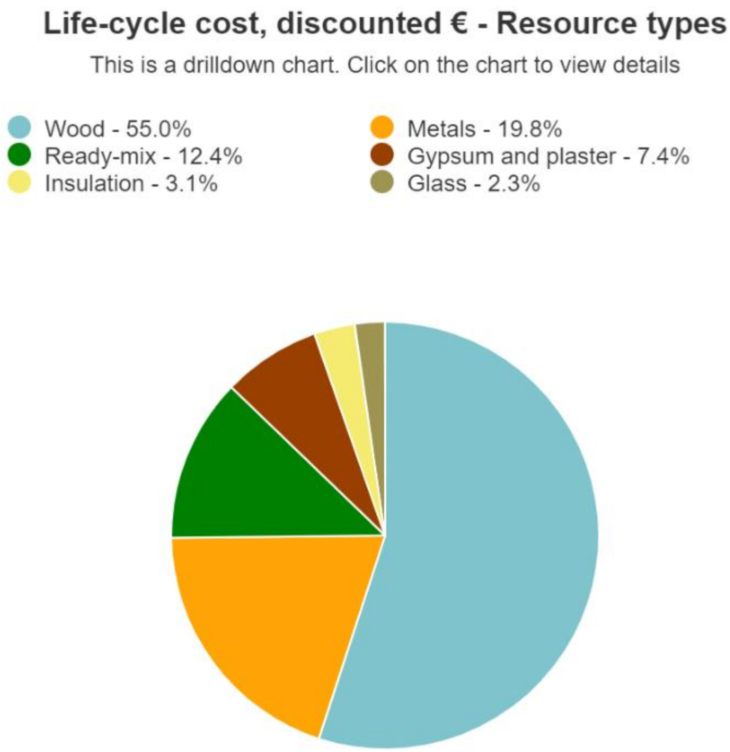


2.3 Variant 3 (Timber)

The life-cycle costing is carried out with One Click LCA, a life-cycle performance cloud software, in compliance with ISO 15686-5 standard while following the structure of EN 16627 standard. This LCC calculation can be used for instance in BREEAM certification process for the Life-cycle Cost Analysis credit.

Life-cycle cost as per ISO 15686-5 and EN 16627

	Result category	Life-cycle cost, discounted €	LCC, nominal (undiscounted, includes inflation) €	
A0-A5	Construction	1 320 024	1 320 024	Details
C1-C4	End of life	2 878	90 619	Details
	Total	**1 322 902**	**1 410 643**	
	Results per denominator			
	Gross Internal Floor Area (IPMS/RICS) 5000.0 m^2	265	282	



E | Appendix E: Tetra Solution Reports for Verification

1. For the relative weight scenario: Financial – 55%, Environmental – 30%, Social – 15%

Tetra Solution Report

Model: TVS Model Verification

By: Default User

Date: Wed Apr 14 19:34:05 2021

Weight Paradigm: n/a

Parent Criterion: Criteria

Overall Ratings

Rank	Alternative	Rating
1	**Variant_1 (concrete)**	**87.766**
2	Variant_2 (steel)	84.117
3	Variant_3 (timber)	24.894

Criteria Weights

Criterion	Local Weights	Global Weights	Weighting Values
Criteria			
Environmental Category	0.300	0.300	30.000
Acidification (kg SO2e)	0.167	0.050	5.000
Eutrophication (kg PO4e)	0.167	0.050	5.000
Formation of ozone of lower	0.167	0.050	5.000

atmosphere (kg Ethenee)			
Global Warming (kg CO2e)	0.167	0.050	5.000
Ozone depletion potential (kg CFC11e)	0.167	0.050	5.000
Total use of primary energy (MJ)	0.167	0.050	5.000
Financial Category	0.550	0.550	55.000
Social Category	0.150	0.150	15.000
Effectiveness and Comfort of Users	0.333	0.050	5.000
Health and Safety of Users	0.333	0.050	5.000
Occupational Health and Safety of Workers	0.333	0.050	5.000

Ratings

Criteria\Environmental Category\Acidification (kg SO2e)

Default User:Acidification ratings

Variant_1 (concrete)	0.000
Variant_2 (steel)	100.000
Variant_3 (timber)	75.000

Criteria\Environmental Category\Eutrophication (kg PO4e)

Default User:Eutrophication ratings

Variant_1 (concrete)	93.913
Variant_2 (steel)	100.000
Variant_3 (timber)	0.000

Criteria\Environmental Category\Formation of ozone of lower atmosphere (kg Ethenee)

Default User:Formation of ozone ratings

Variant_1 (concrete)	100.000
Variant_2 (steel)	0.000
Variant_3 (timber)	63.934

Criteria\Environmental Category\Global Warming (kg CO2e)

Default User:Global Warming ratings

Variant_1 (concrete)	0.000
Variant_2 (steel)	11.040
Variant_3 (timber)	100.000

Criteria\Environmental Category\Ozone depletion potential (kg CFC11e)

Default User:Ozone depletion potential ratings

Variant_1 (concrete)	100.000
Variant_2 (steel)	0.000
Variant_3 (timber)	73.154

Criteria\Environmental Category\Total use of primary energy (MJ)

Default User:Primary energy ratings

Variant_1 (concrete)	100.000
Variant_2 (steel)	5.865
Variant_3 (timber)	0.000

Criteria\Financial Category

Default User:Financial ratings (euros)

Variant_1 (concrete)	99.954
Variant_2 (steel)	100.000

Variant_3 (timber)	0.000

Criteria\Social Category\Effectiveness and Comfort of Users

Default User:Effectiveness & comfort Users ratings

Variant_1 (concrete)	50.000
Variant_2 (steel)	75.000
Variant_3 (timber)	100.000

Criteria\Social Category\Health and Safety of Users

Default User:Health & safety Users ratings

Variant_1 (concrete)	50.000
Variant_2 (steel)	75.000
Variant_3 (timber)	100.000

Criteria\Social Category\Occupational Health and Safety of Workers

Default User:Occupation H&S Workers ratings

Variant_1 (concrete)	75.000
Variant_2 (steel)	100.000
Variant_3 (timber)	100.000

2. For the relative weight scenario: Financial – 100%, Environmental – 0%, Social – 0%

Tetra Solution Report

Model: TVS Model Verification

By: Default User

Date: Fri Apr 23 11:47:21 2021

Weight Paradigm: n/a

Parent Criterion: Criteria

Overall Ratings

Rank	Alternative	Rating
1	Variant_1 (concrete)	99.954
1	**Variant_2 (steel)**	**100.000**
3	Variant_3 (timber)	0.000

Criteria Weights

Criterion	Local Weights	Global Weights	Weighting Values
Criteria			
Environmental Category	0.000	0.000	0.000
Acidification (kg SO2e)	0.167	0.000	10.000
Eutrophication (kg PO4e)	0.167	0.000	10.000
Formation of ozone of lower atmosphere (kg Ethenee)	0.167	0.000	10.000
Global Warming (kg CO2e)	0.167	0.000	10.000

Ozone depletion potential (kg CFC11e)	0.167	0.000	10.000
Total use of primary energy (MJ)	0.167	0.000	10.000
Financial Category	1.000	1.000	100.000
Social Category	0.000	0.000	0.000
Effectiveness and Comfort of Users	0.333	0.000	10.000
Health and Safety of Users	0.333	0.000	10.000
Occupational Health and Safety of Workers	0.333	0.000	10.000

Ratings

Criteria\Environmental Category\Acidification (kg SO2e)

Default User:Acidification ratings

Variant_1 (concrete)	0.000
Variant_2 (steel)	100.000
Variant_3 (timber)	75.000

Criteria\Environmental Category\Eutrophication (kg PO4e)

Default User:Eutrophication ratings

Variant_1 (concrete)	93.913
Variant_2 (steel)	100.000
Variant_3 (timber)	0.000

Criteria\Environmental Category\Formation of ozone of lower atmosphere (kg Ethenee)

Default User:Formation of ozone ratings

Variant_1 (concrete)	100.000

Variant_2 (steel)	0.000
Variant_3 (timber)	63.934

Criteria\Environmental Category\Global Warming (kg CO2e)

Default User:Global Warming ratings

Variant_1 (concrete)	0.000
Variant_2 (steel)	11.040
Variant_3 (timber)	100.000

Criteria\Environmental Category\Ozone depletion potential (kg CFC11e)

Default User:Ozone depletion potential ratings

Variant_1 (concrete)	100.000
Variant_2 (steel)	0.000
Variant_3 (timber)	73.154

Criteria\Environmental Category\Total use of primary energy (MJ)

Default User:Primary energy ratings

Variant_1 (concrete)	100.000
Variant_2 (steel)	5.865
Variant_3 (timber)	0.000

Criteria\Financial Category

Default User:Financial ratings (euros)

Variant_1 (concrete)	99.954

Variant_2 (steel)	100.000
Variant_3 (timber)	0.000

Criteria\Social Category\Effectiveness and Comfort of Users

Default User:Effectiveness & comfort Users ratings

Variant_1 (concrete)	50.000
Variant_2 (steel)	75.000
Variant_3 (timber)	100.000

Criteria\Social Category\Health and Safety of Users

Default User:Health & safety Users ratings

Variant_1 (concrete)	50.000
Variant_2 (steel)	75.000
Variant_3 (timber)	100.000

Criteria\Social Category\Occupational Health and Safety of Workers

Default User:Occupation H&S Workers ratings

Variant_1 (concrete)	75.000
Variant_2 (steel)	100.000
Variant_3 (timber)	100.000

3. For the relative weight scenario: Financial – 0%, Environmental – 100%, Social – 0%

Tetra Solution Report

Model: TVS Model Verification

By: Default User

Date: Fri Apr 23 11:46:14 2021

Weight Paradigm: n/a

Parent Criterion: Criteria

Overall Ratings

Rank	Alternative	Rating
1	**Variant_1 (concrete)**	**71.605**
3	Variant_2 (steel)	31.171
2	Variant_3 (timber)	52.506

Criteria Weights

Criterion	Local Weights	Global Weights	Weighting Values
Criteria			
Environmental Category	1.000	1.000	100.000
Acidification (kg SO2e)	0.167	0.167	10.000
Eutrophication (kg PO4e)	0.167	0.167	10.000
Formation of ozone of lower atmosphere (kg Ethenee)	0.167	0.167	10.000

Global Warming (kg CO2e)	0.167	0.167	10.000
Ozone depletion potential (kg CFC11e)	0.167	0.167	10.000
Total use of primary energy (MJ)	0.167	0.167	10.000
Financial Category	0.000	0.000	0.000
Social Category	0.000	0.000	0.000
Effectiveness and Comfort of Users	0.333	0.000	10.000
Health and Safety of Users	0.333	0.000	10.000
Occupational Health and Safety of Workers	0.333	0.000	10.000

Ratings

Criteria\Environmental Category\Acidification (kg SO2e)

Default User:Acidification ratings

Variant_1 (concrete)	0.000
Variant_2 (steel)	100.000
Variant_3 (timber)	75.000

Criteria\Environmental Category\Eutrophication (kg PO4e)

Default User:Eutrophication ratings

Variant_1 (concrete)	93.913
Variant_2 (steel)	100.000
Variant_3 (timber)	0.000

Criteria\Environmental Category\Formation of ozone of lower atmosphere (kg Ethenee)

Default User:Formation of ozone ratings

Variant_1 (concrete)	100.000
Variant_2 (steel)	0.000
Variant_3 (timber)	63.934

Criteria\Environmental Category\Global Warming (kg CO2e)

Default User:Global Warming ratings

Variant_1 (concrete)	0.000
Variant_2 (steel)	11.040
Variant_3 (timber)	100.000

Criteria\Environmental Category\Ozone depletion potential (kg CFC11e)

Default User:Ozone depletion potential ratings

Variant_1 (concrete)	100.000
Variant_2 (steel)	0.000
Variant_3 (timber)	73.154

Criteria\Environmental Category\Total use of primary energy (MJ)

Default User:Primary energy ratings

Variant_1 (concrete)	100.000
Variant_2 (steel)	5.865
Variant_3 (timber)	0.000

Criteria\Financial Category

Default User:Financial ratings (euros)

Variant_1 (concrete)	99.954
Variant_2 (steel)	100.000
Variant_3 (timber)	0.000

Criteria\Social Category\Effectiveness and Comfort of Users

Default User:Effectiveness & comfort Users ratings

Variant_1 (concrete)	50.000
Variant_2 (steel)	75.000
Variant_3 (timber)	100.000

Criteria\Social Category\Health and Safety of Users

Default User:Health & safety Users ratings

Variant_1 (concrete)	50.000
Variant_2 (steel)	75.000
Variant_3 (timber)	100.000

Criteria\Social Category\Occupational Health and Safety of Workers

Default User:Occupation H&S Workers ratings

Variant_1 (concrete)	75.000
Variant_2 (steel)	100.000
Variant_3 (timber)	100.000

4. For the relative weight scenario: Financial – 0%, Environmental – 0%, Social – 100%

Tetra Solution Report

Model: TVS Model Verification

By: Default User

Date: Fri Apr 23 11:44:30 2021

Weight Paradigm: n/a

Parent Criterion: Criteria

Overall Ratings

Rank	Alternative	Rating
1	Variant_1 (concrete)	58.489
2	Variant_2 (steel)	83.879
1	**Variant_3 (timber)**	**100.000**

Criteria Weights

Criterion	Local Weights	Global Weights	Weighting Values
Criteria			
Environmental Category	0.000	0.000	0.000
Acidification (kg SO2e)	0.167	0.000	10.000
Eutrophication (kg PO4e)	0.167	0.000	10.000
Formation of ozone of lower atmosphere (kg Ethenee)	0.167	0.000	10.000
Global Warming (kg CO2e)	0.167	0.000	10.000

Ozone depletion potential (kg CFC11e)	0.167	0.000	10.000
Total use of primary energy (MJ)	0.167	0.000	10.000
Financial Category	0.000	0.000	0.000
Social Category	1.000	1.000	100.000
Effectiveness and Comfort of Users	0.333	0.333	10.000
Health and Safety of Users	0.333	0.333	10.000
Occupational Health and Safety of Workers	0.333	0.333	10.000

Ratings

Criteria\Environmental Category\Acidification (kg SO2e)

Default User:Acidification ratings

Variant_1 (concrete)	0.000
Variant_2 (steel)	100.000
Variant_3 (timber)	75.000

Criteria\Environmental Category\Eutrophication (kg PO4e)

Default User:Eutrophication ratings

Variant_1 (concrete)	93.913
Variant_2 (steel)	100.000
Variant_3 (timber)	0.000

Criteria\Environmental Category\Formation of ozone of lower atmosphere (kg Ethenee)

Default User:Formation of ozone ratings

Variant_1 (concrete)	100.000
Variant_2 (steel)	0.000
Variant_3 (timber)	63.934

Criteria\Environmental Category\Global Warming (kg CO2e)

Default User:Global Warming ratings

Variant_1 (concrete)	0.000
Variant_2 (steel)	11.040
Variant_3 (timber)	100.000

Criteria\Environmental Category\Ozone depletion potential (kg CFC11e)

Default User:Ozone depletion potential ratings

Variant_1 (concrete)	100.000
Variant_2 (steel)	0.000
Variant_3 (timber)	73.154

Criteria\Environmental Category\Total use of primary energy (MJ)

Default User:Primary energy ratings

Variant_1 (concrete)	100.000
Variant_2 (steel)	5.865
Variant_3 (timber)	0.000

Criteria\Financial Category

Default User:Financial ratings (euros)

Variant_1 (concrete)	99.954
Variant_2 (steel)	100.000
Variant_3 (timber)	0.000

Criteria\Social Category\Effectiveness and Comfort of Users

Default User:Effectiveness & comfort Users ratings

Variant_1 (concrete)	50.000
Variant_2 (steel)	75.000
Variant_3 (timber)	100.000

Criteria\Social Category\Health and Safety of Users

Default User:Health & safety Users ratings

Variant_1 (concrete)	50.000
Variant_2 (steel)	75.000
Variant_3 (timber)	100.000

Criteria\Social Category\Occupational Health and Safety of Workers

Default User:Occupation H&S Workers ratings

Variant_1 (concrete)	75.000
Variant_2 (steel)	100.000
Variant_3 (timber)	100.000

5. For the relative weight scenario: Financial – 75%, Environmental – 25%, Social – 0%

Tetra Solution Report

Model: TVS Model Verification

By: Default User

Date: Fri Apr 23 11:49:22 2021

Weight Paradigm: n/a

Parent Criterion: Criteria

Overall Ratings

Rank	Alternative	Rating
1	**Variant_1 (concrete)**	**95.036**
2	Variant_2 (steel)	89.777
3	Variant_3 (timber)	9.026

Criteria Weights

Criterion	Local Weights	Global Weights	Weighting Values
Criteria			
Environmental Category	0.250	0.250	25.000
Acidification (kg SO2e)	0.167	0.042	10.000
Eutrophication (kg PO4e)	0.167	0.042	10.000
Formation of ozone of lower atmosphere (kg Ethenee)	0.167	0.042	10.000
Global Warming (kg CO2e)	0.167	0.042	10.000

Ozone depletion potential (kg CFC11e)	0.167	0.042	10.000
Total use of primary energy (MJ)	0.167	0.042	10.000
Financial Category	0.750	0.750	75.000
Social Category	0.000	0.000	0.000
Effectiveness and Comfort of Users	0.333	0.000	10.000
Health and Safety of Users	0.333	0.000	10.000
Occupational Health and Safety of Workers	0.333	0.000	10.000

Ratings

Criteria\Environmental Category\Acidification (kg SO2e)

Default User:Acidification ratings

Variant_1 (concrete)	0.000
Variant_2 (steel)	100.000
Variant_3 (timber)	75.000

Criteria\Environmental Category\Eutrophication (kg PO4e)

Default User:Eutrophication ratings

Variant_1 (concrete)	93.913
Variant_2 (steel)	100.000
Variant_3 (timber)	0.000

Criteria\Environmental Category\Formation of ozone of lower atmosphere (kg Ethenee)

Default User:Formation of ozone ratings

Variant_1 (concrete)	100.000
Variant_2 (steel)	0.000
Variant_3 (timber)	63.934

Criteria\Environmental Category\Global Warming (kg CO2e)

Default User:Global Warming ratings

Variant_1 (concrete)	0.000
Variant_2 (steel)	11.040
Variant_3 (timber)	100.000

Criteria\Environmental Category\Ozone depletion potential (kg CFC11e)

Default User:Ozone depletion potential ratings

Variant_1 (concrete)	100.000
Variant_2 (steel)	0.000
Variant_3 (timber)	73.154

Criteria\Environmental Category\Total use of primary energy (MJ)

Default User:Primary energy ratings

Variant_1 (concrete)	100.000
Variant_2 (steel)	5.865
Variant_3 (timber)	0.000

Criteria\Financial Category

Default User:Financial ratings (euros)

Variant_1 (concrete)	99.954
Variant_2 (steel)	100.000
Variant_3 (timber)	0.000

Criteria\Social Category\Effectiveness and Comfort of Users

Default User:Effectiveness & comfort Users ratings

Variant_1 (concrete)	50.000
Variant_2 (steel)	75.000
Variant_3 (timber)	100.000

Criteria\Social Category\Health and Safety of Users

Default User:Health & safety Users ratings

Variant_1 (concrete)	50.000
Variant_2 (steel)	75.000
Variant_3 (timber)	100.000

Criteria\Social Category\Occupational Health and Safety of Workers

Default User:Occupation H&S Workers ratings

Variant_1 (concrete)	75.000
Variant_2 (steel)	100.000
Variant_3 (timber)	100.000