Bachelor

Title
Blockchain for a Circular Economy

An Explorative Research towards the Feasibility of Blockchain in Enhancing the Implemented Material passport and Life Cycle Assessment Methodology within Construction Sector in The Netherlands

Bachelor Thesis

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SUMMARY

Stimulating economic growth and material resources, as well as preserving the world's population's livelihood are culminating the implementation of linear economy in the construction industry that refuses to appreciate the importance of recycling, reusing, and efficient waste management, contributing to material waste, and greenhouse gas emissions, consequently damaging the environment. A lack of information is often cited as main problems that lead to waste and greenhouse gas emission release. Therefore, material passport and life cycle assessment methodology (LCA) are implemented to fill this information gap; nevertheless, material passport and LCA methodology face barriers that could prevent the optimization their use. Using semi-structured interview, there is analyzed which opportunities, barriers of material passport and LCA methodology which aspects can be addressed through salient features of blockchain technology. Concluding that disintermediation, transparency, as well as immutability being the prominent features offered by blockchain can add value to the applied material passport and LCA methodology, through the identification of material ownership as well as assessment the validity and reliability of information source, and the calculation of energy usage, both material and built environment carbon footprint. This research contributes to the realization of sustainable construction industry in the Netherlands through carbon footprint monitoring as well as waste reduction by highlighting important aspects of material passport and LCA methodology and which features of blockchain technology may add value to the implemented tools.

CHAPTER I
Problem Description

The Paris Agreement of 2015 is the first global agreement composing policy and obligations for 195 countries to keep the global temperature rise below 2 Celsius. The accord aims to restrict the concentration of released greenhouse gases in the atmosphere, to prevent devastating consequences of climate change, ranging from health problems, food security, and extreme weather (Ummenhofer & Meehl, 2017; Agreement, 2015). The convention is a catalyst to unify every country in the world in nourishing the preparedness to combat climate change and its impacts on the face of the earth and sustenance of the life of the world's population. The Paris Agreement is considered the ladder of climate change mitigation, which requires the world to take courageous and ambitious actions addressing the environmental problems, specifically the rising carbon dioxide levels, amidst simultaneous increasing human activities and industrialization (Mgbemene et al., 2016). The impact of the high intensity of human activities is justified by the rising levels of carbon dioxide added into the air; in 2015, the world surpassed a carbon threshold of 400 parts per million, which denoted a substantial increase in 2019 of 410.5 parts per million (Plenio, 2020). In 2020, the global spread of COVID-19, caused mere reduction of carbon emission by 4-7 percent that same year (Plenio, 2020). The insignificant decreased carbon dioxide level during the pandemic leads to the expectation that the carbon emission to continue rising each year due to the high energy and resource consumption, despite mobility limitation (Plenio, 2020; Solomon et al., 2009). To meet the goals of the Paris Agreement 2015, in which people from all walks of life are responsible for preventing the rising global temperature.

Human activities have induced a considerable increase in atmospheric carbon dioxide concentration by 47% since the first industrial revolution (Oreskes, 2004). The economic growth aided by industrialization is accommodating the use of abundant resources and transforming them into services and products to augment life quality and living standard, driving to the rising carbon dioxide levels through the burning of fossil fuels such as coal and oil, which merges carbon with oxygen in the air to create carbon dioxide, consequently released into the atmosphere, resulting in incremental warming and leading to the greenhouse effect (Evliya, 2007). Further, extravagance and overconsumption of resources contribute to the greenhouse effect through combustion. The emitted particles symbolize the amount of energy and resources used in the manufacturing process. Natural resources, namely, water, fuel, metal, and timber, added in the production process results in the emission of carbon dioxide and other greenhouse gases (SPREP, 2012). Therefore, channelizing key players' focus on environmental destruction to emission reduction and waste prevention generates a new way of thinking in tackling global climate change.

The adoption of the linear economy as the current global economic model has reinforced the importance of take-make-dispose while neglecting the environmental aspects; namely, the practice of recycling, reusing and emphasizing waste management in which the goods are produced from raw materials, sold, used, and disposed of waste, being the final stage of its lifecycle (Ellen MacArthur Foundation, 2013). The domination of the linear economy in the global market has brought success in generating material wealth in industrial nations, boosting economic growth, and enhancing people's livelihood (Kok et al., 2013). According to Sustainable Europe Research Institute (SERI), around 21 billion tons of material used in the production process are not incorporated in the finished goods due to the manufacturing process's inefficiency, for instance, storage problems or uneven distribution of information. Regarding the statistics conducted by Eurostat, Europe has produced 2.5 billion tons of waste, of which the construction industry contributed 36.4%. In 2018, 38.7% of the waste was dumped in landfills, and merely 40% is being recycled, reusing or composting, which is losing its potential to its original function and source of energy. However, continuing this model will adversely impact the face of the earth as a place to live as well as a place to providing natural resources to sustain the life of society. Simultaneously, the world's population is expected to grow to 8.5 billion by 2030 and 9.7 billion by 2050 (United Nations, 2015).

The construction industry plays an essential role in building the welfare of the Dutch society, ranging from the buildings, houses, and infrastructures are incorporated of resources intensive activities that require finite resources, namely, stone, concrete, and steel. The built assets in the Netherlands are dependent upon 68% imported raw materials (Ministry of Economic Affairs, 2016). Moreover, the construction sector remains the largest contributor of 35% global carbon dioxide emissions, 40% total energy consumption, 30% water consumption, 50% resource consumption despite being the forefront of waste management in Europe (Transition Agenda, 2018). The continuous adoption of the linear economy will threaten not only the availability of the material resources, but also the environmental impacts. The take-make-dispose model fails to recognize the balance between environment and capital. Hence, resulting in a large amount of waste, some are recycled to generate lower quality recovered material, and others are dumped in landfills (Odijk & Bovene, 2014).

Gaining traction on Sustainable Development Goals raises awareness of the importance of safeguarding the environment and creates a realization that transition from conventional linear economy model to the circular economy model in the construction industry. Geissdoefer (2017) referred to "circular economy as a regenerative system in which resource input and waste, emission, and energy leakage are minimized by slowing, closing, and narrowing material and energy loops. This can be achieved through durable design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling". A circular economy creates a closed loop that enables waste prevention and resource efficiency while advocating manufacturers to produce high-quality products to extend their lifespan combatting product life cycle, and redesign products to facilitate repurposing and retrieval of material (Webster, 2017). Implementing a straight-line conventional economy in resource and energy-intensive sectors will deplete a large number of resources, pollute the environment, and use excessive amounts of fossil fuels, adversely affecting the sustainability of the earth. The circular economy within the construction industry encourages the main actors to shift the profit-centred approach of constructing infrastructure without exhausting natural resources excessively, contaminating the environment, and degrading ecosystems.

Becoming a global phenomenon, the urgency of climate change has attracted Non-Governmental Organizations' (NGOs) to persist their commitment to social movements intended to raise the awareness of environmental protection, specifically to big corporations, being the key players in climate change. Further, environmental activism can reshape stakeholders' corporation's attitudes, from the customers' engagement to environmental issues, media attention to capture environmental misconduct, and environmental regulators to pressure big firms to preserve the environment. In responding to society's demands, Corporate Social Responsibility (CSR) is becoming an instrument to signal environmental protection initiatives (Flammer, 2013). As CSR's expectation increases, transparency becomes paramount; therefore, firms are identifying the urgency to act on environmental safeguard, which drives the advent of green firms to take part in embracing sustainability.

The ambitious goal of The Netherlands to be circular constructed environment by 2050 is impelling the local construction industry to face a significant transition in encountering climate change that requires professionals to commence working under totally different methods (Transition Agenda, 2018). This means an active collaboration of players in construction sector is essential to build and design buildings as well as infrastructure that highlights the importance of waste minimization and carbon emission monitoring. The utilization of existing tools and methodology, such as material passport and LCA methodology, may assist construction firms on the journey of adopting circular economy.

Material passports are created with the aim to represent the material that are included in the constructed buildings. The used resources are recorded and transferred from supplier, contractor, owner, and the demolisher or dismantler of a building, enabling the key players to obtain sophisticated and holistic understandings of not only the physical components, but also social, environment, and economic value of a building (Van Sante, 2017). The complex nature and the large amount of data that need to be accommodated by material passport offer a promising opportunity for information management system by allowing the traceability of materials along with its characteristics. In order to develop well-integrated material passport, information sharing within supply chain has become an important instrument. However, confidentiality and accuracy of the exchanged information, reliability, incentive issues, costs of the information management system are becoming root of the problem in the effective implementation of material passport (Damen, 2012; Mukhtar et al., 2013).

Life Cycle Assessment (LCA) methodology provides comprehensive view of environmental and social impacts in relation with the products, services or activities throughout its life cycle, starting from the examination of its input conversion, design, raw material extraction, output production, product usage as well as disposal (Gonzales 2018; Linkov et al. 2017). Data is at the heart of LCA process, as data gathering activity is taking up to 70-80% of the allocated cost and time (Miah et al., 2018). Corroborating data is unable to compensate the lack of information, assumptions about the sources or to use averaged data are made to solve the crisis of data availability, creating skepticism towards the LCA results, and its data quality (Van Den Meer, 2018). Another issue lies upon the difficulty in verifying the social impact declaration that are derived from sustainability standards and certifications, requiring expensive, and laborious auditing process (Mieras et al., 2019). Therefore, data collection and gathering processes are often considered as costly, time-consuming, and challenging task (Fauzi et al., 2019).

A system that possesses the ability to propose systematic quality control, resulting in regularly updated data may be the potential solution for these issues, as it will increase transparency, traceability, and credibility of data which are becoming the fundamental of trust building among supply chain participants, and bolstering the decision making within construction companies. Taking advantage of technology advancement will help actors of circular economy connect the dots of demand, supply, manage, and store a large amount of data in a more efficient way (Pomponi & Moncaster, 2017). Without the need to rely upon an intermediary, the emerging blockchain technology shows the possibility of becoming a solution for construction firms to increase transparency, display information concerning carbon footprints and the source of materials (Dutch Blockchain Coalition, 2017). The research contributes to the field by outlining the advantages and disadvantages of blockchain implementation, and how these features could be added value to the implemented LCA and material passport in the construction industry in The Netherlands as a whole. Therefore, research findings will be useful for the construction companies in The Netherlands that intends to go circular by helping them signal their clients towards curbing carbon emissions and preventing material waste. Blockchain may serve as a tool of accountability and verifiability from the company to clients and society and meet the present's needs without compromising the life of future generations.

Research Objectives

The overall aim of this explorative research is to determine the feasibility of blockchain so that it can enhance the application of Life Cycle Assessment methodology and material passports as a way towards the circular construction industry in the Netherlands. To achieve this aim, three objectives have been identified:

1. Explain the advantages and disadvantages of blockchain technology implementation within the construction sector in the Netherlands.
2. Understand the prominent features of blockchain technology that could be value-added in improving the established Life Cycle Assessment methodology and material passports to address material waste decrement and carbon footprint monitoring.

Research Questions

Main research questions:

To what extent to which blockchain's feasibility is to enhance the application of LCA methodology and Material Passports towards the circular construction industry in the Netherlands?

In order to answer the main research questions, the following three sub-research questions have been identified:

1. What are the advantages and disadvantages of the implementation of blockchain technology in the construction industry in the Netherlands?
2. What are the salient features of blockchain technology that can enhance Life Cycle Assessment and Material passports to monitor carbon footprint and reduce material waste?

Literature Review Methodology

Identification of keywords

The following keywords and abbreviations are used in order to retrieve the supporting articles and journals for the research, namely, *circular economy, circular construction, blockchain, life cycle assessment, climate change, excess material waste, excess material exchange, material passport, circular built assets, carbon monitoring, waste reduction, climate change, distributed blockchain-based ledger, information exchange, waste management, global warming, the industrial revolution.*

Selection of search engines

The following search engines have been used in order to find the relevant journals and articles:

- Google Scholar
- Web of science
- Scopus
- Science direct
- ResearchGate
- Springer
- Semantic Scholar

Selection number of articles

The search engine's search attempt is resulting in the collection of hundreds of professional articles and journals. Therefore, prioritization is necessary to filter the relevant journals and professional articles by combining keywords that fit with the research topic and research questions.

Literature review methodology

The search for relevant journals and professional articles is composed of the following sources:

- Journals (retrieved from reputable sources) are the primary sources.
- Professional articles (retrieved from government bodies and construction consultants)
- Theses and dissertations.
- Websites.
- Conference Proceedings.

Article search method

The following journals provided most of the used relevant journals and professional articles:

- The Dutch ministry of infrastructure and the environment
- Built Environment Project and Asset Management Journal
- Renewable and Sustainable Energy Reviews
- Structural Engineering and Construction Management
- Earth and Environmental Science Conference
- Automation in Construction
- Sustainability Journals by Multidisciplinary Digital Publishing Institute
- Journal of Industrial Information and Integration
- CIB World Building Congress

Research Method for other media

Relevant journals that are published by reputable publishers are the primary sources of this research. Professional articles from government bodies and construction consultants are used as secondary sources. The articles provide current statistical figures regarding environmental and construction-related issues—further corroborating sources such as theses, dissertations, and scientific review, websites. Relevant journals are selected based on both publishers and their authors' reputability, taking into account the year of publication. Theses and dissertations are retrieved from the University Library and the Internet. The professional articles, scientific reviews, and websites are obtained from Internet; search engines.

Data Collection Method

Knowing that blockchain implementation as a means of improving the construction industry's circularity is a relatively new topic, it has not been studied much, and there are few examples in a practical world. The focus of this research is to obtain an understanding of the feasibility of the blockchain technology integration as an added value with Life Cycle Assessment Methodology and Material Passports, aim to monitoring the carbon footprint as well as reducing the material waste. Therefore, gaining a holistic understanding is crucial, which can be done through a qualitative approach.

Qualitative exploratory research is suitable for this study because of the absence of theory and clearly defined hypotheses by previous studies. There are little research and knowledge available regarding the relationship between each topic (blockchain, material passport, and LCA). Besides, to get the desired answer to the research questions, participants' experiences-based information is needed, specifically those who had experience with material passports, Life Cycle Assessment methodology. Hence, interviews are the most appropriate data collection method that will expose the author to the interviewees' knowledge, experiences, and opinions on the implementation of Life Cycle Assessment Methodology and material passport within the construction industry in the Netherlands.

Semi-structured interviews will be composed of the fixated main topics and questions. However, the author, being the interviewer, will rely on further questions when something may spark her interest during the interview. Furthermore, it will allow the author to explore some topics while abiding by the main topics and questions as guidelines. The population of the interview is an expert whose company has implemented Life Cycle Assessment methodology and material passport within his construction operation, as an attempt to gain an understanding of LCA and material passports implementation. The interview aims to understand the barriers that could hinder the implementation of material passports and life cycle assessment. The drivers and requirements that could boost material passports and life cycle assessment are also addressed during the interview. The results from the interview with the construction expert will be analysed. To get a comprehensive understanding of how blockchain technology can add value to the existing life cycle assessment methodology and material passports, a semi-structured interview will be conducted with Jo Bronckers, being the expert of blockchain technology within construction industry in the Netherlands. The semi-structured interview will help eliminate the barriers in implementing life cycle assessment and material passports that can be resolved by blockchain technology. The obtained data will allow the author to analyse the linkage between each instrument and determine the feasibility of blockchain technology in enhancing the application of two instruments (LCA and Material Passport) to promote circularity inbuilt asset construction.

CHAPTER II

Theoretical Framework

2.1.1. The Transition of Circular Economy in Construction Industry

The Dutch government has set the high ambitions to have established a circular economy in 2050, underlining the importance to execute the transition from a linear 'take-make-dispose' economy to circular economy (CE), by taking the built environment as one of the five priority sectors that contribute to economy of the Netherlands (Kabinet; Nelissen et al., 2018). Considered as the most material resources intensive, construction sector weighs substantial pressure on the natural environment. Construction industry plays a crucial role in transition towards a circular economy, due to its responsibility towards roughly 33% of greenhouse gas emissions, more than 40% of resources consumption, and around 40% of waste creation (Debacker et al., 2017; Ness & Xing, 2017; Pomponi & Moncaster, 2017).

Circular economy is becoming the solution to the problems caused by Linear "take-make-dispose" economy, namely, resource scarcity, social tension, market prices volatility, environmental degradation, and global warming. The Ellen MacArthur Foundation (EMF) defined circular economy as "one that is restorative and regenerative by design and aims to keep products, components, and materials at their highest utility and value at all times, distinguishing between technical and biological cycles. This new economic model seeks to ultimately decouple global economic development from finite resource consumption". Circular economy promotes growth in accordance with renewability, reuse, refurbishment, upgrade, repair, capacity sharing as well as decentralization. Consequently, firms with the profit-maximization mindset by concentrating on cost reduction as parameter of efficiency in supply chains, start to rethinking ways to produce products and render services to anticipate the future, and developing methods of minimizing the environmental impacts (Accenture, 2014).

Built environment sector possess the complexity as well as long lifetime of buildings that distinct this sector with others that are attempting to transitioning towards circular economy (Khasreen et al., 2009). Further, it is difficult to estimate the life-expectancy of buildings during its development, however, it may last longer than 50 years. Due to its longevity, buildings can experience numerous alterations and maintenance in terms of its physical appearance and function. Not to mention the environmental impacts of buildings that is dominated during its utilization stage, for example, energy consumption for operational purposes. Therefore, sustainable design and proper material selection are crucial in reducing the in-use environmental consequences. Construction industry is said to have many stakeholders, such as, the designer who is responsible to make decision about the final stage of building, is not responsible for the construction process as well as production of the building materials. Insufficient standardization within the building sector (Pomponi & Moncaster, 2017; Khasreen et al., 2009). Considering the long average life-expectancy of built assets, waste generation is expected to increase considerably within the upcoming decades. To respond to the waste generation crisis, the establishment of proper recycling method is necessary as a means of escalating the recycling rates. This initiative can be realized if the company has detailed information regarding the composition of construction waste. Hence, recyclability constantly changes according to time, it is on the hands of technological advancement and resource markets to support the transition from linear economy to circular economy (Kovacic et al., 2017).

An indefatigable attempt to advocate and project the continuous support in creating sustainable economy and growth by European Union is reflected on the establishment of Horizon 2020 as learning playground for research and innovations that aim to drive development in Europe (Debacker et al., 2017). Buildings as Material Banks (BAMB) is part of Horizon 2020 project which focuses on the accelerating the value of building materials, enabling building materials to sustain their value, the outcome of this is waste minimization as well as reducing the dependency towards virgin resources within construction sector (European Union, 2020). BAMB introduces two solutions in responding to environmental and buildings shortage problems, such as, Material Passports is digital sets of data providing the characteristics of materials, and components in buildings, and Reversible Building Design Protocols is instruments to notify the designers and stakeholders about the reversibility of building designs where it can easily be deconstructed without harming the robustness of the constructed buildings (Debacker et al., 2017). Therefore, BAMB is encouraging value and functionality conservation of building materials which enables the reuse, decreasing the need for primary resources (van Sante, 2017; Debacker & Manshoven, 2016).

Evidenced by the mission of government of the Netherlands in becoming fully circular in 2050, emphasizing the urgency of built environment to radically transform into circular (Kabinet; Nelissen et al., 2018). In addition, the Building Holland 2018 held a forum themed circular economy that facilitated the entire key players involved in construction sector to have intellectual discussion, while exchanging ideas and tackling the existing problems professionally. Despite the momentum, specific knowledge and tools are required to address the problems (K. Adams et al., 2017; Geldermans & Jacobson, 2015; Leising et al., 2018; Pomponi & Moncaster, 2017; Stahel, 2016).

2.1.2. Barriers in Implementing Circular Economy in Construction Industry

Adam et al., (2017b) argued that the fragmented nature of building sector, an unproven business case, and lack of interest as well as awareness are becoming the primary challenges of the transition towards circular economy. Moreover, other authors have marked the material and data quality on materials may hamper the implementation of circular economy within the industry (Geldermans, 2016; Adam et al., 2017b). Stahel (2016) stated that the concept of the circular economy as a holistic concept collides with the silo structures of our society, which recapitulates the built environment sector. Various scholars view the journey towards circular economy can be very complex, proven by the multifaceted, as well as multidisciplinary nature of built environment supply chain (Adams et al., 2017a; Geldermans, 2016; Leising et al., 2018; Luscuere, 2016; Ploege et al., 2017). Thus, the involvement of entire supply chain and social relationships, not to mention the integration between stakeholders within supply chain where trust is fostered and seamless communication is facilitated, is crucial key towards the success of circular economy transition (Debacker et al., 2017; Geldermans & Jacobson, 2015; Leising et al., 2018).

Financial	Measuring financial benefits of circular economy
	Financial profitability
Structural	Missing exchange of information
	Unclear responsibility distribution
Operational	Infrastructure/ Supply chain management
Attitudinal	Perception of sustainability
	Risk aversion
Technological	Product design
	Integration into production processes

Figure 1: Barriers in implementing circular economy in construction industry (Ritzén & Ölundh Sandström, 2017)

Ritzén & Ölundh Sandström (2017) found the connection between components of obstacles hampering the implementation of circular economy, which clearly depicts the complexity of circular economy and the requirements for its transition. Figure 2 projects the five different types of barriers, namely, financial, structural, operational, attitudinal, and technological. Further, the relevant barrier for this research is the missing exchange of information, under structural barrier. The inadequate information and a material exchange system is obstructing the exchange of material between different players within the built environment sector (Winans et al., 2017; Kok, et al., 2013).

2.2.1. Material Passports

Civil society has taken the lead of change towards sustainability for the past 50 years, by forcing governments and business to trumpet their environmental activism. However, decades of environmental action are inadequate to save the planet, evidenced by only 9.1% of world's economy is circular, leaving to massive circularity gap (de Wit et al., 2018). The alarming statistics justify the urgency to close the circularity gap, aims to prevent social imbalances as well as further environmental deterioration (de Wit, et al., 2018).

The construction industry can be double edged sword in societal and environmental perspectives, it provides infrastructures, and employment opportunities, improving welfare of Dutch society. However, buildings and infrastructures in the Netherlands are composed of finite resources, which relies on 68% of imported raw materials (Ministry of Economic Affairs, 2016). The controversy arises when built environment sector contributes to 35% global carbon dioxide emissions, 40% total energy consumption, 30% water consumption, and 50% resource consumption, leaving to 36.4% of 2.5 billion waste generated in Europe (Eurostat, 2018; Transition Agenda, 2018). Digital technology is revolutionising sustainability, it can be used to respond to the waste problems within construction industry, assisting the transition towards circular economy (Pagoropoulos et al., 2017). Further, data is becoming the primary concern in using digital technology, enables to close different loops identified in circular economy, yet information gap is barely in-depth explained by auteurs (Geldermans, 2016; Adams et al., 2017b).

Material passports can solve the problem for missing information barrier, by actively tracking the value of materials and aimed to bring residual value to the market. Reliable set of information is required to obtain understanding the circular value potential of materials, making actions performed in lifecycle of a building, such as use, maintenance, and demolish phases will affect the potential value of recovery, present use, and reuse (EPEA et al., 2016). Material passports will make information related to phases of lifecycle of a building to be more accessible (Luscuere, 2017). Material passports record the name, and the amounts of materials are used as components of a building, which information will be transferred to associated party, namely supplier, owner, and dismantler (van Sante, 2017). Bokeloh, Krayenhoff, Menkveld, Raes, Schotsman (2017) defined material passports as a digital dataset that identifies which materials are included in the used parts, where they are located, how to disassemble them, who the owner is, and what the quality is when they become available for reuse. Thus, value of these materials can be allocated for reuse, resale, and or / recycling.

2.2.2. Material Passports and the Transition towards Circular Economy

Linear model that is ingrained in our daily lives fail to meet a single target to stop destruction of nature. Circular economy can be used as an instrument of material scarcity prevention while reaching a low carbon and resource efficient economy, given that material management is said to be responsible to 67% of world's greenhouse gas emissions (de Wit et al., 2018). In addition, the information and material exchange tools that are operating within wider scale are needed in transition towards circular economy, which requires trusts of each party, rising costs of coordination, consequently decreasing the information quality (Damen, 2012).

To aid the success of circular economy transition, the importance of assembling high quality data on used materials, components, supply chain and properties is inevitable, creating the need of a systematic data quality control and registration, aimed to keep the data in timely manner. Material passports propose the ability to recover value from recovery and reuse of materials utilized in buildings for actors within supply chain. In addition, material passports induce the innovation towards product design, and material recovery systems, that enhancing the quality, value, and security of supply for materials, which can be reused for latter purposes, closing the loops, aligned with circular economy principle. Material passports support the circularity by creating a new value dimension based on the degree of recovery and reuse of materials as resources for other purposes, as benchmark in deciding the quality of materials (Hansen et al., 2012; EPEA et al., 2016). Therefore, material passports are a holding prime position towards the journey of a circular economy, in which information is widely distributed and accessible, resulting to waste reduction. The roles of material passports can be described as follows: (1) data gathering and material tracing; (2) enabling reverse logistics; (3) information sharing.

Damen (2012) analyzed that every party associated in the supply chain is required to provide information that is demanded for material passports, which should be constantly updated. The stored information should offer accessibility as well as confidentiality regarding the access to information. Material passports should provide uniformity, enabling the customization feature towards the stored information. Hence, material passports will make materials to be more traceable, and valuable due to the information it possesses, that can be interpreted to the residual value (Carra & Magdani, 2017; Debacker & Manshoven, 2016).

2.2.3. Barriers and Benefits of Material Passports

Debacker & Manshoven (2016) conducted a research concerning the key barriers of transition towards circular economy in built environment, the following barriers as follows: 1) fragmented policy framework: from the EU to municipalities, generating disintegration; 2) conflicting energy and environment policy measures; 3) lack of standardization of qualitative data over the entire value chain of the building; 4) linear construction industry models; 5) intellectual property of material and product related data; 6) higher complexity of disassembly compared to demolition; 7) general perception that reversible design solutions entail high financial costs; 8) lack of certification and quality assurance for reclaimed products and recycled materials; 9) lack of a business model framework related to circular and reversible building; 10) reversible building is largely unknown to the general public.

Another research disclosed that confidentiality and accuracy concerns, reliability, incentive issues, and capital-intensive investment are hampering the implementation of material passports within construction firms, hence, well-integrated technology that is advocating the traceability, and transparency of relevant data is required in supporting the transition towards sustainable development (Damen, 2012; Mukhtar et al., 2013).

Debacker & Manshoven (2016) found that material passports can mitigate the environmental damage within construction sector, which is bolstering the reusing of materials. Material passports allow the users to share relevant information in the value network, enabling the seamless demolition phase due to the provision of valuable information concerning with building components, which show potential to be reused or remanufactured. Material passports can be instrument for players within construction industry to collaborate as well as communicate with each other. In addition, availability on the information regarding materials, and status in digital passport of a built asset grants suppliers' access to the information whether they are planning to reuse or buy back their products. Material passports are driving innovations by opening the door for new business models.

The material passport gives materials an identity and value. Materials inside a building is not useful when there is insufficient data regarding the location of materials, in which material passports are able to provide accessibility as well as transparency throughout the lifecycle of buildings. During these phases, the utilized materials within buildings can change depending on which phases, such as designing, building, maintaining, and adapting. Hence, traceability is crucial factor, as it enables the user to obtain timely information regarding potential value of materials (Luscuere, 2017).

2.3.1. Life Cycle Assessment Methodology (LCA)

Being the globally emerging sector, construction industry is constantly changing due to the continuous growth of Dutch economy, not to mention the improving social and environmental measurements, putting the industry into the spotlight of sustainable development (du Plessis, 2001; Horn et al., 2018). Besides its aim to fulfil societal needs, and accommodate societal functions, construction sector inflicts negative consequences from environmental perspective, consumes a significant amount of energy, creates solid waste, emits global greenhouse gas emissions, and pollutions, causes environmental deterioration, as well as resource scarcity (CICA, 2002; Melchert, 2007; Zimmermann et al., 2005). According to statistics the construction phase is responsible for 30% of energy losses, 40% of solid wastes creation, 40-50% of global output of global greenhouse gas emissions, causing acid rain (Transition Agenda, 2018; California Integrated Waste Management Board, 2000). Hence, acting towards sustainable construction industry to decrease carbon footprint in the Netherlands is indispensable to meet the stringent emission control targets of the Netherlands adopting circular economy by 2050.

Carbon footprint is the conversion result of emitted greenhouse gasses into equivalent carbon dioxide, abbreviated as CO2e, and is measured in units of weight, while other auteurs argued that carbon footprint is the measurement of CO2 emissions based on the materials or energy consumed (Li & Zheng, 2020; Liu et al., 2011; Yu et al., 2011). Despite the definition that vary, carbon footprint is considered as an effective tool in tracing greenhouse gases emissions by identifying the consequential impacts of products and services on environment, enabling robust measures of environmental degradation mitigation (Lockrey et al., 2018; Lim et al., 2016; Huang et al., 2018; Li et al., 2018). In present time, there are a few carbon footprint analyses conducted by the experts due to the complication of contributed materials and tools during construction stage, in which most of the research on carbon footprint is concentrating on the entire life cycle of the built assets, as well as its construction phase (Lippke et al., 2011; Trappey et al., 2013; El Hanandeh et al., 2017). Leading to a generalized estimation of the results, which accuracy, and completeness, as well as the comprehensiveness of considered factors still need to be enhanced (Roh et al., 2016). The most used model to calculate carbon footprint of buildings are inventory statistics and information model, allowing firms to gather as well as collect activity level data concerning with the consumed energy and associated carbon emission coefficient during the entire phases of construction process (Wu et al., 2016; Li & Liu, 2015).

LCA is a methodology that enables company to examine environmental and social concerns in relation with manufacturing a product or rendering a service, thereby equips firms with holistic view of potential trade-off in environmental and social impacts with a specific activity (Gonzales 2018; Linkov et al., 2017). The methodology evaluates the entire lifecycle of a product, a process, or a system from cradle to grave by accounting the extraction and processing of raw materials through production, transportation as well as distribution; use, reuse, maintenance, recycling where necessary, and disposal (Gonzales, 2018). ISO14040 is an overarching standard covers four analytical phases of LCA methodology, namely, defining the goal and scope, creating the life-cycle inventory, assessing the impact, and finally interpreting the results (Ortiz et al., 2009). Fava, Consoli, Dension, Dickson, Mohin & Dickson (1993) found that ISO14040 referred to LCA methodology as "A technique for assessing the environmental aspects and potential impacts associated with a product, by compiling an inventory of relevant inputs and outputs of a product system; evaluating the potential environmental impacts; and interpreting the results of the inventory analysis and impact assessment phases. LCA is often employed as an analytical decision support tool." Therefore, LCA can be useful tool to detect inefficiencies, in which can boost productivity and minimize environmental burden (CSIRO, 2018).

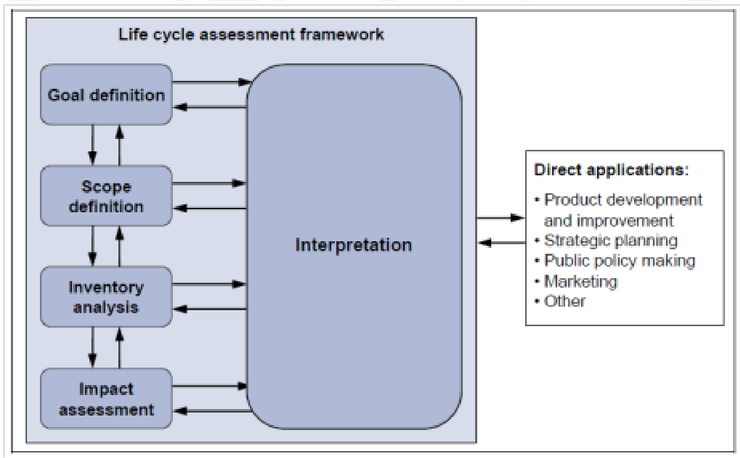

Figure 2: Framework for Life Cycle Assessment (European Commission, Joint Research Centre, Institute for Environment and Sustainability, 2010 modified from ISO 14040:2006)

Step 1: Goal and scope definition

The aim is to cultivate sustainability perspectives in the development of buildings as well as its processes, thereby a clear and detailed description of case study building is required. Ideally, the case study building should encompass the function and geographical characteristics of the building, including technical aspects. The system boundaries should be clearly determined whether the case study is covering the entire stages building life cycle, or one stage of building; the whole built asset, or one system; and impact categories should be defined (ISO, 2006). Further, LCA expert should take into account the functional unit, methodologies of impact assessment, data reqirements, assumptions, limitations, initial data quality requirements, type of critical review, and type of required report (ISO, 2006).

Step 2: Inventory Analysis (LCI)

This step comprises collecting, describing as well as verifying related data concerning with inputs, processes, emissions of the whole life cycle of a building. This step is considered as time and effort intensive process, buildings are considered as complex products, because of its long lifespan as well as complicated production process (Ortiz et al., 2009). Data collection process gathers data related to input-output of energy, and mass flow in respect of quantities and emissions to air, water, and land (Ortiz et al., 2009). The quality of inventory data that is determined by its accuracy and its compliance with the goal of the case study, has direct correlation with the quality-of-life cycle assessment (Ortiz et al., 2009). Another pivotal element that should be considered, such as data source, as it plays essential role to assure the reliability of the data, followed by acquisition methods, used verification procedures, not to mention data completeness, in relation with statistical figures, and representative sampling (Weidema, 1997).

Step 3: Impact Assessment

According to the international standard governing LCIA (Life Cycle Impact Assessment), ISO 14042 (2006) defined the objective of impact assessment is to examine the product system from an environmental point of view using impact categories and category indicators connected with the LCI results, LCIA also provides information for the life-cycle interpretation phase. The step begins with selecting and defining environmental impact categories associated to buildings, namely global warming, ocean acidification, and toxicity (Ortiz et al., 2009). The next step is accompanied by classifying LCI results into impact categories, for instance, assigning carbon dioxide emissions as the cause of global warming, and modelling the impacts within impact categories through conversion factors, for example, modelling the potential impact of carbon dioxide and methane on global warming using Global Warming Potential (GWP) (International Standard Organization, 2006). The results should be evaluated and reported (SAIC, 2006), in which the impact categories are grouped according to its region, whether the event has regional or global impact (International Standard Organization, 2006).

Step 4: Interpretation

According to ISO14040 (2006), the aim of interpretation step is to "analyze the results, reach conclusions, explain limitations and provide recommendations based on the findings of the preceding phases of the LCA or LCI study and to report the results of the life-cycle interpretation in a transparent manner. Life-cycle interpretation is also intended to provide a readily understandable, complete, and consistent presentation of the results of an LCA or an LCI study, in accordance with the goal and scope definition of the study".

Research has shown that employing LCA will escalate raw material utilization as well as opting for renewable energy, hence improving production and business process efficiency (Bourtsalas et al. 2018), enhance waste management (Gong et al., 2018), boosting products' innovation through eco-friendly designs, strengthening brand position, and reinforcing customer loyalty (Ahmad et al., 2017; Chang et al., 2014). Firms that engage with consistent sustainable practices project the ability to create higher shareholder value and improve financial performance (Sroufe & Gopalakrishna-Remani, 2018). Therefore, LCA permits firms to evaluate the environmental consequences of each raw material used within construction process, and decide the best option for construction, that benefits the cost as well as environment.

2.3.2. Life Cycle Methodology and the Transition towards Circular Economy

The building industry is facing major disruption and must rethink and reinvent its business strategies as well as construction practices to survive the new market mechanism based on circular economic model. The concept of circular economy that promotes extensive reuse, recycling, and recovery is gaining popularity in the Netherlands, and elsewhere, although linear economy dominates current global economy. Linear economy brings ecological and material disadvantages such as waste, pollution, and loss of material values, which have led to the conclusion that the world needs to implement circular economy.

LCA is seen as a tool to quantify the environmental impacts of the applied circular system, and circular economy is a philosophy governing society and the global economy, considered as the optimal model that can be applied in both micro level, and macro level by taking into consideration of finite resources, and environmental damages the world creates, it defines economy that is entirely circular (Haupt & Zschokke, 2017). LCA is a suitable tool provides comprehensive assessment towards environmental impacts of products, which in this case is buildings, as well as its end-of-life maintenances (Haupt & Zschokke, 2017). In relation with circular economy, LCA should be used to assess the environmental performance of circular buildings, as well as the transition towards a higher level of circular economy implementation. Further, both circular economy and LCA has common goal, that is to lessen the environmental burden (Haupt & Zschokke, 2017).

LCA enables innovative and creative firms to obtain comprehensive understanding of the building's life cycle, in which will stimulate firms to rethink as well as reinvent their used materials, designs and implemented business model. Those who lead the transition towards circular economy are gaining the sustainable competitive advantage (Lacy & Rutqvist, 2015). In the industry moving towards circular economy and sustainable development, it is vital for construction firms to use robust assessment tool in assisting them in decision making process covering relevant environmental impacts as well as life cycle of buildings, aimed to improve performance and identify solutions. Thus, in overcoming the rising concerns of resource depletion and addressing environmental considerations, LCA can be applied to assist decision making in boosting sustainability within the construction industry.

2.3.3. Barriers and Benefits of Life Cycle Assessment Methodology

LCA encounters additional barriers for the following reasons: 1. Site-specific impacts: several local impacts need to be taken into consideration within the assessments, namely, the effects of constructed buildings on the surroundings, the ability to receive sunlight without obstruction from another buildings, stormwater flows, as well as safety of the neighborhood (Kohler & Moffatt, 2003). 2. Model complexity: wide variety of materials and products composing in one building creates a challenging data collection process, moreover, each of these materials and products possesses a divergent life cycle while interacting as part of an assembly, causing another barrier if firms wish to model the systems (Kohler & Moffatt, 2003; Erlandsson & Borg, 2003). Construction processes have major impact on environment which need to be considered as additional element of assessment framework (Guggemos & Horvath, 2006). 3. Scenario uncertainty and lack of transparency: the long useful lifespan of buildings will result to substantial uncertainties of LCA findings, decreasing the reliability of its results, further, LCA practitioners make assumptions for buildings operations and maintenance during the use stage, and other assumptions are made in the end-of-life stage, such as renovation, and demolition (Kohler & Moffatt, 2003). In addition, the lack of standardization used as the benchmark as well as highly diverse information that is being used in verifying social impact declaration causing expensive and laborious auditing process, causing lack of reliability, and struggle to be widely used in the industry (Mieras et al., 2019). Being the inherent limitation of LCA, lack of transparency of the assumptions and quality of the assessed data is reducing the credibility of LCA results, especially data collection in social LCA (Gonzales, 2018; Norris, 2014). 4. Indoor environments: design choices and indoor environment within the use stage may potentially affect the psychological well-being, performance, as well as behavior of residents, this aspect needs to be included in LCA methodology as this aspect takes place during the longest stage and contribute to most total impact categories (Kohler & Moffatt, 2003).

The life cycle assessment (LCA) methodology regards the building processes and its environmental impacts from cradle-to-grave or cradle-to-cradle to identify as well as resolve problems that may arise (Yu et al., 2015). The methodology generates an estimation of carbon footprint of initial stage construction project, allowing firms to determine suitable design (Li & Zheng, 2020). LCA methodology assists firms to calculate the total carbon footprint of each phase of construction project by calculating the carbon emissions of materials and energy consumed (Li & Zheng, 2020). A research conducted by Teh, Khan, Corbitt, & Ong (2020) found that regardless the expensive cost and complicated process, (unmentioned company) still willingly to endure the process as part of innovative investment, as LCA assists the company to grasp comprehensive understanding of the carbon footprint and the flow of raw material and energy used in every stage of product's lifecycle, proving a longer-term view of improvements and changes that should be made. Although LCA methodology has been commonly practiced within building industry, there is a potential that should be integrated with circular economy concepts which will result to design for disassemble in LCA, potentially reduce the value of embodied carbon and energy in built environment (Eberhardt et al., 2019a, 2019b; Krause & Hafner, 2019). Further, LCA methodology will help to promote the advantages of reusing materials, and decreasing the usage of finite resources, consequently, reducing emissions, embodied carbon, and energy in construction project.

3.3.1 Prominent Features of Blockchain in Construction Industry

Blockchain has recently emerged as a disruptive technology that is advocating decentralization, transparency as well as accountability on the internet (Al Saqaf & Seidler, 2017). Blockchain comprises of salient features that offer improved uses and application within construction industry, have been further elaborated for the following: (1) **Decentralization,** blockchain is a decentralized system of peer-to-peer (P2P) network, causing the absence of central administrator or centralized data storage mechanism in the blockchain distributed ledger system (Walport, 2016). Accordingly, blockchain bolsters robustness while eliminating many-to-one traffic flows to prevent delays and single point of failure (Dorri et al., 2016). (2) **Anonymity**, blockchain protects users' privacy on transactions as people are given freedom to maintain their anonymity while employing third party to verify their identity (Sun et al., 2016). (3) **Security,** encryption mechanisms of blockchain involve public-key cryptography impede sensitive information from getting into the wrong hands, being misused, or forged, as well as maintain the validity of the information (Tapscott & Tapscott, 2017; Weernink et al., 2017). In addition, encryption enables to secure the privacy of private data, and digital signatures ascertain the authenticity, and integrity of the data (Lewis & Larson, 2016). (4) **Immutability**, the stored data on blockchain is protected by the peer-to-peer network of participants, leading to the inability to change or remove transactions (Dorri et al., 2016). Blockchain only permits its users to create and read the stored data, hence, creating ledger of permanent records of all transactions (Lewis et al., 2017; Atlam et al., 2018). (5) **Auditability,** the recorded and validated blockchain transactions contain timestamps information, allowing users to trace prior records by accessing any node within the distributed blockchain network (Zheng et al., 2016). (6) **Transparency**, blockchain offers variety of transparency level as it can be controlled accordingly, for instance, in public blockchain, all the transactions and activity records are transparent and made visible to market participants (Lo et al., 2017; Yli-Huumo et al., 2016). (7) **Disintermediation,** due to the absence of third-party involvement, blockchain creates a secure environment that is trusted by market participants without the need for a central authority, consequently, reducing operational costs as well as boosting the sharing service efficiency (Lewis & Larson, 2016; Sun et al., 2016). (8) **Trust,** the need to use intermediary can be avoided when the trust among its users has been built, blockchain requires the permission of its users to become a part of the definitive blockchain (Lewis & Larson, 2016; Yli-Ojanperä et al., 2018). (9) **Scalability,** blockchain possesses the capability to handle a growing number of workloads, and provide storage for its users (Bondi, 2000). However, blockchain is also facing scalability problems as well (Risius & Spohrer, 2017)

3.3.2 Advantages of Implementing Blockchain in Construction Industry

There are several factors that contribute to the adoption of blockchain in construction industry that have been identified for the following: (1) **Security**, blockchain provides integrity, non-repudiation and authentication through digital signatures, double-spending prevention, unaltered and indelible transactions (Mirzayi & Mehrzad, 2017). These features will be advantageous for construction industry, in which public-key cryptography based blockchain is suggested to be applied by the experts due to high number of approvals required, with numerous parties involved within a project (Perera et al., 2020). (2) **Anonymity**, blockchain facilitates personal information protection as personal details are neither stored not transmitted through the blockchain (Reid & Harrigan, 2013). Further, to conduct a transaction in blockchain, users can use their public key as account number without disclosing any personal data, and blockchain also generates private key that should be kept private (Reid & Harrigan 2013). Anonymity will be beneficial for construction industry, for instance, during the e-tendering process, allowing to bid anonymously (Perea et al., 2020). (3) **No single point of trust**, consensus mechanism enables authentication and validation of transactions on distributed ledger without the need to rely on central authority. Blockchain is viable option for building stakeholders as it is made trustworthy and secure by design, they are free to make secure payments and maintain good supply chains, minimizing risk in payment (Perera et al., 2020). (4) **Fraud prevention**, blockchain is made to be practically immutable, making it impossible for any party to manipulate, replace, or falsify data stored and recorded on the blockchain (Miryazi & Mehrzad, 2017). Construction sector may eliminate the transaction cost collected by banks and financial institution as the intermediaries by applying blockchain that offers fraud resistant instrument, enabling to make direct payment between relevant participants, resulting to decreasing risk of delays or any issues, because the absence of human intervention (Perera et al., 2020). (5) **Non-physicality**, blockchain does not require physical instruments to carry out transactions namely, bank bills and bank vaults to protect cash, and it exchanges digital currency or tokens considered as medium of exchange between parties. Thereby, lowering administrative expenses of printing bills and security (Miryazi & Mehrzad, 2017).

3.3.3 Disadvantages of Implementing Blockchain in Construction Industry

The potential of blockchain is great in solving real world problems, however, the technology is still at an early stage of development, it is important to note that blockchain also brings certain challenges and limitations in the context of blockchain adaptation, which have been identified: (1) **Awareness and understanding**, blockchain is popular but many people are not able to grasp the idea of blockchain and how it works due to lack of awareness as well as thorough understanding of the subject, resulting to the unwillingness to adopt blockchain (Mthethwa, 2016). (2) **Data privacy**, public blockchain has been criticized due to its lack of data privacy and confidentiality, as there is no restriction in participating (Lu & Xu, 2017). Additionally, anyone has the access to all information in blockchain and take part in consensus process (Lu & Xu, 2017). Private blockchain is created to address the privacy concerns in public blockchain (Lo et al., 2017). However, blockchain allows to store data out of the blockchain in protecting confidential information, limiting the data accessibility (Lo et al., 2017). Off-chain feature of blockchain is advantageous for construction sector, it is enabling sensitive information to be stored off-chain, preventing data privacy issues (Perera et al., 2020). (3) **Regulations and governance**, though blockchain is an emerging technology that needs to be regulated, many issues in regulations and governance in an attempt to adapt and embrace the new technology (Mthethwa, 2016). (4) **Data storage**, it is not the best idea to store big data on blockchain because of the large volumes as well as low velocity of data will delay the mining process (Lo et al., 2017). This limitation is an issue for construction industry as each project consists of large amount of data, thus, allowing limited amount of data that needs to be processed on blockchain (Perera et al., 2020). (5) **Scalability**, public blockchain is currently limited to process 3-20 transactions every second, VISA on the other hand, can currently handle approximately 1,700 transactions every second (Buterin, 2017; Mulli; 2018). This shows that blockchain has scalability problem and is not suitable for construction industry, yet consensus protocols such as PoS, DPoS, and PBFT can be a solution to this problem (Perera et al., 2020). (6) **Computing power**, blockchain has been known as energy-intensive technology, evidenced by the energy consumption of each bitcoin transaction is roughly 80,000 times more than credit card transaction (Puthal et al., 2018; Gatteschi et al., 2018). Proof of Work (PoW) mining requires massive computer power that could lead to energy waste to solve the mathematical problem (Lu & Xu, 2017). Hence, other consensus protocols have been introduced to overcome this problem, namely PoS, DPoS that is less energy intensive (Mthethwa, 2016).

3.3.4 Blockchain and Circular Economy

Blockchain is being one of the emerging digital technologies has been harnessed to stimulate the seamless transition towards circular economy, though its development is immature (Pagoropoulos et al., 2017). Shojaei, Wang & Fenner (2019) defined blockchain is a chain of blocks of information that registers transactions, while a peer-to-peer (P2P) network of nodes is used to verify each transaction. Once a transaction is verified by the network, it is added to the blockchain and cannot be altered or tampered with. A transaction is requested; a block is created and represents the transaction; the block is broadcast to the P2P network; the network validates the transaction; the verified block is added to the blockchain; and the transaction is complete. Blockchain aids the transformation towards circularity in some ways, namely, (1) The accessibility of relevant data related to materials and new approach of dealing with data are pivotal stimulant to close the loops. (2) A secure and integrated environment enabling the collaboration between parties involved. (3) Trust and transparency established by blockchain are inducing trustworthy data exchange between participants. (4) Being an advanced technology, blockchain has potential in tackling data issues (Bolier, 2019). Additionally, transparency as well as traceability of buildings and its components may contribute to the journey towards circular economy, resulting to whole life cycle cost, carbon emission estimates, and raw material verification (Shojaei et al., 2019). Therefore, blockchain technology may be a valuable tool in assisting construction industry towards the journey of circular economy due to its advantages such as reliability and accuracy assurance, not to mention its capability to grant access to detailed information regarding the source of products, embedded carbon, and energy footprint. Such technology makes the recorded transaction is verified, reliable and organized, eases its users to use the data for specific phase of building life cycle.

3.3.5 Blockchain and Material Passports

The world's population has quadrupled over the last 100 years, such large population will boost the demand for housing and infrastructure, however, there is currently lacking information about the provenance of building composition, as well as how and when the materials are manufactured, and used throughout their lifecycle (Abeyratne & Monfared, 2016). Research conducted by Abeyratne & Monfared (2016) found the potential of blockchain technology that uses distributed ledger to collect, store, and manage information regarding the materials throughout their lifecycle. The distributed network of information gives promises to provide a secure, shared transaction history, for each material combined with relevant information of each material. The network is decentralized, which allows firms to appraise the origin of building without governing authority and ownership over the entire supply chain (Kim & Laskowski, 2016). Additionally, integrating blockchain with another emerging technology such as internet of things (IoT) may be a response to the inadequate digital footprint of material, enabling firms to capture real time data about material and their environmental attribute, location as well as timestamps of material's journey across supply chain and lifecycle of a building, blockchain technology facilitates a secure platform and grants immutable access to supply chain data (Kim & Laskowski, 2016).

This emerging technology creates opportunities to give value-added to material passports. Being the industry with stringent measures, construction industry entails an evidence on track record of material production, transportation, handling as well as storage (Mondragon et al., 2018). Further, blockchain can store information on product manufacturing certifications, product quality, and resource provenance, while the feature of decentralization negates the potential of single-point failure, projects the resilience, ascertains the completeness of the information (Mondragon et al., 2018). Research have found that blockchain may help to enhance procurement purposes due to its capability to create accessibility of records to parties involved, assisting audits on quality issues (Wang et al., 2017). In construction industry, the entire lifecycle of buildings can be digitalized and stored on blockchain (Swan, 2015). The salient features of blockchain may be beneficial in addressing the transparency and traceability issues in material passports, such as immutable transactions, user centric access control, decentralized data storage. Distributed data storage is giving its users the advantage of resilience towards attacks, manipulation, and counterfeiting, consequently enhancing transparency (Veuger, 2017; Shedroff, 2018). A distributed, consensus-based, permanent, and unalterable ledger assists construction firm to trace the sources and transformations of material throughout the lifecycle of a built asset. In addition, blockchain technology may generate a registry assist firms to identify as well as trace the material ownership across the supply chain, not to mention its ability to determine the validity and reliability of information sources within data systems through a distributed secure record of transactions (Morabito, 2017). This will help companies to assure data integrity, thereby providing a platform where data is reliable, accessible, compliant for interested party (IBM, 2017; Veuger, 2017).

Blockchain is identified as one of the tools that can help construction industry to eliminate lack of trust and insufficient information sharing technologies (Lau & Rowlinson, 2010). Blockchain, its working system negates the need for confrontational contractual relationships due to high level of transparency, security, and trust to relevant parties where decentralized storing and sharing information, that is peer-to-peer architecture (Veuger, 2017; Shojaei, 2019). Blockchain offers another opportunity for material passports, where the chain is demanded to be completed and verified that the database is accurate and avoiding unauthorized transactions from being completed (Shojaei, 2019). In addition, blockchain may enhance the maintenance requirements of a building, by analysing the life cycle performance of materials, resulting to the enhanced reusing as well as recyclability (Shojaei, 2019). Blockchain shows a great potential in improving sustainability in construction sector, it is proven that the technology possesses the ability to mitigate material waste, non-sustainable materials usage for instance, due to the demonstrated data traceability, immutability as well as transparency (Johansson & Nilsson, 2018). Blockchain technology can be used as a means of information verification in regards of materials, the energy source of manufacturer as well as energy used are recorded on the system, further, raw material transaction discloses information related to its origin, the amount is being transferred, forcing parties involved to be more cautious as every action is impacting the environment (Shojaei et al., 2019).

3.3.6 Blockchain and Life Cycle Assessment Methodology

The construction sector is known for stubborn resistance to a radical change as a result from the short-term relationship among stakeholders, poor information and data dissemination, apathy of learning, making the industry is among the least digitalized (Hultgren & Pajala, 2018; Barbosa et al., 2017). The lack of coherence and poor communication has decreased its productivity, impacted the sustainability of buildings, at the same time, the constructed buildings have profound effects on environment (Kibert, 2016). Multiple models have been developed to reduce environmental effects of construction; however, the issues arise due to the lack of transparency of sustainable measurements of a building and its components, uncertainties in the data bases, insubstantial information of individual product, and unclear information regarding the supply chain route (Shojaei et al., 2019; Kosanović et al., 2018). Further, the absence of transparent and modernized tool to display detailed information regarding total embodied carbon and energy footprint of a building and its materials, as well as the limited scope of modelling barely cover one product (Shojaei et al., 2019). The lack of information hampers circular construction practices, such as conscious design and the purchase of raw materials where both designers and contractors need to consider its impact on building sustainability (Shojaei et al., 2019).

Various sustainability assessment methods have been proposed to collect and report information systematically and comprehensively, promised to aid decision making processes. LCA is becoming the commonly used method for evaluating the impacts of buildings and its materials on environment (Soust-Verdaguer et al., 2017). However, LCA has limitations that may lead to the skepticism about the results, such as lacks the comprehensiveness and the reliability, not to mention the large amount of information associated with built environment and its materials causing LCA to be a complex task, discourage construction firms to employ the methodology (Shojaei et al., 2019; Gantner et al., 2015). Hence, the construction sector is struggling to adapt and make substantial action towards the environmental dimension and sustainable development given the rising need for resources efficiency, along with the increasing building projects complexity, and increasing demand for quality and cost efficiency. Digital and disruptive technology such as blockchain may be able to solve above mentioned issues, evidenced by its ability to enhance sustainability and other industries, and potentially improving construction industry (Kouhizadeh and Sarkis, 2018). Data transparency, reliability and validity will create significant influence in decreasing information uncertainty concerning with the impact of decision making, at the same time, enhancing eco-design, eliminating trust issues within the sector due to the verification process (Shojaei et al., 2019). Thus, an integration with a decentralized comprehensive system creates transparent environment, may increase the inclusivity as well as reliability of LCA. Additionally, allowing the methodology to include the impact of energy sources utilized in material manufacturing within the assessment, as well as carbon footprint of a material, and finally, a building can be calculated (Shojaei et al., 2019).

Blockchain technology facilitates digital validation, coordination, and process simplifications, enabling firms to lean towards transparent and sustainable product-oriented activities; this emerging technology can be used to tackle the limitations of LCA, by enabling companies to distribute a permanent, indelible, and unalterable information in a timely-manner to satisfy the needs for information and assist the decision-making process of a fast-paced business environment, enabling companies to gather stakeholders in interconnected activities across value chain, increasing the data integrity, traceability, transparency as well as trust that has been the major concerns within the industry (Favi et al. 2018; Gonzales 2018; Mieras et al. 2019). The challenges of complexity and expensive cost of inventory analysis can be addressed by blockchain, as an instrument to create decentralized networks where a free and transparent database that needs minimal administrative structures is achievable, resulting to cost and time efficiency, making much planning for data collection is not a necessity (Herrara, 2017). In addition, research has shown the capability of blockchain to improve the traceability of material provenance as well as its movement across the whole life cycle of a building; allowing to tag materials with relevant environmental information, namely, carbon accounting information and results of standardization, Environmental Product Declaration (EPD) (Sinistore, 2018). An integration of blockchain and LCA may enhance transparency and verifiability of stages in value chain; it can serve as accountability function from construction firms to society, that they are positively contributing to curbing carbon emissions.

CHAPTER III

Analysis

Clients become more conscious of environmental issues; circularity could be the pathway towards a more sustainable future. Given that construction industry is among the most polluting sector, major players within the sector need to rethink the way they do business; however, an industry-wide circular business model is viewed as lofty ambition as is a long way from grasping the full potentials of circular economy as well as realizing it. Prompt action of the transition towards circular economy is regarded as an imperative and an inevitability. Construction sector is entering digitalization where digital push is accelerating, advanced technology such as blockchain has been promoted to be the solution to every problem. Despite the prominence, blockchain is still an immature technology and is not the simplest way to solve problem in first sight. Blockchain technology is becoming an expensive solution where there is insufficient collaboration between involved parties and information available in the network, on the contrary, information is extremely valued within larger network where multiple stakeholders are aware of the need to collaborate and exchange information, causing blockchain to be an ideal solution. Blockchain is a complex answer, however the road to embracing the technology within construction sector may be difficult but not impossible. In the present day, the appetite of blockchain implementation and the added value of the technology will grow simultaneously because of the increasing number of adapters attempting to reap its benefits.

Construction industry and large investment are inextricably linked that requires trustful stakeholder relationship. Further, construction firms commonly employ third parties to conduct valuation, legal advising, notary service, assessment, and certification reports in order to build trust in the information that has been changed. Blockchain may be a valuable help to accelerate trust to digital information across the associated party when the information is structured in such a way that allowing multi-stakeholders to trust and utilize the information. It can be difficult to assess the value of implemented blockchain, as the adding value is invisible for construction companies. The value is added when firms are able to have a process that they can rely better on information while negating the necessity to hire intermediaries due to the salient features of blockchain technology such as immutability, transparency as well as traceability. Transparency is stated by different authors may be able to backfires as excessive transparency can lead to lack of privacy within construction industry. Nevertheless, transparency can be an instrument for construction firms to demonstrate their professionalism as well as accountability toward the involved party, reinforce data collaboration, prevent silos while reducing costs. Blockchain facilitates firms to safeguard confidential information, and to control the transparency in addressing to given privacy concern, through access control mechanism, off-chain feature as well as private blockchain. These features enable companies to grant access to users with digital identities in specific level of information detail, depending on the role, purposes, and information types. Hence, transparency should be considered as an advantage to project the constructed buildings to associated party in a responsible manner.

Circular economy shifts the thinking of construction actors to design for disassembly and view building as a storage of materials in which buildings are purposely designed for material recovery, and value retention, making the buildings are at ease to be repaired, extending useful life, ascertaining materials to be recycled as well as reused. Timeliness and accuracy of the data are becoming crucial factors as a means to support circular economy transition, requires a system that can be dynamic during building lifecycle. The proposed system may vary from Building Information Modelling (BIM), 3D scans, and blockchain technology, in which depending on the scale of the project and other prerequisites. Thus, there is no one-size-fits-all approach, the ideal solution is structuring the data in material passports which will assist firms to practice a circular construction. Blockchain technology can only be a help when the involved party needs to rely on the trustful information, in which blockchain facilitates companies to trace and track details as well as specifications of materials. Blockchain technology alone does not solve the problem, however the solution lies on structuring the data.

Material passport is a tool to execute the ambition of circular construction practice, as it gives material an identity that helps construction industry to reimagine buildings as material banks enabling to retain the value of materials after the building becomes obsolete. Material passport benefits construction firms in supply chain, maintenance, renovation as well as demolition processes by actively tracking the value recovery potential allowing firms to understand the circular value of materials. The absence of material passport will hinder firms to optimize material value, leading to expensive as well as rise of carbon dioxide emission process. Material passport is considered as value-adding exercise by providing the ability to identify the components of buildings and its quality will create more value in the end of the process which not only increases the over-all building value, but also improves maintenance process. However, material passport requires large amount of information to be stored within every passport from which can be difficult to trace the update at every location, not to mention the frequent unavailability of requested data within material passport. Material passport requires a system that is able to demonstrate security, transparency, verifiability, immutability, and traceability as essential elements for determining the information quality. In addition, the system must also be dynamic over the course of the building's lifespan in which blockchain technology can add value to that.

Blockchain helps to create material passport including different sections of a building that stores information in centralized databases, such as woods in installations, and floors and roof in facades. The integration of blockchain technology with material passport is about information enrichment, it requires the chain to be completed and validated, ensuring the accuracy of database while mitigating unauthorized transactions. Blockchain could improve the building's maintenance requirements, by assessing the life cycle performance of materials, resulting in higher frequency of reuse and recycle. Due to the prominent features of blockchain namely traceability, immutability, and transparency, the technology has immense potential to help construction industry in practicing circular construction by minimizing material waste, as well as the use of harmful materials. Blockchain can add-value to verify information associated with materials, energy source as well as consumption, which denotes raw material transaction in regards of its origin and the transported quantities, compelling concerned party to be more vigilant as any decision may be consequential to the environment.

LCA methodology strengthens proposition of circular economy by providing comprehensive understanding about the environmental footprint of built environment across its lifecycle. Circular economy model encourages to firms to execute design for disassembly in LCA, lowering the value of embodied carbon and energy in buildings. The methodology produces a carbon footprint forecast for an early-stage construction project, enabling companies to decide the appropriate design that aligns with sustainability. Further, it aids companies in calculating the carbon footprint of each stage of a construction project through computation of emitted carbon dioxide of materials and energy used, consequently construction companies will gain a thorough understanding of the carbon footprint and movement of raw materials and used resources in building lifecycle. LCA methodology implementation in construction industry contributes to stimulating materials reuse and to encouraging renewable resources usage, thereby decreasing emissions, embodied carbon, and energy usage in construction projects. LCA practice suffers from skepticism of LCA results, some limitations such as lacking comprehensiveness, reliability, as well as vast amount of information that needs to be stored and processed causing LCA methodology to be a challenging and expensive approach. Construction firms can make use of advanced technology such as blockchain to address the above-mentioned concerns. Blockchain helps construction actors create a single point of truth in the network, enabling users to validate whether they have the accurate information. It is impossible to alter or modify data once it has been verified and approved by the participating nodes. This, combined with the fact that every network participant has a copy of the ledger, indicates that the system is reinforcing social control. The technology is bolstering the input of good information. Blockchain can add-value in terms of managing and recording changes throughout building lifecycle. Therefore, an effective application of LCA methodology integrated with blockchain technology can also serve as a role of accountability to society, projecting sense of responsibility towards surrounding community members and environment by contributing to reduce carbon emissions.

CHAPTER IV

Conclusion

From greenhouse gases emission to construction materials pollution, construction sector in the Netherlands is dramatically affecting the environment in negative ways; if it continues unabated, it will add more weight to the damage experienced by future generation to live in the unhabitable earth. Experts have been attempting to identify effective strategies for mitigating the potential catastrophic impacts through the emergence of circular economy as a replacement of take-make-dispose industrial model with the help of advanced technology, such as blockchain. This research contributes to the exploration of new way of thinking approach to hamper environmental degradation by determining the feasibility of blockchain to enhance the application of life cycle assessment methodology and material passport aiding the construction sector in the Netherlands towards circular economy.

Supported by the semi-structured interview and the literature review research found the advantages of blockchain technology application within the construction sector in the Netherlands as follows: Security, public-key cryptography based blockchain allows construction industry to deal with large number of approval requirements across associated parties, especially within megaprojects. Anonymity, e-tendering process that facilitates efficient sourcing suppliers can be enhanced by blockchain through the bidding anonymously. No single point of trust, establishing trustful partnership among construction stakeholders as well as maintaining good supply chain across the industry by offering secure payment. Fraud resistant, fraud resistant instrument aids direct payment method among construction players, reducing delays due to lack of human intervention., not to mention its ability to minimize transaction and administrative costs. Non-physicality, enabling construction actors to conduct transactions to safeguard cash and to exchange digital currency.

Despite benefits that blockchain offers in advancing construction industry in the Netherlands, there are limitations that should be considered by construction players in the Netherlands before normalizing the technology, namely: Awareness and understanding, lack of awareness as well as understanding of the technology creates perception among construction players that the cost of technology will not be able to exceed the benefits, hence discouraging the application. Data privacy, the transparency of blockchain has been criticized threatens data privacy of construction companies in the Netherlands, however this should not be taken into consideration, as transparency projects the professionalism of the industry. Further, it can be easily tackled by off-chain features, private blockchain as well as access control mechanism. Regulations and governance, the absence of laws regulating the technology. Data storage, large volume of construction data may result into delay in mining process, lowering the efficiency of the technology. Scalability, blockchain limits to process small amount of transaction every second, which is not suitable for construction industry that requires rapid data processing. Computing power, construction industry consists of numerous as well as continuous megaprojects that require rapid data processing, however, blockchain tends to be energy intensive, contributing to excessive power consumption that is bad for environment.

Blockchain technology is cultivating a collaborative environment where construction actors are actively cooperating to assert waste minimization and carbon emission monitoring to actualize the idea of circular economy within construction sector through the established tool such as material passport as well as life cycle assessment methodology. Evidenced in literature and semi-structure interview, the prominent features of blockchain that can add-value to material passports are immutable transaction, user centric access control, and distributed data storage that exhibits the immunity towards attacks and improves transparency within construction industry in the Netherlands. A decentralized, immutable system such as blockchain, supported by the consensus mechanism aids construction companies to trace the origin as well as transformation of material throughout the building lifecycle. Blockchain may help construction companies in the Netherlands to identify and trace material ownership within supply chain, as well as to assess the validity and reliability the origin of information. These benefits of data integrity offered by blockchain is supporting the journey towards greener future, embracing the implementation of circular economy that promotes elimination of waste and continual recycling and material recovery by analysing the life cycle performance of each building component. The ambition on the wide-spread application of sustainable construction practices is becoming achievable, for instance waste minimization, continual usage of safe materials and meticulous decision making through data traceability, verifiability, immutability, and transparency.

A distributed ledger such as blockchain demonstrates the capability to create a transparent platform aimed at construction industry in the Netherlands, enhancing the inclusivity and reliability which is simultaneously decreasing the suspicion on LCA results. Being the salient features of blockchain, disintermediation may add value to established LCA methodology by flattening the administrative structures leading to cost-effective and time-efficient process, resulting to straightforward data collection planning. Transparency on the other hand, may add value to the increasing inclusivity of LCA results that covers the environmental consequences as well as advancing the calculation of consumed energy, and carbon footprint of each building component, and the whole building. Thereby, blockchain can be a help to LCA methodology in improving transparency, and verifiability within construction processes while taking imperative measure for combatting climate change by reducing emissions.

Blockchain is a valuable and disruptive technology that has big potential in accelerating circular construction practices in the Netherlands through the provision of salient features that can add value to the established material passport and LCA methodology. Blockchain is still considered as immature technology that has a long way to go before it is widely applied within construction industry in the Netherlands. The industry requires early adopters that are willing to experiment and take huge risk, later the technology will spread exponentially to early majority that are wary yet still enthusiastic to implement the technology, as well as late majority, knowing as the risk-averse and skeptical companies. One of the remaining challenges of blockchain implementation despite of the gained traction is finding enough early adopters.

CHAPTER V

Policy

Continued unabated pollution and greenhouse gas emissions will further increase changing climate patterns have become international business concern due to its significance in impacting value creation, financial performance, strategic positioning, market competitiveness, and long-term growth (Husted et al., 2015; Nakao et al. 2007; Epstein 2008; Porter & Kramer 2006). Economic growth of organizations is not only assessed by financial value, but also value creation for stakeholders; accordingly, organizations are encouraged to incorporate stakeholders' expectations and sustainability into their business strategies to remain relevant in constantly evolving business environment (Elkington 1997; Laszlo, 2008). Chasing sustainability creates pathways towards the sea of opportunities for construction firms to remain competitive within the industry while provokes firms to adopt innovative approach that enables to project economic success without neglecting duty to operate in a way that protects the environment. However, to make a construction industry sustainable remains a challenge when the world operated according to linear economy.

Despite its success in bolstering economic growth and material wealth, as well as sustaining the life of world's population, the adoption of linear economy in construction sector fails to identify the urgency of recycling, reusing and effective waste management; consequently, resulting to resource scarcity while threatening the environment through excess waste and greenhouse gas emissions (Ellen MacArthur Foundation, 2013; Kok et al., 2013; Odijk & Bovene, 2014). Construction sector is regarded among most polluting sector to the environment, evidenced by releasing 35 percent of world's carbon dioxide emissions, consuming 40 percent of energy and 50 percent of resources; accounting to 36.4 percent of overall waste in Europe from which fraction of waste is being dumped in landfills (Transition Agenda, 2018). Construction sector is expected to balance quality of life of society with environment conservation, yet construction practices utterly downgrade environmental protection through profit maximization and cost minimization. Circular economy adaptation along with advanced technology integration, blockchain for instance, can be the answer to the dilemma of upsetting environmental balance within construction sector in the Netherlands by encouraging waste reduction and resource efficiency (Webster, 2017).

It is important for every actor in construction sector to take steps towards mitigating environmental burden, and to achieve sustainable development. The practice of sustainable construction can be done by using fewer finite materials, more sustainable materials, supported by the shift to renewable energies consumption, with the objective of reducing environmental damage (Sansom et al., 2013). Circular construction provides not only environmental benefits, but also create better shareholder value as well as enhance financial position (Sroufe & Gopalakrishna-Remani, 2018). In moving towards achieving circular economy and sustainable development, construction firms in the Netherlands need to utilize comprehensive and robust tools to manage performance and identify solutions corresponding to the relevant information of materials, life cycle of buildings as well as its environmental impacts from which blockchain can help the existing implementation of material passport and LCA methodology aiding the decision-making process (Teh et al., 2020; Hauschild et al., 2018; Hansen et al., 2012). Blockchain can enhance the implementation of material passports enabling construction firms to examine as well as evaluate the life cycle performance of materials consisting in buildings which expands the opportunities to reuse and recycle building materials, once the buildings are demolished, or disassembled (Shojaei, 2019). In addition, salient features of blockchain such as decentralization, immutability, as well as transparency along with implemented material passport can prevent material waste, and non-sustainable material usage (Johansson & Nilsson, 2018). Blockchain can help LCA methodology in ensuring transparency of the relevant building information that improves the inclusivity and reliability of LCA results through the comprehensive information regarding the impact of energy used, material carbon footprint, as well as whole-building (Shojaei et al., 2019).

The adoption of material passport, LCA methodology and blockchain technology within construction industry in the Netherlands is still in its infancy. This research contributes to construction field by outlining the advantages and disadvantages of blockchain implementation, and which major features of blockchain technology could add value to the existing material passport and LCA within construction industry in The Netherlands. Therefore, the result of this research will be useful to construction firms in The Netherlands that are interested to take part into the journey towards circular economy by assisting them to contribute to a sustainable future through monitoring carbon footprint and reducing material waste while keeping up with the incredibly popular technology, blockchain. The results highlighted aspects of current implementation of blockchain technology, material passport as well as LCA that could be improved, and a recommendation for business implementation as follows:

- Exploration, to achieve widespread adoption of blockchain technology in mainstream market, construction sector in the Netherlands requires firms being early adopters that are willing to take risks and bold actions in exploring and adopting the technology while aligning the capabilities of blockchain with strategic opportunities to outperform competitors and to assist the journey towards a greener future. Further, construction firms need to conduct extensive research regarding the application of blockchain technology in order to have a comprehensive understanding of the technology, avoiding technology traps that give more harm than good.
- Collaboration, Construction actors are currently experimenting with the application of blockchain technology, material passport, and LCA methodology. Construction sector deals with large volumes of heterogeneous data which is expected to increase exponentially as technology adaptation as well as large supply chain. Further, the large amount of data that needs to be processed has always seen as a barrier in technology

adaptation, as a result it is likely that parties within the sector will be secrecy towards their own data, building a wall of separation between important actor that restricts them to interact with one another. Such a situation opposes the concept of blockchain technology, material passport, and LCA methodology. To provide trustful environment within construction sector and to achieve success implementation of blockchain technology, all stakeholders need to cooperate on a wider scale.

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