Research report from the project Circular Living Lab

Author: Lina Lefstad
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Introduction

This research was conducted as a study for the KIEM-VANG CE.02.032 project Circular Living Lab, funded by regieorgaan SIA. : Circular Living Lab, to enable new circular concepts to be tested by companies and residents in a real living environment in the context of sustainable renovation.

This research is in line with the needs of companies (construction companies, engineering companies, contractors, developers of new materials, etc.) who are involved in sustainable renovations in order to be able to test (and adapt) their products and services with residents before they are put on the market. This leads ultimately to a stronger position for the entrepreneurs.

In this research, knowledge is developed and made accessible about the circular renovation of dwellings. Chapter one, Circular Building, adresses the influence of residents on the success of circular renovations. In chapter two, Residents and Circularity, focusses on how a Living Lab can be used to build up more knowledge from a real practical situation. In chapter three, Circular Living Lab, addresses how a house developed by the “Selficient Team, students of Hogeschool Utrecht together with companies, will be used as a Circular Living Lab house for this purpose. This house was built at the Utrecht Science Park in 2018.

The outcomes of this research are applied in developing the Circular Living Lab as part of the Wonen 3.0 program, a long-term collaboration between HU and companies. In this way the knowledge base on sustainable living is expanded and made available for interested parties. The project offers room for the involvement of professors and students through projects on sub-themes and provides insights for the continuation of Living Labs as a method in education. It also contributes to innovation in education.

Circular Building

The first chapter gives the reader a brief introduction to the Circular Economy and how it is applied in the Province of Utrecht. Also the basic strategies for evaluating and measuring circularity and how this can be applied to buildings are introduced. The last part of this chapter focusses on a practical inventory of SME questions that can be included in the research design for the living lab.

The Circular Economy

The Circular Economy is an economic model where the focus lies on minimizing waste, by maximizing product´s valuable life-time and finding new use for the materials at the end of the products´ life. This is done to minimize environmental pollution, ecological footprints, resource depletion and greenhouse gas emissions. The Dutch government has chosen the construction industry as one of five industries which they intend to be circular by 2050 (Rijksoverheid Nederland, 2018). In international as well as national politics, the urgency of closing the loops on materials and processes is becoming increasinly present, with important global actors such as the OECD and the World Economic Forum pressing it forward (D. Reike, 2018). The Province of Utrecht is also building a circular portfolio. Last month the five leading principles of the "New Style of Utrecht" were published, which aims to make Utrecht a "circular city" based on Circular Economic principles. These guiding principles are:

1) Utilize the whole value of materials again and again,
2) Economic activities should have a positive impact on people and the environment,
3) Energy comes from renewable sources,
4) The scale of cycles is as small as it can be and as big as it needs to be, and
5) Products and other designs are flexible, modular and adjustable.

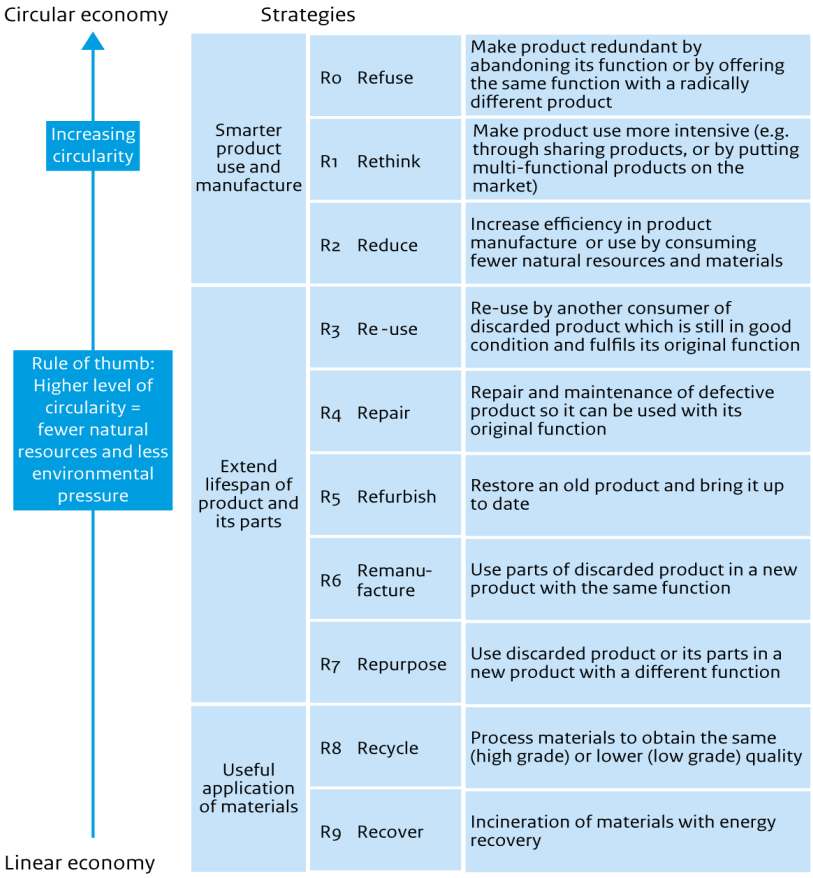
(Province Utrecht, 2019)

Throughout this report, these five founding principles of circularity in Utrecht will be applied to the prospected Circular Living Lab. Before getting started, it is helpful to first gain a clear idea of what a circular building actually is. The Circle Economy, Metabolic, The Dutch Green building council and SGS collectively agreed on the following definition for circular buildings:

> *A circular building is a building that is developed, used and reused without unnecessary resource depletion, environmental pollution and ecosystem degradation. It is constructed in an economically responsible way and contributes to the wellbeing of people and other inhabitants of this earth. Here and there, now and later. Technical elements are demountable and reusable, and biological elements can also be brought back into the biological cycle.*

(Circle Economy, 2018, page 18-19)

Based on this definition, circularity indicators and measurements can be agreed upon. These measurements should be used by designers and engineers in the design-, building- and renovation- phase of buildings, as well as during the user phase, in order to make educated selections of products and materials and to understand the impact of the choices made. In order to be able to close the loop and for materials to retain value, this must be designed for. Likewise, to keep material and product cycles small, the design should be flexible and adjustable. To ensure that economic activitie (such as building a house) has positive impact on the environment, planning between different stakeholders is needed. The circular economy is founded on collaboration: figuring out how to ensure that what you need now will be useful to others later. This will contribute to the overall level of circularity as products and materials remain in circulation for longer, preferably indefinite, periods of time.

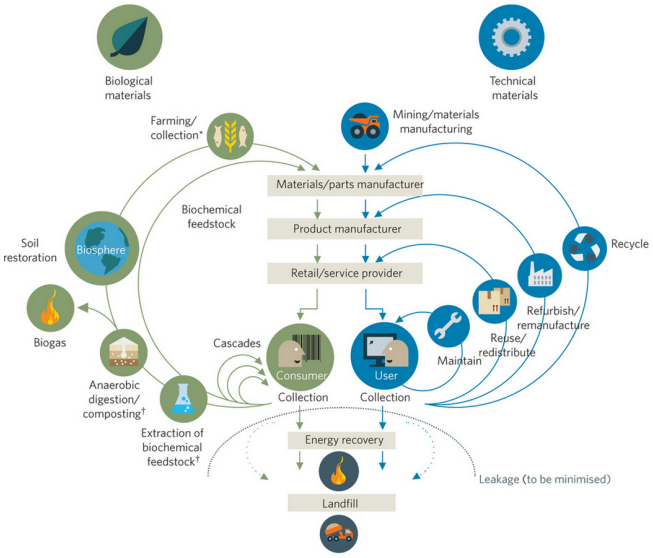


Strategies			
Smarter product use and manufacture	R0	Refuse	Make product redundant by abandoning its function or by offering the same function with a radically different product
	R1	Rethink	Make product use more intensive (e.g. through sharing products, or by putting multi-functional products on the market)
	R2	Reduce	Increase efficiency in product manufacture or use by consuming fewer natural resources and materials
Extend lifespan of product and its parts	R3	Re-use	Re-use by another consumer of discarded product which is still in good condition and fulfils its original function
	R4	Repair	Repair and maintenance of defective product so it can be used with its original function
	R5	Refurbish	Restore an old product and bring it up to date
	R6	Remanu-facture	Use parts of discarded product in a new product with the same function
	R7	Repurpose	Use discarded product or its parts in a new product with a different function
Useful application of materials	R8	Recycle	Process materials to obtain the same (high grade) or lower (low grade) quality
	R9	Recover	Incineration of materials with energy recovery

The Circular Economy´s strategy for retaining material value is based on the circular ladder of the 10 R´s. One example out of the 10 is recycling, which is the strategy most commonly used today, but recycling is the second last step on the ladder and one that belongs to the Linear economy. When a material is recycled, it becomes downgraded and loses value, which is why the goal of the circular economy is not to just close loops by recycling more.

(J.Potting, et.al, 2016, p. 7)

These R´s are represented in the famous Butterfly model of the Ellen MacArthur Foundation, which can be seen on the right. There are two main cycles in this model, the technical and the biological. Especially the technical cycles benefit from the 10 R-approach in order to extend the useful lifespan of products and materials. The Butterfly model is a good visual starting-point when moving on to the topic of measuring circularity in buildings, which includes both technical and biological materials.
(Ellen MacArthur Foundation, n.d.)



Measuring Circularity

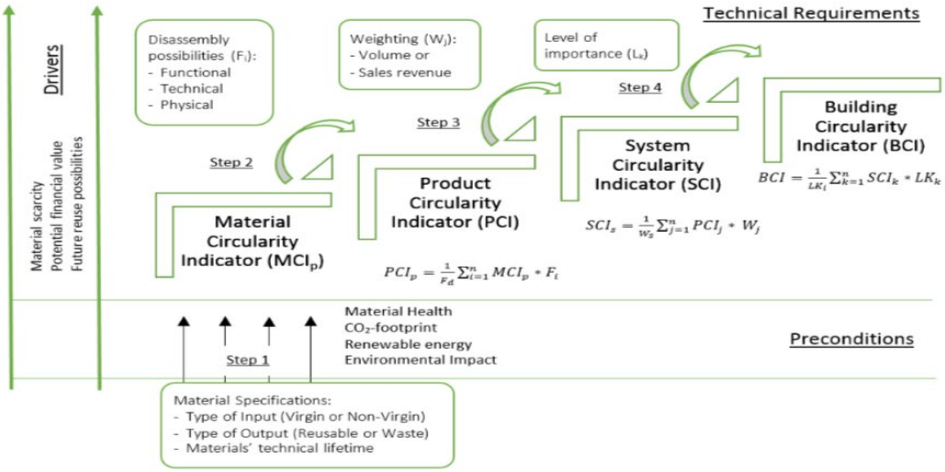
The Material Circularity Indicator (MCI) as developed by the Ellen MacArthur Foundation is the most commonly used cross-sectoral measurement tool for circularity to date. The MCI measures the extent of which linear flow has been minimized and restorative flow maximized for the component materials of a product (Ellen MacArthur Foundation, 2015).

The Circle Economy, Metabolic, The Dutch Green Building Council and SGS applied these MCIs to circular buildings. Five main circular strategies and indicators can be applied to reach circularity in buildings according to this framework (B. Kubbinga, 2018):

1. Design for circularity by reducing the amount of materials
2. Design for reassembly in order to increase the utility and the after-life value, and to be able to use the materials/products more intensely
3. Maximize the amount of reused materials used
4. Minimize the amount of non-renewable materials used
5. Develop and share the knowledge gained in the process to benefit others

The building circularity indicator assessment is made up of four components which are visualized in the table below. To start with, the Material Circularity Indicators (MCI) must be assessed. Next is the Product Circularity Indicator, which is made up of materials. The third step is the System Circularity Indicator, each system being made up of different products. Lastly is the Building Circularity Indicator, which is made up of all the different systems. This hierarchical way of measuring circularity in buildings is commonly used due to the complex structure of- and many components which make up a building. The table includes the mentioning of drivers, which are material scarcity, financial value, future reuse possibilities, the technical requirements, the preconditions, these being material health/toxicity, CO2 footprint, renewable energy and environmental impact. Lastly the material specifications are shown, which are the type of input, the output and technical

lifetime. The next section will mention some risks related to circularity measurements and the choices to be made in the process of reaching circularity.



Conceptual structure for the circularity assessment model of materials within the technical cycle.
(J. Verberne, 2016, p. 57)

Risks associated with Circularity Measurements

When applying the MCIs several risks can be associated with each choice made during the process. Ellen MacArthur identified complementary risk and impact indicators, which have been applied to buildings in the following paragraphs. First of all, complementary risk indicators give an indication of the urgency for implementing circular practices and for deciding on which aspects to improve on first. For example, the material price variation risk, the material supply chain risk, the material scarcity level and the material toxicity level area may all be complementary risks (Ellen MacArthur Foundation, 2015). Data from the McKinsey Global Institute, the EU Ad-Hoc Working Group on Defining Critical Raw Materials and the EU REACH Regulation can be used to make these assessments.

Secondly, complementary impact indicators give an indication to some of the benefits of circular models, as well as measures the energy and water usage of a certain product. Two examples that are relevant to buildings are energy- and water usage. Established standards for assessing energy and CO_2 emissions already exist, and a building should minimize energy consumption and minimize the environmental impact of the energy source (Ellen MacArthur Foundation, 2015). Well-known assessment methodologies include Life Cycle Assessment (LCA); assessing the energy consumption and environmental impact at each product-life-stage, for example using the ISO standard, and the Environmental Product Declaration (EPD), a standardized way of quantifying environmental impact of a product or system, based on the LCA calculations.

Lastly, moving on to water, the buildings water impact can be assessed at two stages, the building stage and the usage stage. For the building, the ISO standard for reporting water footprints can be used to calculate the water intensity of materials. The water impact depends on the geographic location of where the materials are extracted from, for example a desert area has more water stress and hence a higher water impact compared to another location. The renovations undertaken should aim to minimize water consumption and evaluate the use of a

grey water system, rainwater collection system, and resource recovery through water cascading. Water intensity during the usage of the building can be calculated using the LCA format and compared with numbers on average water usage for typical homes of a certain size.

These risks are important to evaluate when making decisions for building a new building - but have already taken in an existing building. But just because a building already exists does not automatically mean that it cannot become (more) circular, sustainable, and contribute less negative impact to its environment. In order to be able to measure circularity in a building, key performance indicators for the Circular Living Lab are proposed based on the aforementioned literature.

Key Performance Indicators

For buildings, two main indicators have the most influence on its level of circularity. The technical perspective includes the building itself, the design of it and the use of materials, and the second is the functional perspective, which is more concerned on people´s perception of mainly the location, facilities, accessibility and adaptability, and comfort. When making choices, the boundaries to consider are material toxicity, material scarcity, energy use, and the environmental impact (Ellen MacArthur Foundation, n.d.). These elements have been put together to form Key Performance Indicators for measuring circularity for the materials in buildings. In addition to the aspects mentioned above, social impact and disassembly possibilities have been included. It is important to note, that for renovation-phases of buildings both Design-phase KPIs as well as the User Phase KPIs should be used to streamline the renovation-phase as much as possible, with the goal of making it entirely circular.

Design Phase KPIs				
Material	**New or pre-used?**	**Amount of material**	**Circular-ladder R**	**Impact Assessments**
X	New	0.00kg	Chose the R which retains most value and creates lowest impact	Toxicity: EU REACH Regulation as guide
				Scarcity: EU Ad Hock on Defining Raw Materials
				CO2 Emissions released in the extraction process
				Environmental impact of the extraction process (LCA assessment can be used)
				Social impact: Working hours & conditions to extract the material
				Ease of disassembly
Y	Used	0.00kg	Chose the R which retains most value and creates lowest impact	Toxicity: EU REACH Regulation as guide
				Scarcity: EU Ad Hock on Defining Raw Materials
				CO2 Emissions released in the remaking process
				Environmental impact of remaking process (LCA)
				Social impact: Working hours & conditions to retain the material´s value
				Ease of disassembly
Total amount of materials used		Assembly		Total amount of materials re-used
		Renovation		Renovation

Total amount of waste created	Disassembly		Total amount of water used	Disassembly	
	Assembly			Assembly	
	Renovation			Renovation	
	Disassembly			Disassembly	
User Phase KPIs					
- Energy Usage					
- Water Usage					
- Waste creation					
- Comfort					
- Affordability					
- Quality					
- Adaptability					

The Design-phase has been distinguished from the User phase of the buildings KPIs, which can be related to the distinction between the technical and functional life mentioned above. During the design-phase, the material´s new or used status, the amounts of it and the chosen R will determine the impact felt on the five assessments; toxicity, scarcity, CO_2 emissions, and environmental and social impact. The distinction between new or used materials is important as the building should only calculate the impact it is making and not that of the material´s life prior to the building. The choice of R will be depending on the materials´ technical function and will contribute towards the impact assessments. The KPIs can be applied to technical requirements, such as technical lifetime, disassembly possibilities and cycles (Verbene, 2016). The coherence of circularity measurement tools is discussed in the next section.

Coherence of Circularity Measurements

The measurements and frameworks previously evaluated are all based on the Ellen MacArthur Foundation´s Material Circularity Indicators, which creates a general level of cohesion and agreement to the components of the measurement frameworks. The Paris´ Climate Agreement set the foundations for the general cohesion with the common goal of limiting global warming to 2 degrees Celsius. Combined with the United Nation´s Sustainable Development Goals this has created a general level of mutual understanding when it comes to production, the choice of materials, and that efforts should be made to produce products that last, especially in the built environment.

What is generally receiving less attention however, is the social impact of the circular economy. Only one framework for circular buildings, the BAMB framework, includes the social value centrally in its measurements. For the BAMB renovation-framework user information is also included, with specific information on for example health and mobility, in order to customize the renovation to fit both circularity as well as the individual user´s need (Hobbs, 2018). Another example of social impact is potential trade-offs between material circularity and social conditions. This could for example be a hypothetical highly-circular and non-toxic material, which is extracted from a war zone where corrupt officials regulate the trade. Such an example would only be applied to a new material, but trade-offs may be found also when using second-hand materials. For example, what if a material is only usable for its next desired function after going through an intensive remanufacturing stage, which has negative impact on the working conditions of the individuals working there? The trade-offs on materials are also relevant, as one should be critical to choose a material which requires energy-intensive refurbishing stages. The principles of Utrecht Province are important to keep in mind as a guidance when taking such decisions, as yes, it is desired to utilize the whole

value of materials over and over, but at the same time such activities should have a positive impact on people and the environment. Hence, negative impact in any sense must be minimized as much as possible. One method could be by designing flexible and adjustable products and another making the scale of material cycles as small as possible.

These trade-offs furthermore indicate that reaching circularity for an individual building will be based on the local environment in which the building is placed. Which materials are available locally to build from? What does the local natural environment consist of? Which renewable energy is available locally, and can it facilitate energy-intensive processes? The Netherlands has a lot of peat environment, and here it would be best to use material biomass that is able to grow in wet conditions for the peat area to be able to restore itself and not to dry out, which will impact which materials are most suited for a circular house or to do a renovation in the most circular way (Oostra M. , 2015).

Assessing trade-offs, decisions and total impact as well as the total circularity indicator, does require a large amount of data. Therefore consensus is growing for implementing "material passports" for buildings, to make the assessments more accurate as well as easier to conduct. This topic will be investigated in the next section.

Material Passports to aid Circularity in Buildings

In order to be able to measure a building´s level of circularity, one must know what kind of materials, products and systems the building is made up from. This can only be done if there is an up-to-date, complete, and accurate overview of the contents to the building available.

In another KIEM-Vang project "Old School, New School", on circular renovation of schools, the first step in the renovation-process was making an inventory of the materials in the old schools, based on a visit to the location and expert ratings. The experts focused on which materials would be released and what their qualities were, in order to gain insight into what kind of materials could possibly be used again in a new building. The analysis was based on the following aspects:

- Location, inside or outside the building?
- Specifications of the object
- Material type
- Quantity or number of objects that are released
- Category of reusability: Category 1) reusable in current state or function,
  Category 2) reusable as element in current state but not in current function,
  Category 3) Not reusable as element in current state and function but can be used for recycling.
- General technical and aesthetic quality, where a distinction is made between bad, moderate and good.

(E.J. Velzing, 2019)

By implementing a material passport in the building, the next use-phase of the different materials can be streamlined, and waste is easier to avoid as one has the exact overview of amounts, types and elements of various objects. The Circular Living Lab can utilize the platform that resulted from input from the previously mentioned project made by BOOT

Engineers, called “Insert”. Insert is an online marketplace for reusing building-, civil-, and green materials. This platform can be used for both finding the needed “new” materials, as well as for finding new use for discarded materials in the renovation process based on the knowledge they own in the material passport of the building (Insert, n.d.).

Some companies and actors in the industry are concerned about the privacy associated with sharing the material passport with others. Sharing information is arguably the most effective way to be able to have an overview of total materials available and their technical function when collaboration on extending material-life is needed. According to the Blockchain Lab at Hogeschool Utrecht, Blockchain technology has the potential to overcome this obstacle, by for example only publishing basic information publicly in the blockchain and creating secure data storage for the more sensitive information in underlying layers for which one would need granted access to reach. In the next section a short inventory of SMEs practical questions relating to the Circular Living Lab and circularity in the building industry are laid out.

Inventorising SMEs questions

On the 21st of February, companies and industry partners, including Gemeente Utrecht, were invited to a brainstorming session about circularity and renovations. During this valuable afternoon it became clear that industry partners have a lot of questions when it comes to these topics.

The idea of having a knowledge alliance on circularity in the building and renovation sector appears promising. Where knowledge and experiences can be shared, but also importantly, collaboration can be facilitated. This knowledge alliance will have the most value if it takes a cross-sector approach, by not only involving building and engineering companies but also local (and regional, national) government, as well as members from other sectors, such as for example financial institutions, juridical experts, and residents themselves. Innovations are happening everywhere, but the belief that they are more likely to have a bigger impact if they result from an integrated and collaborative approach was expressed. Hogeschool Utrecht has a good starting-point to facilitate cross-sector integration, due to the many studies offered at the institutions and hence experts available on various topics, as well as the industry network of the Center of Expertise Smart Sustainable Cities.

Companies and partners at the event were a group with varying involvement and knowledge about the circular economy and circularity in the building sector. One central question was, how do you measure circularity in a building? Further questions included how supply and demand can be streamlined in the industry - how do SMEs know what residents want? On the financial affordability aspect are companies interested in gaining knowledge and understanding of home-owners, as well as hopefully to get expert advice on own operations related to business models and activities related to the circular economy. Finding integrated solutions to this challenge through the network behind the Circular Living Lab can aid the government in furthering the circular and sustainable agenda, based on social and industry input. For companies and home-owners to be granted the opportunity of having an arena where also these types of questions can be researched will add value to the applicability and impact of this Living Lab.

Practically speaking, how can this be tested in the Circular Living Lab? Which products, systems and services can be tested and addressed here? SMEs are interested in environments where a lot of user-data can be obtained on the implications of the technologies and the systems that are used. Integrating user friendliness and “mass customization”-principles is wanted. The Living Lab can offer a closed and conditioned environment where experiments and tests can be executed, in a real-life and real-time setting, by industry players. The network supporting this lab can, and should, include the social impact areas, as this is especially one aspect which is missing in literature on the Circular Economy. The concept of a material passport is further welcomed, and here Hogeschool Utrecht can take advantage of programs inside its institution, such as the Blockchain Lab, to find solutions to the previously mentioned privacy concern as well as developing the concept further.

The experimentation and renovation processes in the Circular Living Lab can first of all be divided on a topic-level, where the following four topics can be taken as the foundation and further investigated in collaboration with the network:

1. Installations
   For example, the ventilation system, air conditioning system, bathroom installations, et. Cetera.
2. Constructions
   For example the facade, the floors, testing different types of paint and its functions, new ways to insulate the house in an easier and less wasteful way, etc.
3. Materials
   Testing new materials and their impacts on the functioning of systems and other installations.
4. Societal impact
   E.g. measuring the impact on the resident(s) resulted from the renovation, their experience with the process, wishes and needs for future renovations and how this can be implemented in a financially- and environmentally viable way.

This marks the end of the first chapter of this research. The next chapter moves on from the discussion about the circular economy and circularity in buildings and renovations, to include residents and their perceptions of sustainability/circularity in renovation of their homes.

Residents and circularity

- *The impact of the resident on the success of circular renovations*

The following chapter makes an inventory of the current state of affairs on the motivation and behavior of residents in investment decisions in the context of (circular/sustainability-related) renovations of their homes. Critical success factors will be touched upon, and the most important factors for residents will be laid out. The findings will be applied to the Circular Living Lab, by evaluating residents´ impacts on the Lab, ethical considerations, and the added value of real residents in a Living Lab context.

Renovations

To reach circularity in a building, or even just to make a home more sustainable, normally a comprehensive retrofit of the residency is required. Residents have a big impact on the outcome of the renovation, as well as whether or not there will be a renovation at all. After all, each individual home will have individual residents with their own needs and motivations. With regard to the various motivations, it can be established that the financial benefit of a renovation plays a major role (Energielinq, 2013). In renovations, the three topics of cosmetic preservation, to improve the life course of the dwelling, and to improve the energy-efficiency/lower the CO_2 footprint of the dwelling are in focus, with the end aim being to achieve optimum safety, comfort, and health in homes (Bouwend Nederland & UNETO-VNI, 2016).

Renovating buildings becomes more and more important to improve the overall level of the housing stock, and in this context valuable research has been done by the "Vereniging de Stroomversnelling" on renovating buildings to become net zero energy buildings. The researchers have shared success-factors when it comes to renovation, where the most relevant are (Vereniging de Stroomversnelling, 2018):

1. Begin with a good analysis together with the building company, building corporation, and resident. There are many technical differences between buildings which should be included in the analysis and evaluated in a business case. Working together with the resident is one of the most important critical success factors.
2. The renovation should be financially interesting. For example, by adhering to the guidelines from Energieprestatievergoeding (EPV).
3. Create a project team with a representative from each of the participating parties, who receive support from their organizations. It is advised to arrange a common kick-off event, have short decision-making processes, share expectations and work together to solve dilemmas.
4. Evaluate the best way to proceed with the plan. It can be good to start with a test-building which can later be scaled up.
5. Dare to renew! A strictly planned project can be too rigid, allow for space to renew the process not only on technical aspects but also in the process and in the collaboration.
6. Share the knowledge.

Residents´ spontaneous association of the word "sustainability" is something that is good for the environment, and something that lasts longer/is of higher quality (Bouwend Nederland & UNETO-VNI, 2016). The term "sustainability" can be linked to the term of "circularity", as the focus of circularity is to make products and materials last as long as possible, to make

healthy and energy-efficient living-quarters, and to minimize the impact on the environment. Sustainability is a focus of the UN´s Sustainable Development Goals. Especially the Sustainable Development goals of Affordable and Clean Energy, Industry Innovation and Infrastructure, Sustainable Cities and Communities, and Responsible Consumption and Production are relevant to the sustainability of circular buildings (Heikamp, 2019), and can be associated with circularity in general. The KPIs proposed in the previous chapter can be argued to create a more sustainable, and circular, as well as comfortable building. The two terms of "circularity" and "sustainability" have some overlapping characteristics and can apply to the same group of residents when it comes to the topic of renovating homes (Oostra M. , 2015).

Residents and their perception of renovations

Residents can typically be divided into two groups, where one is tenants living in rented homes and the other being home-owners. Tenants living in rented houses may find sustainability a difficult concept and are not likely to spontaneously invest in making their rented home more sustainable. The main reason for this is that the investment will be lost when they stop renting that particular house. About three quarters of the tenants in a study believe that it is the landlord who is responsible for making the rental home more sustainable. Only when the sustainability leads to clear improvements in living comfort, where the costs and possibilities are clearly communicated, and if the tenant will be financially compensated if they leave the home (early), will they be more prone to performing these renovations themselves on a rented dwelling (Bouwend Nederland & UNETO-VNI, 2016).

When it comes to home-owners who do not plan on making their homes/houses more sustainable (this includes both landlords and private persons living in their own home), the two most frequent reasons are both financial in nature. Either, it takes too long before the investment in the renovation is recovered, and/or they currently do not have the financial resources. The big question here is to find out how the house owners who do not want to make their house more sustainable can be persuaded to change their mind? More than half of the sample could become more sustainable if the investment can be recovered within a year, for example via the energy bill, or if the comfort of the owner-occupied home is tangibly improved (Bouwend Nederland, 2016).

On the other hand, two of the five homeowners who had made their home more sustainable did this primarily to save or to achieve a higher return. More than a quarter renovated to become more energy efficient, and the same amount of home-owners did so to increase comfort-level or decrease the noise pollution. One in six renovated for sustainability because it is good for the environment, yet almost nobody renovated mainly because of the potential appreciation of their house or for the subsidy they may receive (Bouwend Nederland, 2016).

In research done by EnergieLinq information has been gathered on residents´ satisfaction-level on renovations. A lot of impact can be imposed in the social, economic and technical aspects on a building during and after renovations, and hereby the most important factors to keep residents´ satisfaction-levels high:

- Residents do not want to pay more than their neighbor – the financial aspects are important, and so is immediate remuneration. Subsidies are effective.
- Residents want to have a feeling of control over the installation, and freedom of choice reduced resistance to the renovation.
- Building-companies need to base their approach on facts and communicate clearly to the residents. Ensure high quality, as "losing is worse than not winning".
- Public interest (for example, "doing your part for minimizing climate change") is motivation only for very few.
- Take the interest of the residents as the starting-point and involve them early.
- Distinguish different target groups and offer tailor-made solutions.
- Distrust is the biggest obstacle.

In this research it also became clear that tenants and residents did not accept the renovations mainly because of a new lease or rental price after the renovation, the amount of the relocation allowance, or if the renovation would be expected to take too long and thereby create a bigger financial and logistical burden on their lives (Niels Sijpheer, 2015).

In the beginning phases of the renovation-process, residents want to be given choices, according to a research by Breukers. There is no such thing as "standard-people" and "standard-wishes", and simple things such as what kind of shower/bath-tub and the color of the tiles will have a lot of impact on the perceived living comfort of each individual resident. It is furthermore important to keep each individual´s situation in mind in the process, as especially mobility factors have a big impact on the living comfort. Something as simple as making sure that the residents can reach the different systems and buttons that are mounted on walls is essential (Sylvia Breukers, 2014).

To summarize, residents are generally open to renovations that improve sustainability and circularity of their homes, under certain conditions. In short, these four factors are most important to them when considering renovation of their home:

1) The price/cost aspects, both the financial burden of the renovation itself and the benefits and gains that are realized as a result of the renovation.
2) Residents want to be a part of the decision-making in the process and clear communication strategies should be created which link the players in the renovation-process with the resident(s), especially in rented homes. The residents want to renovate their home the way they like. Trust is the key in the process!
3) Safety, comfort and health are the key-words representing the motivation to renovate homes, both during and after the renovation.
4) How long the renovation takes. If the renovation takes longer than one week, it will have a large impact on residents living comfort at the time, which may force them to move out for the duration of the renovation. This again will increase costs and effort to accomplish the renovation and may then become an obstacle or a reason for not renovating.

Impacts of the findings on the Circular Living Lab

For the Circular Living Lab, resident´s wishes will have less impact on the lab than they do on their own homes, for the simple reason that all residents will be temporary test-residents. The learnings from home-owners and "real" Dutch residents in the normal housing stock, however, still remain highly relevant to the lab. First of all, participating partners should keep the main motivations of safety, comfort and health in mind when planning renovations. In this regard, the circularity indicators and the KPIs can serve as helpful tools when communicating between partners and residents on the goals of the next renovation.
The companies that have been talked to during the conduction of this research did express that they would like to gain more insight into for example which kinds of choices people want to make when renovating their homes, versus which choices they are generally happy to leave up to the experts to take care of. They feel like they are making "top-down" decisions on what residents want, and therefore are not sure whether they are doing a satisfactory job. To bridge this gap, residents in the Living Lab and participating members in the knowledge network should be invited to participate in knowledge-sharing and feedback on decisions. The research and experiments may benefit from leaving space to facilitate for residents´ motivations and needs, as would be necessary in the practice. Mass customization based on Lean principles have been previously used with success and can create a more flexible structure.
Measurements can be done on how the renovations impact the life in the living lab and the lives of the respective residents at the time. Potential changes in the residents´ behavior can be measured before and after the renovation(s) have taken place, as well as the perceived impact of these renovations, by for example conducting interviews and evaluating the outcomes with the network.

Ethical considerations of real residents

The ethical considerations of using real residents as test objects are undeniably important. First of all, it is important to make clear that test-residents will be temporarily living in the lab. Next, the test-residents should be given proper instruction on what is expected from them, how the systems in the house are operated, and information about how their data will be used. The new EU-law on Data Protection must be adhered to, and no data should be shared with third parties unless test-residents have agreed for this to be done. Furthermore, a contract must be signed, which includes a mutually agreed (temporary) time-frame. Specifications as to whether renovations are allowed to happen during the occupation of the house by these individual residents must also be mentioned. If for example, renovations that take less than one day can be performed whilst the residents are at work? Or, if a more comprehensive renovation needs to take place and the perception of the house before and after this renovation is wanted, do they agree to stay elsewhere for a period of time and then return temporarily to the living lab? For the network behind the lab, it will be important to act from a multi-cycle renovation perspective. By approaching the renovations with flexibility in mind, it is possible to future-proof buildings as the demands to the living environment changes over time, whilst giving consideration to the preferences of individual residents (Brinksma, 2017).

Student research on recruiting residents

When it comes to recruiting residents, research has been done by students investigating user´s perception of the Selficient house, and specifically towards perceptions on living in the house for a limited period of time. In January 2018 53% of respondents to a student survey found it important that the house was built using recycled materials, and that this increased their positive perception of the project (Scompany, 2018). Furthermore, almost three quarters of the sample study found it important that they could help "Selficient" as a learning concept by staying in the house. In the market-research on the "Selficient House" at a vacation park, 85% of the respondents were positive about circular buildings and would like to stay in the Selficient house when they go on vacation (Scompany, 2017). Furthermore, during the kick-off of the Selficient house on the 10th of October, a survey was conducted with the visitors to the house. 94% of the respondents said it would be beneficial for them to live in a circular house which they could adapt as their lives would evolve. Majority would also choose to live in a modular house over a "normal" house, with 80% of respondents choosing this (C. Hilferink, 2018).

The recruitment of residents will depend on the research designed by the network and partners involved in the Circular Living Lab. Which specific requirements are wished for in the test-residents? Their age, occupation, mobility levels, et cetera? An agreement must be reached here and streamlined with the overall research objective of the lab. The physical limitations of the lab having only one bedroom may for example indicate that only one or two people, if a couple, can stay there at the time, or a couple with a young child who sleeps in the bedroom with the parents. Recruitment will also depend on financial means. Access can be granted to test-residents on the basis of Pay-What-You-Want-Pricing (PWYWP), as one example, or through an auction, as another example. This will again depend on the network´s desires on the target group.

Future prospects

To conclude, it will be beneficial to continue the research with residents´ motivation and behavior around sustainable(/circular) renovations, where in the next step the concept of modularity is included. The Selficient house could aim to become fully circular-modular, and this concept may receive a different welcoming compared to sustainability - even though it will still be making homes more sustainable. The reason for this may be that residents will see less limits and constrictions associated with circular-modular compared with sustainable. The issue of trust, which was experienced by both building companies and residents, may be improved if the resident sees that the circular (-modular) renovation happening now can still be customized a few years down the line by making use of the circular aspects, and the renovation may then be seen as less permanent of nature and therefore lower the threshold. Especially in social housing, where 50% of the buildings are built between 1950-1970, is there a lot of potential for being more sustainable and save energy, but the residents are generally reluctant to renovate (Oostra M. , 2015). Measures should be taken to reduce reluctance so that the housing stock can be improved.

This marks the end of the chapter about residents and circular renovations. The next chapter is about the Living Lab, where the goal is to investigate how some of the questions which have

been raised in the two previous chapters can be answered in the context of a Circular Living Lab.

Circular Living Lab

The following chapter is about the Circular Living Lab. First the living lab will be defined and critical success factors determined. Then a step-by-step approach to setting up the Lab is presented.

What is a Living Lab?

A Living Lab is a tool used to generate societal change through a series of experiments which are conducted with the aim of transferring knowledge and to create a lasting impact. Usually, a location-transcending scenario has the most impact, where a structure with which experiments can be done at multiple locations over longer periods of time is used. Co-creation on location only becomes really effective as a transition instrument if the learning process becomes part of a location-transcending vision and approach (Raven, 2018).
A living lab has potential to create an experimental environment where co-creation, exploration and evaluation of innovative ideas and concepts can be put to the test in real-life scenarios, and evaluated. This approach allows involved stakeholders the opportunity to consider both performance as well as user perception/user acceptance of their product, from the design-stage and all the way to the end of its life. A Living Lab is defined by the Rathenau Institute to be a typical instrument and tool for realizing not only transition policy, but also research and innovation policy aimed at societal challenges (T. Maas, 2017).

What are Critical Success Factors for the Circular Living Lab at USP?

Applied to the prospected Circular Living Lab, these are relevant aspects that can generate innovation through the co-creation with users, companies, government, researchers and students, on a multitude of relevant, and challenging, societal topics. For this lab to be a success, an expert on Living Labs from Utrecht Province was contacted. Three critical success factors for the Circular Living Lab at the Utrecht Science Park were identified. These are as follows:

1. **Be aware of how the lab can fuel innovations in the region and create social contribution to sustainability**. For small-scale experiments on location to contribute to a broader, social transition often a coordinated deployment of Living Labs is required. The most influential living labs transcend years and perform experiments over multiple locations. For the Circular Living Lab at Utrecht Science Park it is therefore advised to design a long-term vision and approach which transcends the Circular Living Lab and includes intermediate steps beyond this temporary dwelling, with possible future projects and experiments where the findings here will be used as input to fuel the next innovations and to aid scaling up the solutions found. It is important to not forget that the lab will have social implications related to the impact upon the people who live in its surroundings.

2. The second critical success factor is to **monitor constantly and to share the data and learnings with the network**. Is it successful? Are the experiments creating helpful knowledge and information? Co-creation connects partners from various

sectors who complement each other with a diversity of competences, human knowledge and skills, financial resources and political influence (K. McCormic, n.d.). The innovations are tested in a real-life and real-time settings, which can be challenging. It is important to have a clear idea of how the knowledge that is produced can be incorporated into broader activities, strategies or policies in order to scale up the impacts and share the knowledge. On this aspect it will be helpful to learn from other Living Labs in the region.

3. Lastly, to learn in a network with different perspectives is hard. **It is invaluable to establish a learning environment that shares a common vision, for all parties to work towards the same goal**. Designing a flow-chart to visualize potential transition-pathways so the innovations can find their way to homes in the province, where they are needed to aid circular renovations, is one way to develop this common goal which can accommodate different perspectives. Three examples are given; The energy module can be used first for the specific Inside Out renovations in Utrecht Overvecht. Next, the material flow-experiences and knowledge generated can fuel the prospect of the circular city. Lastly, the learning-experiences created and generated within the lab can be shared with the people living in the house, with building companies and other companies involved, and with residents in the province. It is essential to share and discuss the experiences with the stakeholders in the network so everyone can benefit from the knowledge that is being generated (van den Heiligenberg, 2019).

Setting up the Circular Living Lab

To set up the Circular Living Lab in the USP-house at Utrecht Science Park will require compliance to local regulations. However, there are no standardized rules and regulations for a dynamic living lab where renovations are continuous. The regional and city governments must give specific approval for the running of this lab.
Utrecht Province´s recent publication on circularity is in favor of experiments that can bring a circular Utrecht closer, yet there is a need for arenas where experiments and innovations can be tested in real-life settings. Furthermore, one of the main obstacles for circularity in Utrecht is to get companies involved. By designing a lab where companies´ questions are answered can generate cross-sector advantages on multi-level dimensions. After all, the Circular Economy is about collaboration and closing circles!
To have a clear purpose with the research, to have a strong network and a shared vision which fits within the local and regional vision of Utrecht Province as a circular pioneer, and ultimately a strategy for how the region and stakeholders can benefit from the findings, will be strong arguments for being granted the opportunity to run the Circular Living Lab. Based on this information, the first five steps for getting the Living Lab started have been identified.

1. Determining what the Circular Living Lab is expected to deliver in the course of its operation, and what the intended outcomes are. Designing milestones and attach resource needs to these milestones creates an overview of for example which regulations must be applied for, juridical questions, personnel, knowledge, materials and financials.
2. A common vision for the future should be developed together with industry partners and the local/regional government, with a strategy for how the Circular Living Lab can contribute to this vision. A flow-chart, which includes the expected continuation of the

various aspects of the Living Lab beyond its temporary lifetime, should be included in this step.

3. Implementation plan for the lab: How, when and by whom will the renovations, experiments and research be carried out? What kind of experiments will be organized in the lab? Determine the wished population for participation in experiments, and how they can be reached.
4. A Stakeholder Management Plan should be made, highlighting how the Circular Living Lab will be managed and communicated between the stakeholders. This includes a Living Lab Agreement, documentation committing the partners, stakeholders and others directly involved in the delivery of the agreed operation.
5. Develop good laboratory practices concerning the temporary test-residents. Contracts must be signed, information given and shared with the individual(s), and ethical codes of conduct, especially concerning safe and grounded data practices implemented.

(iSCAPE, n.d.) (K. McCormic, n.d.)

Conclusion

The power of this Circular Living Lab lies in its integrated multi-purpose applicability to reaching specific societal goals, hosted by the Hogeschool Utrecht as an independent institution. It became clear during the last event arranged in association with this KIEM VANG, that companies find it an added value to get the out-of-the-box perspective from students. New ideas and perspectives can be gained through the younger generation, which combined with the perspectives of the users can add value to its environment.

The Circular Living Lab has potential on the basis of its geographical location, the Utrecht Science Park, as a learning environment and a showcase for sustainability. Both Hogeschool Utrecht as well as potentially Utrecht University can beneficially use the lab for different purposes which adds value to the tuition and education offered at the Utrecht Science Park, for students as well as lecturers and researchers. Furthermore, findings on the topic of the energy transition with the energy module of the house can be used for upgrading and renovating for Zero Energy Housing, of which is becoming a growing focus in the Dutch society to contribute to lowering CO_w emissions and the Paris Agreement agenda (Ministry of Economic Affairs, 2017). The contributions the lab can deliver on the topic of Circular Economy is another, especially considering the Dutch Government´s goal of reaching a circular construction-industry by 2050 (Government of The Netherlands, 2016), and the recently published Five Principles of the New Style of Utrecht, which are grounded in a circular approach. When considering residents specifically, the benefits of visualizing, experimenting with and promoting a “levensloopbestendig” (Life-course proof) building, through the modular aspects of the lab, furthermore has the potential to motivate and inspire residents and home-owners to renovate their homes in a circular way. Not only would this create benefits for the environment, the industry and the economy, but also potentially on societal issues, for example related to health and mobility.

Furthermore, through conversations with companies and industry experts it became clear that there are several research-gaps when it comes to circularity. The biggest one, from the perspective of the residents, is the financial affordability of generally renovating ones´ home. This of course impacts the companies too, and this serves as one example of where the Hogeschool Utrecht and the network can do research beyond only the practical aspects of lab. Another example is to test the use of Blockchain technology as a way of safely handling Big Data. The Blockchain Lab of Hogeschool Utrecht is a potential candidate to participate in this research, which can concern both social aspects around the residents and their privacy, as well as aiding the development of a material passport for the building itself.

The Selficient house as a Circular Living Lab can contribute to renovation and innovation in a multi-purpose context, where an interdisciplinary and integrated approach can be supported. The transition of this house into a fully circular house can create province-wide benefits for all stakeholders and should be seen as a first step to fueling innovations of this nature, where the goal is to find ways of scaling up the findings to reach broader impact. The strong connections that can be created in the Wonen 3.0 knowledge alliance-network, combining students, researchers, HEIs, companies and the government, should be taken advantage of.

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