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# Local experiments in transition processes to increasing circularity in the building sector

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# Abstract

The objective of this master thesis is to develop knowledge to explain the possible effects of demonstration projects in circular building and their contribution to the building sector's transition to a circular economy. Based on this objective, this study asks a question regarding the ways in which demonstration projects in circular building such as the Circle House contribute to increasing circularity within the building sector. In this study, the answer to this question is firstly based on an evolutionary approach of the Danish building sector, in light of the multilevel perspective approach. Secondly, the study focuses on the analysis of local experiments (i.e. explorative experiments and demonstration projects) in circular construction. Finally, the study presents a discussion revolving around the interactions and effects of demonstration projects in the building sector and at a niche level. It is then suggested that demonstration projects perform important roles in circular building niche formation, and under certain conditions constitute important factors for the dissemination of circular building.

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## Clarification of Abbreviations

AK: Aarhus Kommune

BIM: Building Information Model

BREEAM: Building Research Establishment Environmental Assessment Methodology

CDW: Construction and Demolition Waste

CE-marking: indicates a product's compliance with EU legislation

CE: Circular Economy

COM: European Commission

DAC: Danish Architecture Center

DGNB: certification tool for buildings and neighbourhoods developed by the German Association for Green Building (Deutsche Gesellschaft für Nachhaltiges Bauen).

DEA: Danish Energy Agency

DEPA: Danish Environmental Protection Agency

DT: translated from Danish

Ecodesign: European directive which places requirements on the ecological design of energy-related products, including consumer electronics, white goods (both professional and domestic) and lighting.

EMF: The Ellen MacArthur Foundation

EU: European Union

GHG: Greenhouse gases

KADK: The Royal Danish Academy of Fine Arts

LCA: Life Cycle Assessment/ Analysis, a method used to calculate the environmental impact of a product or activity, from the mining of raw materials to produce the product to the waste phase of the product

LCC: Life Cycle Costing, a method used to make an inventory of the financial costs of a product or service

LCT: Life cycle thinking

LEED: Leadership in Energy & Environmental Design.

MLP: Multi-level Perspective

SBi – (Statens Byggeforskningsinstitut)

SNM: Strategic Niche Management

SME: Small and medium-sized enterprises

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# 1. Introduction

This is a master thesis for the Master in Engineering of Sustainable Cities at Aalborg University. The project was developed in the 4th semester and aims to analyse the contribution of local experiments to socio-technical transitions exemplified by the role of demonstration projects to increasing circularity in the Danish building sector.

## 1.1 Background

Globally, consumption of material resources and CO2 emissions continue to increase as the world population grows and income increases. In the last 100 years, global population has grown more than four-fold to 7,6 billion and global economic output (global GDP) more than 20-fold (Krausmann et al. 2009; UN 2017). At the same time, material consumption has grown eightfold, meaning that today humanity uses the equivalent of 1.6 Earths to provide the resources we use and absorb our waste (GFN n.d.). Additionally, CO2 emissions have increased at an annual rate of 3.5% reaching 100 million tonnes of carbon in 2001 (Sherbinin et al. 2007).

Similarly, population growth trend is expected to intensify in the current century, with particular emphasis on developing countries (UN 2014). The United Nations (2017) projected that the world population will reach 8.6 billion by 2030, 9.8 billion by 2050 and 11.2 billion by 2100. Moreover, predictions indicate that the urban population - which already accounts for half of the planet's population - will grow in higher percentages than world population. In 1950, 746 million people lived in cities, which was less than 30 % of the world's population; at present, that proportion has risen to 54 %. It is projected that by 2045 some 6 million people will be urban dwellers, approximately 70 % of world's population (UN 2014). In addition, estimates from OECD (2012) indicate that globally the middle class will continue growing significantly over the coming years, from 2 billion in 2010 to 4.9 billion by 2030.

As the global population is urbanized, access to adequate and affordable housing is also a growing challenge. Around one quarter of the world's urban population continues to live in slums and informal settlements (UN-Habitat 2015). Although more than 100 countries recognize the right to adequate housing in their constitution and national legislation the production of adequate housing lacks an appropriate scale. UN Habitat (2015) estimates that over 880 million people are currently living in slums in the cities of developing country.

With regard to consumption trends they are somewhat more difficult to predict as they depend largely from uncertain social and economic factors such as: "*global economic conditions, efforts to achieve sustainable development and potential comments on the environmental systems upon which the global economy relies on resources and sinks"* (Sherbinin et al.2007, parag. 5). Nevertheless, aside from major political changes or economic recessions, it is not expected that consumer trends will change significantly in the short term (Sherbinin et al. 2007).

From an environmental and economic perspective, the likely consequences of this dynamics of population growth and consumption, include scarcity of resources, fertile land, clean water and air, leading to global increased volatility of commodity prices (EMF 2012; McKinsey 2013). Indeed, the depletion of low-cost reserves of raw material and degradation of natural capital, and increasing resource demand, are already leading to a constant increase in raw material prices across the world (ARUP 2016). In Europe, despite there is no shortage of resources to mine, it is becoming more difficult and costlier its extraction, either because of a lower degree of purity of resources or because the access it is more limited due to more restrictive environmental regulations to protect fragile ecosystems (EMF & McKinsey 2015a). In Asia, in turn, the urban population is rising sharply as well as average income, is leading to a high demand for mineral resources and energy to meet the demands of industry and households. Therefore, "*the costs of* *raw materials are rising on a scale and at a pace that is unprecedented*" (McKinsey 2013, p.5). In a global context, prices of raw material (Non-food agricultural materials) have more than doubled, on average, since 2000. As an example, the nominal price increase of steel, up 167% since the turn of the century, which is notable given its "domino effect" within a range of industries such as construction (McKinsey 2013).

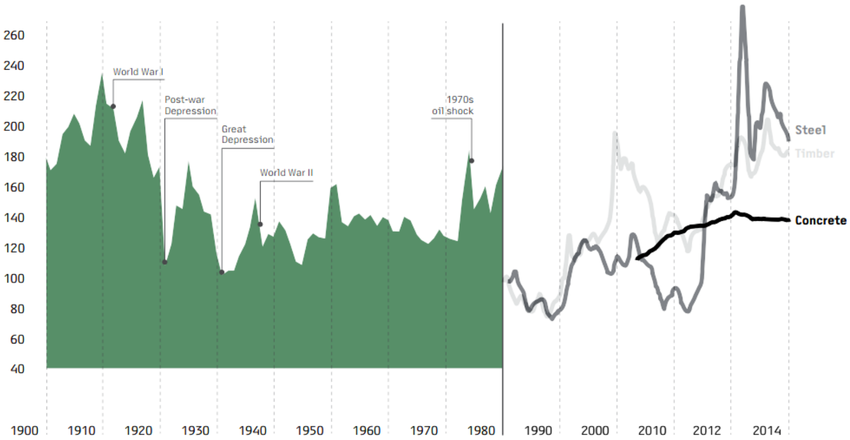


Fig. 1. Diagram McKinsey Commodity Price Index: Concrete, Steel and Timber.10 The price on concrete, steel and timber in relation to the average commodity prices. 11 In 2013 and 2014 there has been a decline in commodity prices. (This diagram is an interpretation of an original owned by Ellen MacArthur Foundation): Source 3XN-GXN et al. (2016).

Against this backdrop, the building sector is under increasing pressure to minimise its environmental impacts, as it is one of the most resource consuming sectors (UNEP-SBCI 2009). In global terms, construction is believed to consume around half of all the resources humans take from nature, 25 % of global freshwater, generates large amounts of pollution and waste and accounts for considerable land use (UNEP 2003).

In OECD countries, the building sector consumes between 25% and 50% of total energy consumption (UNEP 2003) and, since production of construction materials is mostly based on fossil fuels, the bulk of energy used entails emission greenhouse gases (GHG). As an example, the global trend for concrete used in construction is leading to an expansion of cement production (one of the main sources of GHG emissions), being expected to quadruple by 2050 (UNEP 2003).

In Europe, considering the 27 EU Member States, one of biggest fractions of construction materials is concrete with 42%, following closely aggregate materials, which represent about 45% of the total materials by weight. Bricks represent with 6.7%, and steel, the largest metallic fraction, accounts for about 2.5% of materials. Wood (timber) accounts for around 1.6% of material use, and the rest of the materials (including copper, glass, aluminium, etc.) each make up to less than 1% of material use (Ecorys 2014).

The building sector is also increasingly under pressure to enhance resource efficiency and reduce waste (COM 2014). The environmental pressures cover the various types of construction, from buildings to infrastructure, and "*different stages of a building's life-cycle including the manufacturing of construction products, building construction, use, renovation and the management of building waste*" (COM 2014, p. 2).

In EU region, construction and demolition waste (CDW) is considered one of the largest waste streams. According to Eurostat (2017) the amount of CDW generated in 2014, was 868 Mt, one third of total waste generated across EU member states. This amount includes waste produced by construction activities, total or partial demolition operations, refurbishment and enlargement processes.

CDW consists of numerous materials, including concrete, bricks, gypsum, wood, glass, metals, plastic, solvents, asbestos and excavated soil, many of which as the potential to be recycled (COM 2016). In the EU, however, the level of recycling and material recovery of CDW is only 55%, in average, varying very widely from country to country (between less than 10% and over 90%) across the 27-EU member states (COM 2016). In Denmark, currently 87% of the total amount of CDW produced is recycled (DEPA 2016).

The Danish waste management that also includes CDW, has progressed over the years, from its initial focus on the protection of human health, in the 1970s and 1980s, to a current integration of environmental protection with the extraction and recovery of resources in waste (DEPA 2016). The shift from landfills to recycling was precipitated, in the 80's, by concerns over groundwater contamination, particularly because Denmark uses groundwater extensively as a drinking water source, and landfill capacity was exhausted in some regions, such as Copenhagen (DEPA 1999, DEPA n.d). In 1982, the law the environmental protection was revised requiring municipalities and counties to set out waste disposal strategies and waste management plans to implement their targets (LegCo 2014). In 1987, the Danish government introduced landfill and incineration taxes. In addition, in 1990, a new tax was introduced aiming to promote the use of recycled products from CDW and reduce extraction of raw materials, such as sand, gravel, stones, peat, clay and limestone (DEPA 1999: COM 2016; Fischer et al.2012). In 1997, following the enactment of the European Union Landfill Directive, in 1991, Denmark completely banned landfilling of combustible waste, which has a major contribution to shifting the waste treatment paradigm from landfilling to recycling. Later, municipalities and local councils were charged with the duty to draw up regulations on separation of CDW, thereby making clear where and how the waste must be delivered for recycling, incineration or landfilling (Montecinos & Holda 2006).

Recycling has, however, implications from the environmental and resource efficiency perspective. Recycling is an energy consuming process, using mostly non-renewable energy sources contributing thus to GHG emissions, and much of this waste is downcycled (i.e crushed products) so that the value, quantity and functionality are lower than the original product (Rambøll 2016; Adam et al 2017). Downcycling may cause adverse effects on more sustainable and profitable business practices such as deconstruction and building material reuse, which is associated with higher reductions of emissions to air, water, and embodied energy (Walsh 2011).

Reuse has also its challenges. Reuse has also its challenges. Especially when products are designed, as it is important to consider economic and environmental impacts on the various phases of buildings life-cycle. For example: "*Some solutions to improve the energy efficiency of a building could make later* (reuse) *or recycling more difficult and expensive"* (COM 2014, p.3).

Resource efficiency is also a matter that concerns to all stages of construction products since the conception the end of buildings life, although some small differences in terms of building phases to be valued (COM 2014). According to O'Brien et al. (2011), resource efficiency is usually related with the concept of achieving "*more from less*", which means using fewer natural resources to achieve the same or improved output. However, they state that in construction, "*it not only refers to using the resources more effectively in building or renovation phases, it also means reducing the amount of resources needed to operate the building*" (O'Brien et al. 2011, p.5). Sfakianaki (2015), on other hand, argues that resource efficiency in construction includes a life cycle approach and extra initial costs whit long term benefits:

> *"Using resources to their highest potential throughout the product lifecycles – manufacture, design, construction, operation, refurbishment and end of life – may involve extra initial costs, but the environmental measures that will be incorporated in the process will lead to a long-term recurrent cost reduction and potential increase on asset valuations. "*(Sfakianaki 2015, p. 240)

With a similar perspective, EU and member states launched in recent years a comprehensive range of policies aiming to address resource efficiency in the building sector, energy efficiency, and to promote the environmental performance of buildings. (Ecorys 2014). The European Commission presented, in 2014, the initiative "*Resource efficiency opportunities in the building sector* "aimed at promoting efficient use of resources consumed by buildings and to reduce environmental impacts throughout their full life cycle (COM 2014).

In Denmark, the Government laid out the waste management strategy *Denmark Without Waste I* and *II,* focused on moving from incineration to recycling and waste prevention, respectively (DEPA 2015). The strategy emphasizes the top priority on waste prevention, followed by the preparation for reuse of products or materials that can re-enter in the production chain, following thus the waste management hierarchy (Fig. 2) from EU Commission's Directive (DEPA 2015).


Fig 2. Waste management hierarchy. Source: (COM 2008)

Regarding the construction sector, the strategy is aimed at closing the resources cycle, creating better cohesion in the value chain, and avoid waste of resources and prevent substances of concern in construction and demolition waste (DEPA 2015).

Although these policies have given rise to improvements in few European countries in terms of resource consumption, waste prevention, and recycling, in practice the average rate of reuse of construction products tends to remain very low. According to Osmani's (2012) this means that international governmental, industrial and academic efforts in terms of waste management continue to fail to achieve the intended objectives. Therefore, he argues that: "*for waste minimisation to be effective and self-sustaining (...) it is important that all stakeholders along the construction supply chain adopt a more proactive approach in dealing with waste, that is designing out waste"* (Osmani's 2012, p. 40). This presupposes that efforts should start from the early design stages and the initial design approach to waste and material resources minimization.

From a more comprehensive perspective, the circular economy framework builds on the idea that "*working towards efficiency as a solution, will not alter the finite nature of material stocks but can only delay the inevitable*" (EMF 2013, p.3). Instead, products and assets must be designed and made to be more durable, shared, repaired, refurbished, reused and disassembled (EEA 2016). This maintains components and their materials at the highest useful purpose as long as feasible, and therefore minimizing resource waste (EMF n.d ; ARUP 2016).

From an economic and social point of view, it is predicted that by decoupling resource depletion from economic growth, the circular economy may result in reduced risk of price volatility and supply; increase in gross domestic product; and delivering net benefits in terms of job opportunities (EEA 2016). The business benefits may include increasing competitiveness of industry; considerable material and cost savings; and flexibility and different business models to enable value creation (EEA 2016; Adams et al. 2017).

The European Commission recently estimated that circular economy-type economic transitions can create 600 billion euros annual economic gains for the EU manufacturing sector alone (COM

2014 ; EMF 2013). In Denmark, according to a study carried out by EMF (2015), it is estimated that the potential impact of further transitioning to the circular economy, considering a time frame of 20 years, reads as follows: the growth in GDP from 0,8 % to 1,4% (2015 prices); increase of employment Job equivalents from 0,4% to 0,6 %; reduction of CO2 footprint from 2,5 % to 6,9%.

The concept of circular economy is becoming increasingly common-place and promoted by the EU, by several business organizations, and governments around the world including China, Japan, UK, France, Canada, The Netherlands, Sweden, Finland, and Denmark as well as by several businesses around the world (Davis & Hall 2006, Korhonen et al. 2016, EMF 2015). The European Commission is developing circular economy policies, such as "*Closing the loop -Circular Economy Action Plan*", aiming to encourage design improvements in buildings to reduce environmental impacts and increase durability and recyclability of their components (COM 2015). The plan includes the development of indicators to assess lifecycle of buildings, and promote large demonstration projects (COM 2015, Pt 5.4).

The circular economy framework has been created mainly by practitioners, business community and policy-makers based on a fragmented collection of ideas derived from a number of scientific sources (Korhonen et al. (2017). These sources include, for example, industrial ecology, industrial ecosystems and industrial symbioses, cleaner production, cradle-to-cradle design, biomimicry, resilience of social-ecological systems, performance economy, natural capitalism, and the concept of zero emissions (EMF & McKinsey 2015; Adams et al 2017; Korhonen et al. 2017). According to Adams et al. (2017) the common subjects include "*eliminating the concept of waste and maximizing the value of materials* "(p. 16).

The definition developed by the Ellen MacArthur Foundation builds on the concept of' *"restorative and regenerative by* design' *emphasising systems thinking and the need to design out negative externalities*" (EMF 2015; Adams et al. 2017). In correspondence to this the concept the EMF and McKinsey (2015) created a model divides the material flows into two interacting loops: the biological cycle and the technical cycle (Fig. 3).

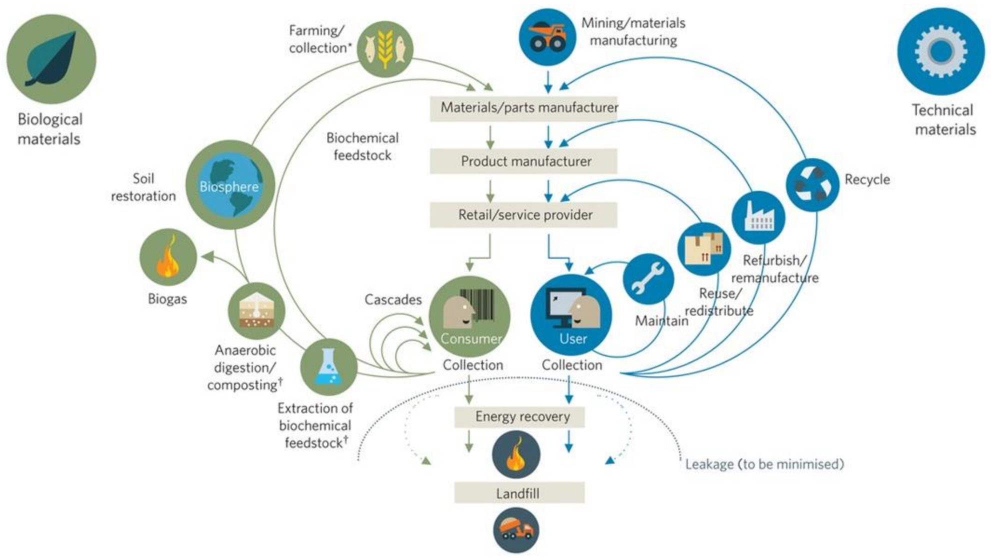


Fig 3. Circular Economy Model. Construction Value Chain. Source: (EMF 2014)

In the biological cycle, renewable and plant-based resources are used, regenerated and safely returned to the biosphere. In technical cycle, man-made products are designed so that at the end of their service life – when they can no longer be repaired and reused for their original purpose their components are extracted and reused, or remanufactured into new products, avoiding this way sending waste to landfill and creates a closed-loop cycle (ARUP 2016).

The EMF's definition has been popularized in the business community which is an important contribution in driving the circular economy forward. However, concern has been raised on the lack of a commonly accepted definition of circular economy. According to Adams et al (2017), the term is evolving, and boundaries are constantly shifting, which poses a significant challenge to its uptake. The risk is that circular economy might be seen "*as another recycling or sustainability initiative*" (Adams et al 2017, p.16)

As regards to the research content of circular economy approach, according to Korhonen et al. (2017) it remains largely unexplored and many key questions are still open. Much of the recent studies on circular economy has been directed to the limits of circularity[1] concept and to short and medium consumer products (Korhonen et al. 2017). In addition, there has been limited research on the application of circular economy aspects in the built environment, particularly to the life cycle of buildings (Adams et al. 2017). There are, however, a few exceptions such as "Building Revolutions: Applying the Circular Economy to the Built Environment" by David Cheshire (2016), and "*Circular economy in the built environment*", a report by ARUP (2016). This literature gives an overview of a diversity of design case studies oriented by circular economy principles, although the mentioned cases are mainly related to material choice and design considerations (GCB 2017).

According to Adams et al (2017) applying the circular economy key aspects across buildings life cycle, involves a number of possible options in each phase of the process. It depends on the complexity and timeframe of the building project. Firstly, the design phase in which design concepts may include design for adaptability and flexibility, design for disassembly, design for standardization, or design out waste. Secondly, the manufacture and supply involving eco-design principles, use of less materials and less hazardous materials and increase of life span. Thirdly the construction phase in which key circularity aspects are related to minimizing waste, procurement of reused and recycled materials and off-site construction. Fourthly the in-use and refurbishment phase which includes minimal maintenance, easy repair and upgrade, adaptability and flexibility. Lastly, the End of life in which deconstruction, selective demolition, reuse of products and components, and recycling, are key circularity aspects to consider.

According to a survey carried out in the UK, conducted by Adams et al. (2017) for the UK Green Construction Board (GCB), there are a number of barriers and challenges to overcome for greater adoption of these circular economy principles by the building sector, such as the following:

- a lack of greater understanding of cost benefit of applying circular economic principles to each part of buildings, due to large amount of uncertainty on material prices into the future and difficulty to predict the potential value of materials at the end of life, particularly long-lived products;
- a lack of holistic approach and collaboration due to issues related to the fragment structure of construction industry which result in "silo" approach of undertaking design, construction, facility management and end-of life activities;
- lack of incentive to design for end of life, as the benefits of adopting circular economy may not be shared equally across the supply chain;

[1] *Circularity* is a trending topic that in countries such as Nederland is on its way to becoming the new sustainability (Geldermans 2015). For scholars such as Geldermans (2015) circularity in its basic form can be explained as being a regenerative approach to resources, materials and products based on high-quality cycles and ideally circular without the addition of 'virgin' resources (Geldermans 2016) Although circularity is used as a value and a criteria for measuring the transition from linear to the circular economy (EMF 2015b) and it is also used as an alternate term to Circular Economy (Niero & Hauschild 2017). Thus, currently, we can find almost as many definitions for circularity as for circularity. According to Kirchherr et al. (2017) who have studied 114 definitions of circular economy, the *significantly varying circular economy definitions may eventually result in the collapse of the concept* (p. 221)

- lack of knowledge among designers on how to adopt circular economy principles mainly due to the complexity of buildings system."

These barriers, combined with challenges such as: the fragmented nature of construction industry; the complex design of buildings, suggest that further incentives are required to enable a transition to circular economy (Adams et al. 2017).

## 1.2 Problem Formulation

Local initiatives based on circular principles can be seen as experiments that may contribute to wider societal transitions (Hodson and Marvin, 2010). Experiments have the potential to aggregate knowledge from research and experiences from other local initiatives, and the expectation is also that they also might render lessons that can be more generally valuable from the perspective of broader transition (Matschoss & Heiskanen 2017). They entail learning and gain experience about immature technologies that struggle to compete with the current structures of building sector (Geels 2002, Kivimaa et al. 2017). Due to regulations, infrastructure, user practices and maintenance networks that are aligned to the existing technology, it is difficult for radically new technologies and practices to break through to the mainstream building system (Geels 2014).

With regard to demonstration projects, they are considered crucial for the emergence and diffusion of radical new technology. According to Harborne, et al. (2007) they provide valuable stimuli to reduce uncertainties and the risk associated with radical new technologies, while help incumbents to innovate and/or imitate to prevent new technology to breakthrough. However, it remains less clear why and how individual organisations engage with such forms of experimentation.

In Denmark, several initiatives based on circular economy principles have been emerging in different areas of building sector. These initiatives include: government policies and programmes (e.g. "Danish Eco-Innovation Program"); design strategies for recycled materials and recycling potentials (e.g. Idécatalog and Materialatlas, by InnoByg); demonstration projects (e.g. "Building a Circular Future" by GXN and MT Højgaard, and "Upcycle House" by Lendager Group); explorative experiments (e.g "The Nordic Built Component Reuse" by Vandkunsten Tegnestuen). Although these initiatives are meaningful for the transition process towards a circular economy due to their contribution to building knowledge and dissemination in the building sector, they seem to be developd in isolation having no special relationship between them.

A recent initiative that aims to be a turning point in circular building in Denmark is the Circle House. The project is supported by MUDP, a program under the Ministry of Environment and Food, which supports development, testing and demonstration of environmentally efficient technology. The Circle House is now being developed by a large number of partners from the building sector (developers, local authorities, architects, engineers, consultants, contractors, suppliers, etc). The aim is to plan and build 60 affordable dwellings in Aarhus according to circular economy principles. The goal is that 90 percent of the materials can be reused or recycled without losing crucial value (MUDP 2017).

The project brands itself as the first large full-scale project built exclusively according to circular principles. The aim is to demonstrate how environmental sustainability and economic gain can go hand in hand. The project's ambition is both to have a signal effect for subsequent projects that look towards it for inspiration and guidance, and work as a solid base to scale up circular building projects.

However, there are several aspects in this local initiative that remain less clear. Firstly, it is not less clear what the project's main focus is. It is less clear if the project is focused on the creation of a niche of circular housing construction, market creation aiming to scale particular solutions, or if is a societal problem solving and change of processes. Secondly, it is less clear how are evolving the project internal processes in material and building system choices. Thirdly, which is the influence and contribution of knowledge and past experiences from other projects or initiatives to this innovative project. Fourthly, the challenges and barriers posed by a complex building sector with a fragmented value chain and often reticent attitude about fundamental change. And finally, which possible contributions does demonstration projects can give to ease the transition of building sector towards the circular economy. As such, "Circle house" contains all the elements of interest for the present research project.

## 1.3 Research Question

Against this backdrop, the research question is:

**In which ways demonstration project of circular building such as the Circle house contribute to increasing circularity within the building sector?**

The given research question comprises several sub-questions:

1. How have changes in the construction sector occurred and what are current internal dynamics?
1. What does circular economy entail for the building sector?
2. Which are the main implication for circular economy adaptation by the building sector?
3. What is the background of innovation and experiments based on principles of circular building in Denmark?
4. Can the Circle House contribute to circular building niche formation?

## 1.4 Outline of the report

Chapter 2, describes my methodologic framework for analysing the main research questions presented in section 1.3. This methodologic framework is organized in two sections: the theoretical framework built on two pillars: i.e. Multilevel perspective and strategic niche management; and a method section which describes the approaches taken, i.e literature review, and data collection through interviews and document analysis. Chapter 3 introduces the empirical context, including concepts and approaches to circular building, as well as an introduction to the illustrative case, the Circle house. On the basis of the theoretical framework and the data empirical data collected, Chapter 4 focuses on the existing building sector and the role of local initiatives and experiments of circular building. The Chapter 5 presents the conclusion.

# 2. Methodology

This chapter presents the theoretical and methodological approach used to produce an informed answer to the research question. The research focuses on the building sector configuration and characteristics as well as in innovation experiments guided by principles of circular economy. Emphasis will be given to emerging design and construction concepts, technologies, processes and products, and their potential impact on the transition of building sector towards circular economy.

Considering innovation activities as niches and the building sector as a socio-technical regime, experiments can throw light on the processes involved in this transition, the theoretical lenses chosen for the research study were the "multi-level perspective" and "strategic niche management".

The first section of this chapter introduces and describes the theoretical framework, and its operationalization, and the second section describes the methodological approach, that includes a literature review, case study justification, and data collection methods (interviews, document analysis, and field notes).

## 2.1 Explaining the uptake of new design and production methods

This section presents the theoretical background of the analytical framework of the research project. First, the conceptual basis the Multi-level perspective is outlined. This is followed by a review of literature on strategic niche management, and the role of demonstration projects. Finally, this section describes how theories are operationalized with a view to the analysis of empirical data and answer the research question.

### 2.1.1 Multi-level Perspective

The Multi-level Perspective (MLP) is an approach to describe and analyse the complex transformation process of sociotechnical sectors and which is an apt characterization of the building sector (Jensen & Bronke 2011). The Multi-level Perspective (MLP) is an approach to describe and analyse the complex transformation process of sociotechnical sectors. As a quasi-evolutionary approach MLP builds on the idea of sustainability journeys from one set of requirements to another, while emphasises variation and selection as mechanisms of change and transition in sectors, and organizations (Garud & Geham 2012). Moreover, in this approach to transitions actors involved are framed by the existing regimes, which follow certain paths of development (Garud and Karnøe 2001)

In recent years, the notion of sociotechnical transition has gained attention in science and policy as a way to understand, and guide changes towards more sustainable regimes (Raven et al. 2010). According to transitions scholars, transitions can thus be defined as major shifts in "socio-technical regimes" or in the way main social needs such energy, mobility and water, are fulfilled (Rip and Kemp 1998). However, transitions are complex and long-term processes, mainly because regimes tend to be stabilised and resist to structural changes (Raven et al 2010).

The multi-level perspective on transitions distinguishes three analytical concepts: the sociotechnical regime lying between technological niches, and a broad sociotechnical landscape (Rip and Kemp 1998; Geels 2002).

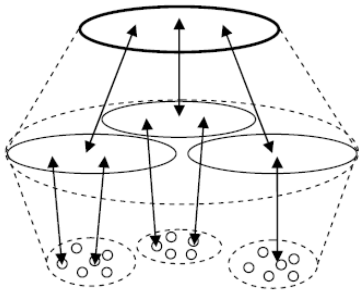


Fig 4. Multi- level perspective. Source Geels and Kemp (2002)

The central concept is the regime, but it is used in various contexts with a variety of meanings:

1- the meso-level in technologi*cal and* social change (*Raven et al 2010, p. 61)*
2- a coherent set of rules and institutions that enables and constraints the choices and behaviour of a wide of range of social groups such as policy actors, firms, users, scientists, engineers, etc (Geels 2002).
3- the "*deep structure*" that accounts persistence and rigidity of the existing sociotechnical system (Geels and Schot 2007).
4- a constellation of structures, culture and practices made co-evolutionary that are the prevailing mean for realizing key societal functions (Smith et al. 2010).
5- the selection environment for innovations (Raven et al 2010)
6- the backbone of the stability of ruling societal systems, characterized by rigidity that typically prevents innovations from altering the standing structures fundamentally (Debacker et al. 2016).
7- the dominant culture, structure and practice embodied in physical and immaterial infrastructures (e.g. roads, power grids, routines, actor-networks, regulations, government and policy …) (Debacker et al. 2016).

Some of these meanings build upon institutional theory, particularly due to studies carried out by Rip and Kemp (1998) and Geels (2004), which widen the regime concept and argue that three central elements of institutions and organizations[2] - Regulative, Normative, and Cognitive - better explain path dependence and stability in technological change than just see it as a problem of changing technologies, structures, and engineering abilities or routines.

According to Raven et al. (2010) the regime concept is often used in a negative way to explain why certain types of innovation do not breakthrough. The regime tends to stabilize existing trajectories, by promoting formal and informal rules (e.g. shared cognitive routines regulations and standards, societal norms and practices, assets and competences) which guide actors (e.g. engineers) in specific directions and make them 'blind' to radical variations (Geels and Schot 2007, Raven 2008).

[2] Scott (1995, 2014) categorizes institutions in three elements, or "pillars", according to their effect on actors– regulative systems, normative systems, and cultural-cognitive systems. Together with associated activities and resources these there "pillars" function to stabilize, keep order, and provide social meaning to individuals (Scott 1995, 2014). The regulative pillar is concerned with rule-setting, policy guidelines, monitoring, and sanctioning activities to which members of the institution have to conform. These can be formal or informal rules or laws that may be enforced either legally or through incentives. (Scott 2014). The normative pillar is concerned with conceptions of preferred or desirable actions, and how things should be done; therefore, social obligations and expectations are at the core of the normative systems. The third pillar corresponds to the cultural-cognitive element of institutions: "the shared conceptions that constitute the nature of social reality and create the frames through which meaning is made" (Scott 2014, p.67) The cultural-cognitive systems, therefore, provide frameworks that offer meaning and internalized representations of the world. These are constructed ways of doing and being that operate within a shared notion of meaning (Scott 2014)

The regime pays less attention "*to the fact the current regimes have actually developed from a positive and legitimised way of doing things* (Raven 2010, p. 61).

According to Smith et al. (2010), due the high level of alignment between the different social and technological elements in regimes, alterations may occur due to specific "*sources of dynamism"* which create tensions and realignments, and thus open windows of opportunity for innovation and *"niche alternatives to compete for attention and influence*" (Smith et al. 2010, p.441)

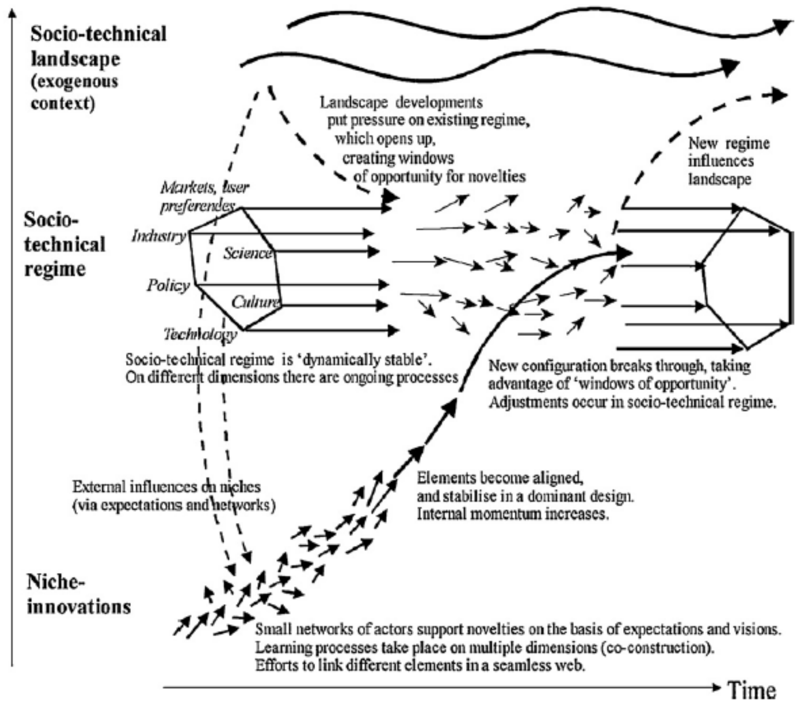


Fig 5. Multi- level perspective diagram. The figure shows the transition from a socio-technical regime to another as a consequence of niche innovations and landscape changes. Source Schot and Geels (2008)

The second concept is the concept of niches. The idea of niches in transition literature has the following meanings:

1- protected spaces from dominant regime which enable dedicated actors, often outsiders or fringe actors, to develop innovative ideas and build networks without immediate pressure from the governing regime (Geels & Schot, 2007)
2- the micro level of technological and social change (Raven et al 2010)
3- a new and relatively set of rules and institutions for innovative practices (Raven 2010)
4- socio-technical configurations which are the potential for inducing change in regime structures from the "bottom-up" (Genus & Coles, 2008).
5- a constellation of structures, culture practices that deviates in the way social need are fulfilled (Raven 2010)
6- the variation environment for radical innovations (Raven 2010)
7- protected environments, where novelties and innovations are created and tested. They accommodate incubators for transition experiments and proofs of concept of radical innovations (e.g. new technologies, new rules and legislation, new concepts, new organizations, innovative business models and financing mechanisms) (Debacker et al. 2016).

The niche concept is often used in a positive way and as an alternative for regime problems. Niches represent thus radical change and a promise of improvement and progress (Raven 2010). In the multi-level perspective, niches are related with protected spaces where radical innovations are developed, and where they are maturated to replace existing practices in the regime level (Raven 2010). Protection may arise from deliberate government policy (e.g. subsided projects for research demonstration and learning) or specific tailored institutional contexts (Smith & Raven 2012). But protection can also occur inside firms through mechanisms such as "shunk works" which are internal technology platforms (Garud & Geham 2012). Niches therefore "*enable transition experiments in which visionary actors can innovate with social goals and learn about social challenges"* (Raven 2010, p. 62)

The third concept is the landscape. The socio-technical landscape represents "*an exogeneous environment beyond the direct influence of niche and regime actors"* (Geels and Schot 2007, p.400). The landscape concept has also a variety of meanings:

1- the external context that enables and constraint the possibilities for regime change, including include environmental and demographic change, social movements, shifts in general politics, broad economic restructuring, emerging scientific and cultural developments (Smith et al. 2010, p.441);
2- the macro-level of social a technological change;
3- the space where societal changes occur, and the discourses evolve "*top down*" source of exogeneous change (Geels 2010; Garud & Geham 2012);
4- the source of pressure on the regime level which consequently generates opportunities for niches (Smith et al. 2010);
5- a constellation of structures, culture and practices with semi-exogenous and semi-autonomous functioning (Raven 2010).
6- the level of dominant trends and evolutions from which it is difficult to deviate, and which are rigid in the sense that it is hardly possible to change them on an individual basis (e.g. globalisation, climate change, ageing populations, etc) (Debacker et al. 2016).

The landscape concept is thus mainly used in transition literature to characterize autonomous and slow developments, normally over decades, that individual actors cannot influence or change, such as demographic trends or international policies as well as sudden events like wars (Smith et al. 2010; Raven 2010).

An important contribution of multi-level perspective to understand transitions is the insight that transitions only occur through the dynamic interplay between landscape forces, regimes and niches, coupling developments at all three levels (Raven 2010). There is, therefore, no single cause or driver in transitions. The processes occur in multiple dimensions, successive link-up, and mutual reinforce, in what Geels and Kemp (2012) calls the "*circular causality*" (p.58)

The transformation on the sociotechnical regime, may range from incremental innovations to radical transitions (Geels and Schot 2007, Smith et al. 2010). According to Raven et al (2010) transition only occur when:

> *"the regime is sufficiently "open", "stable" or adaptation to accept radical innovations; when there is sufficient pressure from the landscape for sociotechnical change; and when radical innovations have been developed in niches that can be used to exploit the opportunities of change*" (p. 63)

According to Geels and Schot (2007) the progress of changes and their intensity, depend on various factors: the timing of the processes, the adaptive capacity of the regime, and the nature of the niche and the pressure exert by the landscape. While the timing of multilevel interactions is related to the question of whether niche innovations are relatively well developed when landscape pressures occur, nature is particularly related to whether niche innovations have a competitive relationship with the existing regime or symbiotic relationship (Geels and Kemp 2012). The transition pathways identified by Geels and Schot (2007) are as follows:

- *Transformation*: This pathway occurs when the landscape pressure is moderate ('disruptive change') at a moment when niche-innovations have not yet been sufficiently developed, leading regime actors to respond by modifying the direction of development paths and innovation activities.
- *De-alignment and realignment path*: This path way occurs if landscape change is divergent, large and sudden ('avalanche change'), causing big internal regime problems. This leads to de-alignment and erosion of the regime. If niche-innovations are not sufficiently developed, then there is no clear substitute, leading uncertainty and the emergence of multiple niche innovations that co-exist and compete for attention and resources. Eventually, one niche-innovation becomes dominant, forming the core for re-alignment of a new regime.
- *Technological substitution*: This pathway occurs when there is much landscape pressure ('specific shock', 'avalanche change', 'disruptive change') at a moment when niche innovations have developed sufficiently, the latter will break through and replace the existing regime.

This means that possibilities for guiding transitions in sectors such as the building sector are limited, both because the stabilized mechanisms at the regime level, and because of dependence on actors, developments, and events on other levels (Raven 2010; Markard and Truffer 2008). Moreover, the development of radical innovations in niches it is relevant but is not sufficient condition for transitions (Raven 2010).

Although the strength of the MLP approach to analyse socio-technical transitions, critical concerns have been raised by scholars regarding the following: "*inconsistent operationalization of regimes, over emphasis of niche as driver of change, unclear conceptualization of landscape level, misrepresentation of levels hierarchy and implicit treatment of spatial dimensions*" (Fuenfschiling & Truffer 2014, p.773).

### 2.1.2 Strategic Niche Management

Strategic Niche Management (SNM) highlights the importance of niche development, technological experiments and social innovation as fundamental elements of transitions. The approach is aimed at stimulating learning processes and processes of societal embedding of socio-technical innovations (Van den Bosh 2010).

According to Kemp et al. (2001) SNM can be described as a way to induce and manage technological regime shifts. Similarly, Hoogma et al. (2002) claim:

> *"Ecological restructuring of production and consumption patterns will require not so much a substitution of old technologies by new ones, but radical shifts in technological systems or technological regimes including a change in consumption patterns, user preferences, regulations, and artefacts. It is here that the SNM approach makes a contribution"* (p. 5).

The niche development model of SNM emerged from the observation of researchers such Rip (1992), Schot et al. (1996) and Kemp (1997) that many sustainable innovations fail to leave the laboratory or take a long time to cross the so-called '*valley of death*', which refers to the gap between research and market introduction (Raven et al. 2008, Raven & Geels 2010).

Building upon insights from evolutionary theories on technological change such as Multilevel Perspective (MLP), Kemp et al. (1998) argued that an important notion for understanding this is the regime concept (Raven et al. 2008). They are retention mechanisms and it can be explained by a wide variety of rules enable and constrain the development and adoption of sociotechnical variations (Raven et al. 2008).

Kemp et al (1998) argued that for radical variations to develop effectively and become knowledgeable there is a need for 'protected spaces'. They provide platforms for new social networks to emerge, such as pilot projects and demonstration projects, which protection may include subsidies or regulatory exemptions. According to Raven et al. (2008) "*those new emerging networks can negotiate, struggle, learn and experiment in a partially shielded environment provided by, for example, subsidies or strategic investments by powerful actors"* (p.3). In these protected spaces, the regime rules (e.g. price/performance ratio, user preferences or regulatory requirements) are not applied broadly, thereby making new practices possible (Raven et al. 2008)

According to Schot & Geels (2008) the type of innovations in technological niches include:

1) Socially desirable innovations serving long-term goals;
2) Radical novelties that face the mismatch regarding existing infrastructure, user practices, regulations, etc.

Several SNM scholars have also investigated whether it is possible to manage a transition process into a new regime, or, more precisely, how sustainable innovations can benefit the wider transition process (Kem, Rip& Schot 2001; Raven et al. 2010). For this purpose, the approach has been applied, tested, and improved in the research of sustainable innovations such battery powered vehicles, fuel cell vehicles, photovoltaic cells, organic food, energy efficiency, renewable energy technologies, biogas plants, biomass co-firing and biofuels (Raven et al. 2008). The analysis in these studies covers series of experimental projects such as pilot projects or demonstration projects over periods up to thirty years (Raven et al. 2010).

The first group of results is related with the emergence of experiments and local projects and the distinction between local practices and niche in a broad perspective. SNM scholars argued that projects do not emerge in a "vacuum" but they are based in experiences from similar projects (Raven et al. 2008). This is conceptualized by Deuten (2003) and Geels and Raven (2006) in the niche model (Fig. 6) as 'global niche level' that forms the reservoir of rules for specific fields of innovation or proto-regimes (general organizational models, financing structures, technical standards, shared ideas about what users want, best-practice publications etc.) exchange of and resource flows transcending local contexts (Raven 2008, Smith & Raven 2012). "Local practices" refers to experimentation in specific places with local contexts, supported by local networks, and generating lessons accordingly. The relations between the two levels occurs in both directions, i.e. while the local is guided the level above in terms of design specifications, market choices, type of partnership, the global is shaped by local variations of local actors which reinterpret and reinvent them by learning under local circumstances (Raven et al 2008).

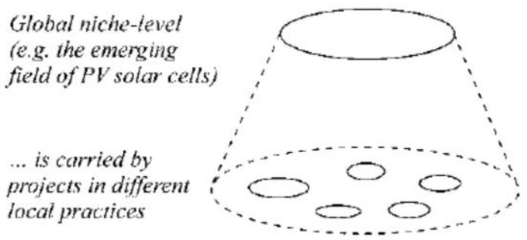


Fig 6. Local projects and global niche-level Source: (Geels and Raven 2006)

Raven (2005) adds a distinction between four types of experiments or local practices that may play a role in creating niches:

- *"Explorative experiments: their most important role is to help researchers define problems, discover user preferences, explore possibilities for changing the innovation, and learn how future experiments should* *be set up. They are especially useful at the very early stages of learning, when there are many uncertainties about the potentials and impacts of an innovation;*

- *Pilot experiments: their objective is to raise public and industrial awareness, stimulate debate and open policymaking. Such experiments can test the applicability of innovations in locations with similar conditions to those where the explorative experiments were conducted, and also test the feasibility and acceptability of innovations in new environments;*
- *Demonstration experiments: the main purpose of such experiments is to show potential adopters how they may benefit from the innovations. They may either be the follow-up of explorative or pilot experiments, or be designed specifically to promote the adoption of an innovation.* [More detail of this experiment in next section]
- *Replication or dissemination experiments: these experiments aim to disseminate tested methods, techniques or models through replication. They involve full-scale implementation of a technological system"* (p.37).

The second group of results aimed to answer a core question of SNM: why a certain innovation journey was a success or a failure? According to Schot & Geels (2008) in early SNM works the transition process was conceptualized as a bottom-up process, in which innovative technologies emerge in technological niches, which consequently conquer market niches, and eventually a regime shift, with new rules, standards, skills, and regulations (Schot & Geels 2008). Later, however, the question that came about was: "*how and under what circumstances is the successful emergence of a technological niche possible?*" (Schot & Geels 2008, p. 540). Three hypotheses of internal processes were then identified by SNM scholars such as Raven (2005) and Schot & Geels (2008) and amended by Raven et al. (2010).

The first process is **voicing and shaping of visons and expectations**. Expectations are considered crucial for niche development because they provide direction to learning processes (e.g. cognitive frames for making choices in the design process) attract attention, and legitimacy for actors to invest time and effort into a new technology that does not have any market value (Schot & Geels 2008). In this process firms, users, policymakers, entrepreneurs, project managers and other relevant actors participate in transition experiments on the base of expectations. The processes of voicing and shaping of visons and expectations is good when:

a) an increasing number of participants share the same expectations (expectations are converging to a shared vision);
b) the expectations can become more specific based on tangible results from transition experiments;
c) the vision that is developed promises a major jump on social and environmental dimensions.

A specific example of use of expectations is related to projects managers. According to Raven et al. (2008):

> "*they use expectations strategically and rhetorically when they make promises to attract attention and resources from sponsors and try to persuade potential partners and stakeholders to participate.* […] *This indicates that reinterpretation and reinvention requires dedicated work and efforts, because it is likely that in many cases potential partners and stakeholders hold different interpretations and thus articulate different expectations. Successful negotiation of expectations about the future project is thus at the heart of successfully implementing a local project variation of an emerging niche technology"* (p, 3).

The second process is the **building of social networks**. In particular in early phases of development, the social network is still very fragile. Transition experiments require new combination of actors, often coming from previously unconnected fields and disciplines. Experimentation in niches requires thus "*new actors which are important to create consistency behind the technology, and* *to get together and make new social networks emerge"* (Raven 2010, p. 64). Building social networks is considered good when:

a) the networks are broad (including firms, users, policy makers, scientists, and other relevant stakeholders from various domains eg. science, technology, politic, social, and both regime actors and outsiders). This criterium is important to ensure that outsiders are not excluded from the transition process;
b) when alignment within the network is facilitated through regular interactions between actors.

The third process identified in SNM is the **learning process.** Learning is central in the experimental introduction of technologies in society. It enables adjustment of technology and or social embedding to increase chances on successful innovation. A good learning process is:

a) broad – focusing not only technological performance or economic feasibility, but also on alignment between the technical (e.g. design specifications, infrastructure and maintenance networks) and the social (e.g. market and user preferences, regulations and government policy and cultural and symbolic meaning);
b) is reflexive- if is not only focused on the accumulation of facts and data, but also if there is attention for questioning underlying assumptions such as social values, and willingness to change the course if the innovation does not match these assumptions.

Although early SNM research focused on individual experiments as sources for addressing regime tensions or even blueprints for wider transformation, further SNM research changed the focus to multiple experiments (Raven el al. 2010).

In addition, recent SNM research also shifted the focus to interaction between the three niche internal processes (articulation of visons and expectations, building of social networks and learning processes) and the influence of external environment (regime and landscape). This interaction of processes is conceptualized in the Geels and Raven's (2010) model of cognitive evolution depicted in Figure 7.

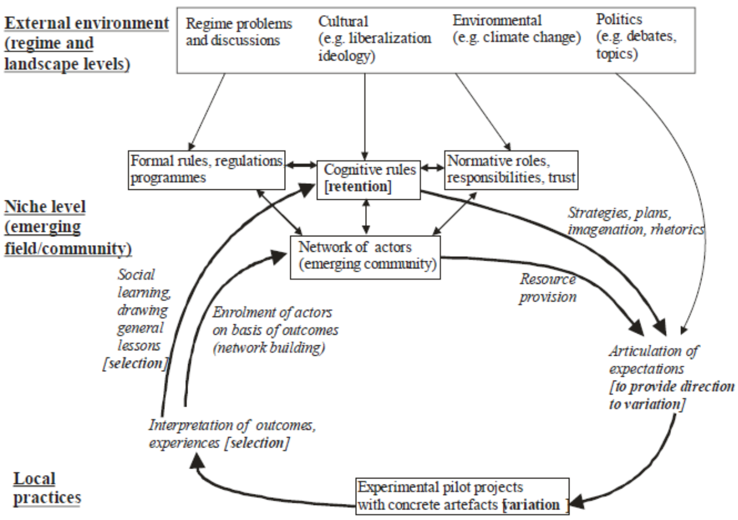


Fig. 7. Dynamics in the relation between projects and socio-cognitive technology evolution. Source: Geels and Raven (2010) adapted from Geels and Raven (2006)

The model builds on the interaction between niche internal processes (Geels and Raven 2006), and also in concepts of *retention*, *selection*, and *variation*, from evolutionary theories. In this model, cognitive rules at global niche-level act as retention mechanism and resources for innovative projects. Expectations give direction to projects at the local level and help to mobilise resources. Local practices, which include as pilot projects or demonstration projects, are carried out by local actors and provide space for local activities. These local projects form therefore spaces for *variation* and adaptation with specific artefacts in practice. The outcomes and experiences from these projects are discussed, interpreted and compared with other projects. The transformation of local experiences into more generic abstract cognitive rules is a *selection* process that requires "*socio-cognitive work: eg. aggregation, formalisation and codification"* (Geels and Deuten 2006, referred by Raven and Geels 2010). The adoption of codified lessons at the global niche-level leads to global cognitive rules, which in turn form resources for a new round of adjusted expectations. The actors imbedded in networks, are willing to invest resources (money, people) in experiments, if they have shared positive vision of a new innovation. The shared vision, together with shared rules and other institutional elements, provide also direction to projects. Outcomes are also used to adjust previous expectations and enrol more actors and expand the social network (Raven et al. 2010). In sum, as argued by Raven and Geels (2010) "*selection trough social learning and codification is this a social process*" (p. 90)

In this conceptual model, external factors at the regime and landscape level may influence niche development. According to Raven and Geels (2010) this influence acts in two ways: "*distal causaction*" an "*direct causation"* (p. 90). The *distal causation* operates through the effect of external factors on expectations. The *direct causation* acts trough institutional rules (cognitive, normative and formal). Although in this model external influences are mainly mediated and promoted by the socio-cognitive process, it doesn't exclude other two the institutional elements, and their effect on actors– regulative systems, normative systems, and cultural (Raven and Geels 2010; Scott 1995, 2014).

This evolutionary perspective, which can explain specific patterns in niche development, is complemented by a conceptual model of sequence of sequences of local project that gradually add up to a new trajectory (Smith &Raven 2012; Geels &Raven 2006). In this model, depicted in Figure 8, rules and other institutional elements that in a first stage are diffuse and unstable, become gradually more articulated, specific and stable (Raven et al. 2010).

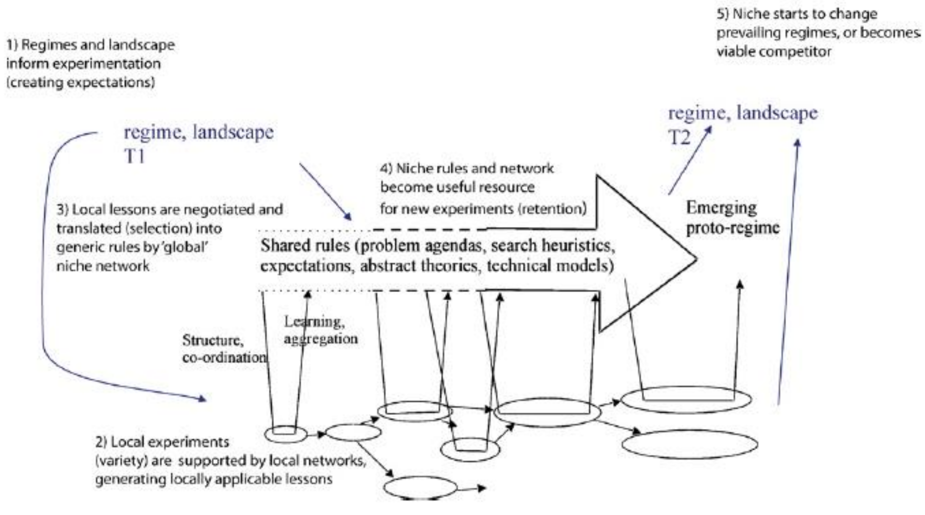


Fig. 8. Emerging technical trajectory carried out in local projects. Source: (Geels and Raven 2006)

In this process dedicated "aggregation activities" are required. According to Raven et al. (2008) they include a range of formal and informal, such as standardisation, model building, handbook writing and formulation of best practices, etc. Circulation of knowledge, site visits and excursions, internet forums, conferences, workshops, technical journals, proceedings and newsletters play also a major role. They may be performed by a variety of actors, including: intermediary actors (professional societies, industry associations, standardisation organisations), large firms with multiple projects in different locations, research organisations, governmental project coordinators, etc.

This model is line with research by Raven (2005) and Smith (2007) which explore opportunities for niche engagement with regimes when both are relatively stable. Different kinds of opportunities are presented, but the main argument is the niche-regime dichotomy may eventual breakdown as niche influence grows or is reformed in response to the appropriation of practices into the regime (Smith 2007).

### 2.1.3 Operationalisation

This section aims to explain how the theories and approaches will be elaborated further in the analysis chapter.

As aforementioned, the chosen theoretical framework is primarily based on evolutionary theory that seeks to explain possible pathways for transition. The Multilevel perspective (MLP) will be used as the framework to characterize "*path dependencies with deep historical roots*" [3] and current trend as influences (Verbong & Geels 2008) This will be based on four main areas: 1) introduction to the building sector framework; 2) historical description based on MLP components (technology, industry, market and costumers, culture, policy, and research and education); 3) identification of main trends (at the landscape level); 4 barriers, and drivers to the circular economy in the building sector.

Thereafter, the Strategic niche management (SNM) will be used to analyse the process of niche formation when it comes to the development of circular building, including the study of Circle house as an illustrative case.

Finally, the discussion will focus on potential contribution of niche initiatives to a transition towards a circular building sector.

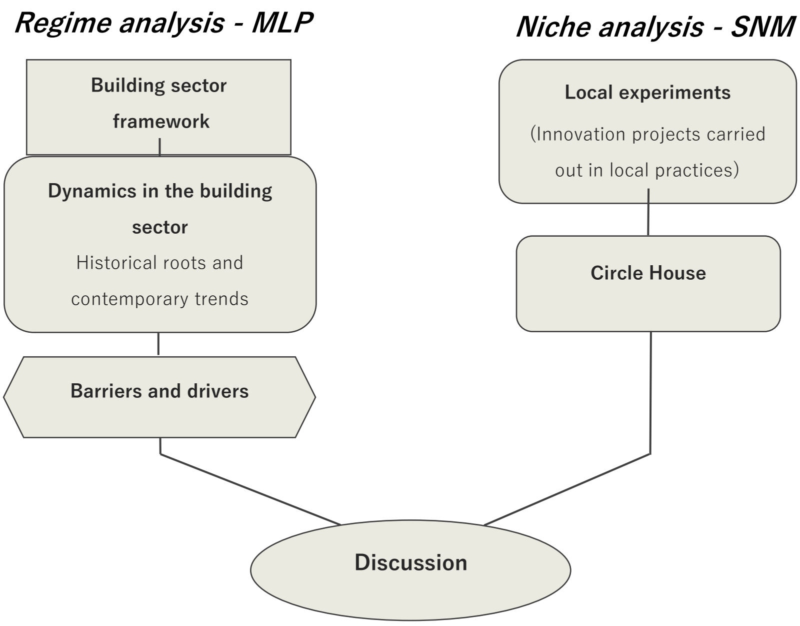


Fig. 9. General overview of operationalization of theories and approaches

[3] Extract from an inspirational paragraph from Verbong and Geels (2008) for building sector analysis: "*Existing systems are characterized by path dependencies with deep historical roots. This means that research on future transitions should not simply take the present situation as the starting point and extrapolate promising innovations (for example learning curves), but should take into account the path dependencies in existing regime. Historical research is necessary to say something sensible about future transitions" (p. 178)*

## 2.2 Methods

The following section describes the methods that have been employed in this research project.

The development of the conceptual framework is based on two main methods: a literature study and a case study research.

### 2.2.1 Literature review

A literature review has been conducted on two dimensions, i.e. both empirically and theoretically. Firstly, an overview of the most relevant literature about the background of circular economy in the building sector, which is also supported by a zooming in the literature related to circular economy principles, concepts, methods and tools for design and construction. Secondly, the literature study explores transition theory (Section 2.1), and includes dynamics in sustainability transitions (e.g. multi-level perspective), Strategic Niche Management (e.g. niche-development, niche-regime interaction), and the role of demonstration projects. Finally, the literature study explores the evolution and dynamics of transition within the building sector and several initiatives and experiments aiming to introduce circular principles in the building sector.

### 2.2.2 Illustrative case study

An illustrative case study approach was chosen because it enables an in-depth study of transition experiments within a specific context, as it is the case of Circle house. The study of this illustrative case differs from a case study analysis, because the empirical data that was possible collect is not sufficient to investigate the real-life context to its full extend.

Although the circular house is a project that is at an early stage of development, it has a series of ingredients for analysing possible contributions of demonstration projects for a sectorial transition to circular economy. Primarily, because of its scale and social objectives involving the construction of a number of circular housing. Then, because it involves a large number of actors across the value chain. Next, because its initial vision seems fairly ambitious, but, indeed, was important to mobilize resources and a wide range of relevant stakeholders. Lastly, because it might become influential for other further projects and to eliminate some barriers to increasing circularity in the building sector.

### 2.2.3 Data Collection

This section describes and justifies the data collection methods chosen in the study, and states how they were used. Interviews and document analysis were used as the main method to collect empirical data. The data about the illustrative case study was gathered by conducting open interviews, analysing documents, conferences, seminars and exhibitions.

#### 2.2.3.1 Interviews

One of the main sources of qualitative data was provided by semi-structured interviews. The process of interview request was made in the early stage of the study and involved a few relevant players in the building sector. The focus has been relevant actors that either are involved in Circle House or expressed their views circularity in the building sector. The requests have been mostly unsuccessful.

Thus, the interviewed were chosen because of their particular overview of the building system, as well as due to their experience and knowledge of innovation in architecture and construction, experimental activities, and circular construction. The interviewees were: Søren Nielsen, architect, partner at Tegnestuen Vandkunsten Architects, which beyond his background in sustainable buildings and circular construction, is also involved the case study; and Anne Beim, Professor, Head of Center for Industrialized Architecture (CINARK), Ph.D. Institute. Architecture and Technology.

The interviews provided important in-depth qualitative information on the state of art of circularity in the building sector in Denmark and about process, and the intermediary actors involved in the building project studied.

#### 2.2.3.2 Document analysis

Document analysis, understood as a systematic procedure used for reviewing or evaluating documents, was the method used to develop empirical knowledge, gain understanding and extract meaning about the elements included in present study project. Documents used a variety of forms, such as Internet disclosure material, interviews in websites or magazines, conference presentations, manuals, papers, Phd Thesis, books and brochures.

#### 2.2.3.3 Field Notes

Fieldnotes are intended to serve as supplement information collect from sources such as documents and interviews. The fieldwork was conducted between October and November 2017 in the following events:

- "Good architecture in a circular economy", seminar in: *Circular economy in architecture and design*", 2017 October the 24th, , KADK, Copenhagen

The seminar aimed at providing insights into some of the most significant architectural projects that currently transform the circular economy from theory to practice, and promote the debate about the role of architecture the sustainable use of resources. Practical cases, including the Circle House were shown to by Anders Lendager, architect and CEO of Lendager Group, and also by Nikolaj Callisen Friis and Line Tebering from Fæallestegnestuen.

- " The circular of the future of the future", conference and debate in Building Green 2017, November the 2nd, Forum, Copenhagen

The presentation was held by Kasper Guldager Jensen, senior partner of GXN Innovation, branch of 3XN Architects, member of government's Advisory Board for circular economy, central figure of Circle House project. The presentation pertained to showed that a circular future is already under construction. He emphasized the role of new collaborations, business models in the industry, recommendations of the Government Advisory Board for Circular Economy, and provided a description of the Circle House. The presentation was supplemented by an exhibition about the Circle House.

# 3. Empirical Context

The following chapter aims to explain the empirical context regarding the circular building by presenting main concepts and approaches that will allow an understanding of the analysis chapter that follows.

## 3.1 Circular building – Concepts and approaches

The term 'Circular building', also referred as 'circular construction' (ING Bank 2017), and "circular value chain" (ARUP & BAM 2017), should be seen in contrast to 'circular buildings', as its focus it is not the building as a static physical object but the collection of functions and processes that are subject to change. According to Geldermans (2015):

> *"Circular building can be addressed as the dynamic total of associated processes, materials and stakeholders, led by the owner/user. A building can be a temporary manifestation of that activity. For the sake of materials and products, the stages before and after this physical temporary manifestation are just as important* "(p.5).

In circular building the entire construction value chain needs to be involved for mutual gain (ING Bank 2017). According to ARUP & BAM (2017) a circular value chain in the building system requires "*all stakeholders to contribute towards an outcome that achieves the best value for all parties, using components that retain the highest value throughout the lifecycle and minimises losses from the system"*. Therefore, products need to be designed with future uses in mind and all members of the value chain need to work with different business models, and levels of incentivisation, to achieve longer term benefit and higher residual value of buildings, components and materials (ARUP & BAM 2017, ING Bank 2017).

To realise such a significant change in the value chain, it is necessary to reduce the unfamiliarity of the stakeholders with the concepts behind the circular economy.

### 3.1.1 Building's life cycle

#### Life cycle thinking

Life cycle thinking (LCT) means accounting for economic, environmental and social impacts across all stages of building, product or process life cycle (CE Guide n.d). The main goals of LCT are to reduce a product's resource consumption, emissions and waste as well as improve its socio-economic performance through across all life cycle stages (LCI n.d). This perspective informs project teams and partners involved in the process about product's life cycle impacts across a range of sustainability issues, such as energy, GHG emissions, jobs created, etc. Furthermore, it allows project teams and organizations to compare life cycle impacts of a product or process to their mission and goals (EU Ecolabel 2010).

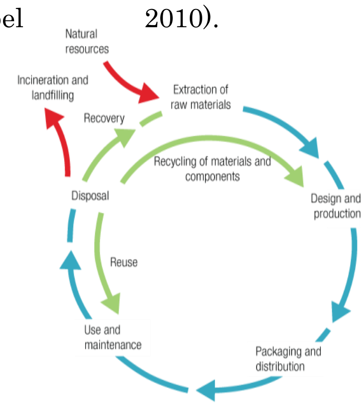


Fig. 10. Product Life-cycle.

A product life cycle (Fig. 10) can begin with the extraction of raw materials from natural resources in the ground and energy generation. Materials and energy are then part of transport, processing, production packaging, distribution/transport, use/operation, maintenance, and eventually, reuse, repair, recovery recycling or final disposal (LCI n.d; Kauschen 2010).

## Life cycle assessment

Life Cycle Assessment (LCA) provide the framework for assessing the potential environmental impacts of products. LCA is also being used in the building sector, where it is a crucial part of the assessment of buildings environmental sustainability. LCA can be applied to buildings on different levels, including at the level of the building materials and products, building parts and elements, whole buildings and even entire neighbourhoods (Schlanbusch et al. 2016). The life cycle approach moves focus from factors related to the completed building, to involving the entire life cycle of the building. (Birgisdóttir & Rasmussen 2016). This means including all of the stages in the assessment: the product stage, construction process stage, use stage, the end-of -life stage and benefits and loads beyond the system boundary (Birgisdóttir& Rasmussen 2016). Although the first two steps are the best known, in practice the acquisition of sufficient data for the calculations can become problematic. The next three stages are scenario-based. Therefore, assumptions have to be made about how the building will be used, maintained, and finally demolished (Birgisdóttir& Rasmussen 2016).

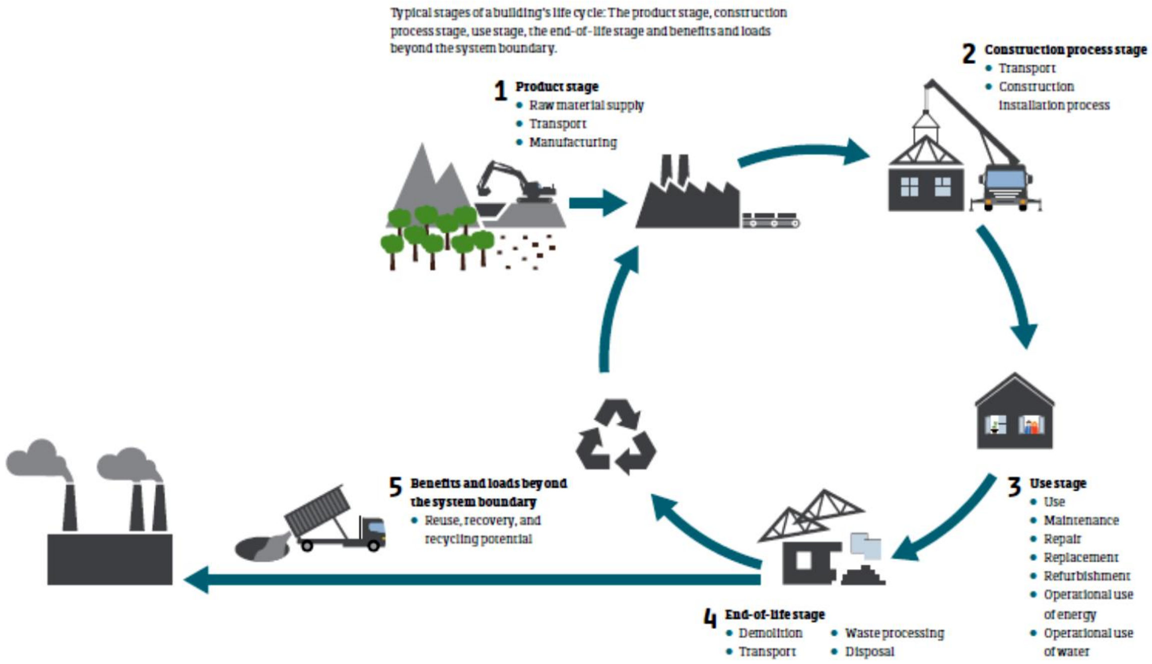


Fig 11. Typical stages of a building's life cycle: Source: Birgisdóttir & Rasmussen (2016).

Buildings life cycle typical stages (Fig. 11) are characterized by the following:

1. Product stage - this stage involves the production of construction products, from the raw material supply, transport to the production site and final production of the construction products.
1. Construction process stage - involves the journey of construction products from production line to the point where they are installed as a part of the finished building, including the transport from the manufacturer to the construction site as well as installation in the building.
2. Use stage - The processes in this stage are scenario-based. The use stage involves the processes related to the construction products' continued performance as part of the building (e.g.

maintenance, replacement, repair). In this stage processes related to the building's ongoing operational energy and water use are also included.

3. End-of-life stage - The scenario-based processes in this stage to concern what happens when the building reaches the end of its life, such as the building's demolition and the subsequent processes involved in reprocessing or handling the construction products/materials before further use of in other product systems.
4. Benefits and loads beyond the system boundary - The processes in this stage are also scenario-based. This stage contains the calculated gains and drawbacks from reusing and recycling construction products/materials. In accordance with the European standards, contributions from this stage must be considered outside the system boundary and be reported separately. (Birgisdóttir& Rasmussen 2016).

### LCA tools and software

The calculation of the LCA results should be carried out when all of the material quantities have been identified and the data for all of the materials and processes are available (Birgisdóttir & Rasmussen 2016). In order to make the calculations much easier software tools intended for this purpose have been developed. There are a number of modelling tools available for use by LCA practitioners, such as Ecoinvent 3.0, GaBi, SimaPro, and LCAbyg. There are similarly multiple data sets such as U.S. Life Cycle Inventory Database, CPM LCA Database, European Life Cycle Database, and Ökobau (Devotail 2017; Birgisdóttir & Rasmussen 2016).

Insofar as, in the case of Circle House, the LCA tool to be used it is LCAbyg a short description is present as follows: LCAbyg is an LCA tool developed by the SBI -Danish Building Research Institute. LCAbyg is based on a German database for construction products, Ökobau. The software can calculate a number of the building's life cycle stages on a sample of the indicators that are found in the European standards for assessing the building's environmental quality. LCAbyg was devolped to be flexible and it can be used for new buildings and for refurbishment projects. The program shows the type of information that an LCA for a building contains, and the LCA results of a couple of typical Danish buildings (Birgisdóttir & Rasmussen 2016).

## 3.1.2 Design for Product-Life Extension

Product Life Extension is meant to increase the utilization period of products (Den Hollander & Bakker 2012). The product has to maintain product integrity or stay as close to its original state over time and suppress perceived reasons for obsolescence. According to Stahel (1998: p 29), the key to product life extension *"lies in the transformation of the actual linear production focused industrial economy into a utilization-focused service economy operating in loops"* (p. 29).

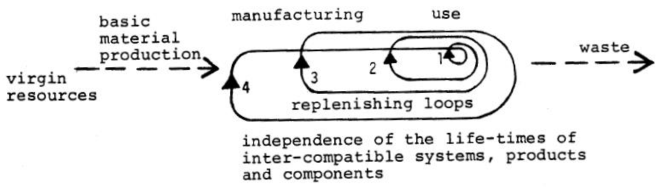


Fig 12. The Self-replenishing System (Product-Life Extension). Source: Stahel (1984)

Stahel (1984) defines a spiral loop system (Fig. 12) based in four levels of loops: the Re-use loop (1); Repair loop (2); Reconditioning loop (3) when used products are source for new ones; and Recycling loop (3). The effectiveness of this spiral loop system *" is greatly enhanced by a built-in inertia which keeps the loops as small as possible*" (Stahel 1984, p. 74). Moreover, will allow the "*independence of the life-times of inter-compatible systems, products and components*" (Stahel 1984, 74).

A central concept for product life extension is the product's lifespan. According to Bakker et al. (2014) this concept be can defined as "*the period from product acquisition to discarding of the product by the final owner"* (p.11). The lifespan period includes any repair, refurbishment, remanufacturing, and eventually periods of storage when the product is no longer in use (Bakker et al. 2014).

Also, important for product life extension is the consideration that a building is composition of different systems and products with different lifetimes.

Stewart Brand in his book "*How buildings learn*" (1994) argues that the answer to life extension of buildings lies in longevity of different building layers (Brand, 1994). He supports that any building is actually a hierarchy of pieces, each of which inherently changes at different rates.

Inspired by the British architect and historian F. Duffy's, he developed the Shearing-Layer Concept, and the model "Six S's", which refers to buildings as composed of several layer (Fig. 13).

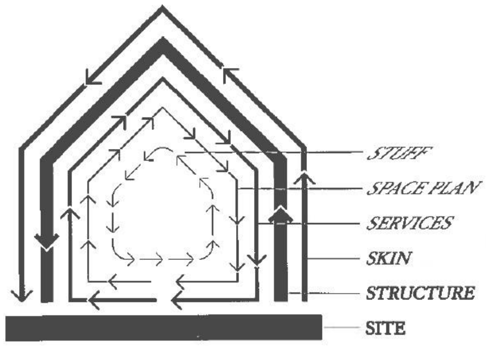


Fig. 13. Brand's layer diagram. Source: Brand (1994)

The *Site* is related to the geographical setting, urban location, and the legally defined lot whose boundaries and context outlast generations of ephemeral buildings ("*Site is eternal*"); the *Structure* It is related with foundation and load-bearing elements, and it is good for 30 to 300 years ("*but few buildings make it past 60, for other reasons*"); the *Skin* is related with exterior surfaces and it change every 20 years or so, to keep up with fashion or technology, or for wholesale repair (recent focus on energy costs has led to reengineered Skins that are air-tight and better insulated); the *Services* are the working guts of a building (wiring, plumbing, heating and cooling, sprinkler systems, kitchen appliances) and moving parts like elevators and escalators, and can change every seven to 15 years, perhaps faster in more technological settings; the *Space plan* is related to partitioning and pedestrian flow (walls, ceilings, floors, and doors), and changes every two or three years in offices and lasts perhaps 30 years in the most stable homes; and finally the innermost layer of *Stuff* that change continually and it is related to furnishings (chairs, desks, phones, pictures; kitchen appliances, lamps, hair brushes).

Over-connection between the different layers is considered only one flaw. Brand (1994) notes in the difficulty of modifying modern buildings. In this respect Kauschen (2012) argues that "*the independence of lifetimes of products is one of the major issues in todays' constructions, a fact that usually is not taken into account properly during the design stage* (p. 9). Kauschen stresses:

> "*If layers are interconnected, or worse, locked-in between other layers with longer lifetimes, the building will in effect be torn apart over its lifetime. This results in much higher renovation costs as layers (or components) are exchanged prematurely. Even more important than the initial higher costs are the increased environmental impacts due to the increased material input." (*Kauschen 2012, *p. 9).*

According to Bakker et al. (2014) design knowledge on product life extension strategies (longer product life, reparability, refurbishment and remanufacturing) and product recycling is currently underdeveloped. When it comes to buildings these strategies need to be tailored to the specific construction product and building elements hand with the generic waste management hierarchy (prevention, reuse, recycling) providing only limited guidance (Bakker et al. 2014).

### 3.1.3 Design for adaptability

The concept of adaptability refers to the capacity of buildings to accommodate effectively the evolving demands of its context thus maximizing it value across of their lifetime (Schmidt et al. 2010). When applied to a building or a construction product, adaptability means it will be utilized more efficiently and stay longer in service, because it can respond to changes at a lower cost (Moffatt & Russell 2001; CE Guide n.d).

For Moffatt & Russell (2001) the concept of adaptability can be subdivided into a number of simple strategies, that in practice can be achieved through changes in design, and through the use of alternative materials and technologies. These strategies include:

- Flexibility, or enabling minor shifts in space planning (the use of underused space, demountable partitions, and mobile or modular furnishings);
- Convertibility, or allowing for changes in use within the building;
- Expandability, (alternatively shrinkability) or facilitating additions to the quantity of space in a building.

According to Schmidt et al (2010) adaptability forces design to become an ongoing social process between designer and user over time. In this respect, they argue: "*adaptability as a design principle brings time and change to the forefront of thought, but requires a reconceptualization of time through shifting mindsets and (re)shaping of values"* (p.8).

### 3.1.4 Design for disassembly

Design for disassembly calls for the end-of-life options of how the product, components and materials can be deconstructed. Designing for disassembly can make easier for products to be repaired or upgraded, prolonging its useful life. It can also help ensure that a product is recycled and enables whole components to be reused. In fact, the degree to which your product can be disassembled easily often determines how the product will end its life (CE Guide n.d).

As in seen in previous sections of design for product life extension and design for adaptability, an understanding of time related building layers (see 3.3.2) is also relevant to design for disassembly. According to Crowther (2005) "*it is at the junctions of layers that disassembly will need to occur*" (p. 2). He supports that these junctions need to be designed to facilitate appropriate disassembly of building components with different service life expectance. Designing to facilitate disassembly, will then allow buildings to change over time (Crowther 2005).
A design for disassembly strategy can occur in many different ways. For Crowther (2005) there are a range of four possible end-of-life scenarios:

- Building reuse or relocation of whole building;
- Component reuse or relocation in a new building;
- Material reuse in the manufacture of new building components;
- Materials reprocessing into new building materials recycling (down cycling)

Although all these scenarios are theoretically possible, in practice some of them are more environmentally and socially desirable than others, or even economically feasible. The reuse of a building component has the added advantage of requiring less energy or new resource input than the recycling of base materials. Buildings should then be designed for the reuse of components rather than simply for recycling of materials. However, according to Crowther (2005) since the future reuse possibilities of a building cannot be accurately predicted decades before eventual disassembly, it will be advantageous for buildings to be designed.

Examples of design for Disassembly in Denmark are show in section 4.2.1.2.

### 3.1.5 Material passport

The material passport is a document consisting a set of data describing defined characteristics of all the materials that are included in a product or construction. The purpose of the passport is to generate value for recovery, recycling, and re-use by mapping all products and materials at various levels and making them available for the right parties and at the right time (EPEA n.d).

The core idea behind the concept is that the material passport will contribute to a "circular economy" in which materials that are being recovered, recycled and reused can be traded in an open market. The concept of the material passport is currently being developed by multiple parties in mainly European countries, aiming at contributing to a second-hand material market or material-bank in the future. In line with these objectives, in July 2013, the European Resource Efficiency Platform recommended '*product passports*' in its interim set of recommendations, among other measures (EMF 2014).

### 3.1.6 Upcycling of building components and materials

Upcycling is the opposite of downcycling, which is the other half of the recycling process. Downcycling involves the conversion of materials and products into new materials with lower quality. Upcycling reduces the consumption of raw materials and the embodied energy of creating new products.

The term upcycling was used firstly by Reiner Pilz, in 1994: "*I call it downcycling. They smash bricks, they smash everything. What we need is upcycling- where old products are given more value, not less*" (Alter 2013). The concept was later used by William McDonough and Michael Braungart in their *Cradle to Cradle: Remaking the Way We Make Things* (2002). They state that the goal of upcycling is to prevent wasting potentially useful materials by making use of existing ones. This allows to reduce the consumption raw materials to create new products.

Although the upcycling of building materials and products is not yet a common practice, the upcycling of building finishes, fixtures are becoming more popular. In Denmark is possible to acquire antique doors, windows, wood flooring and other building components through online stores such as Genbyg.DK., to transform into something that has even more value.

Lendager Group sees upcycling as the natural next step after the growing focus on the energy consumption of buildings in the operation phase. "*Upcycling describes the process whereby the value of materials increases through the recycling process, and ideally the resulting product has a longer life than the original"* (Lendager Group n.d).

## 3.2 Introduction to the Circle House

The Circle House is a demonstration project of circular housing. The project consists of the construction of 60 new dwellings by 2020, in Lisbjerg. The goal is that 90% of construction elements can be separated and reused without losing significant value, and that the square meter price may be within the limit determined for social housing (Lejerbo 2017a).

The Circle House project aims to develop and disseminate knowledge about circular building throughout the industry. The project brings together 30 different companies across the entire value chain of building sector. In terms of market the goal is to offer a list of solutions and products that used in all scales of construction. (Vandkunsten 2017s).

The project explores value chains, business models, business cases and framework conditions to identify where the chain or legislation is missing needs to be adapted to recycle the materials.

*Organisational structure*

Behind the project are a number of organizations such as: Lejerbo, a nonprofit social housing association; GXN, the Innovation Unit of 3XN Architects; Association for Building Society Social Responsibility (FBSA); MT Højgaard, and SBi at Aalborg University Copenhagen (Lejerbo 2017b).

The demonstration project is funded by the Danish Environmental Protection Agency Development Danish Environmental Protection Agency (DEPA) through the Danish Eco-Innovation Program (Miljøteknologiske Udviklings- og Demonstrationsprogram - MUDP), and by Realdania's Innovation Program in Construction (DanskArk 2017). The municipality of Aarhus contributes by providing an urban plot in Lisbjerg.

The project involves also major companies in the building industry from manufacturers, contractors and downhillers to engineers and architects, including Danish Concrete, Spæncom, Peikko, Kalk, Dovista, Velfac, Komproment, Rockwool, Cavarion, Gyproc, Tarkett, MT Højgaard, NCC Construction, Kingo Karlsen, Tscherning, RGS90, Orbicon. The architecture project is developed by Fællestegnestuen, a common architecture office that includes 3XN/GXN, Vandkunsten and Lendager Architects (Lejerbo 2017 c)

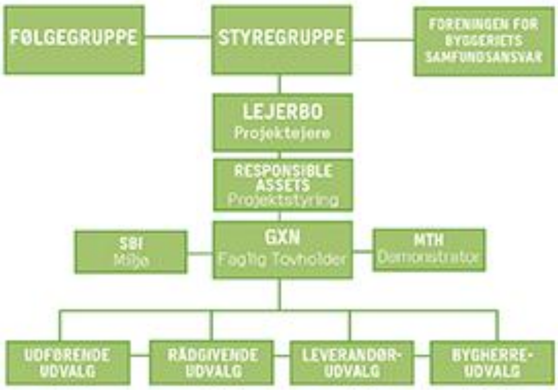


Fig.14. Circle house - Organization diagram (Source: Lejerbo 2017)

In the organizational structure of Circle House (Fig. 14 above), Lejerbo is the developer, Responsible Assets is the project manager, GXN is the technical and stakeholder conductor, SBi is the environment advisor, MT Højgaard is the demonstrator. Apart from these central elements in the organization, there are also four teams which are coordinated by GXN (advisory team, supplier team, executive team, and promotor team), and at the top the steering group, which is related to the monitoring team, and to the Association for Building Society Social Responsibility (FBSA).

*Location and master plan*

Lisbjerg is the largest urban development project in Aarhus. The location is in the middle of the countryside and at the same time is part of Aarhus (AK 2017).

The plan for Lisbjerg aims at creating an entirely new neighbourhood with room for up to 25,000 residents, where sustainability, architectural quality, and green spaces are the key factors to local quality of life (AK 2017). The area will have a direct light rail connection and new super bike path to downtown of Aarhus. The idea is to "*combine the original village communities with the city's diversity and urban life and combines the best of suburb and city*" (AK 2017).


Fig. 15. Circle House neighbourhood development (Source: Vandkusnten 2017s)

*Circular design concept*

The design concept adopted is design for disassemble and in principle of load bearing construction. The concrete structure consists of few elements that can be separated and reused in their complete existing form.

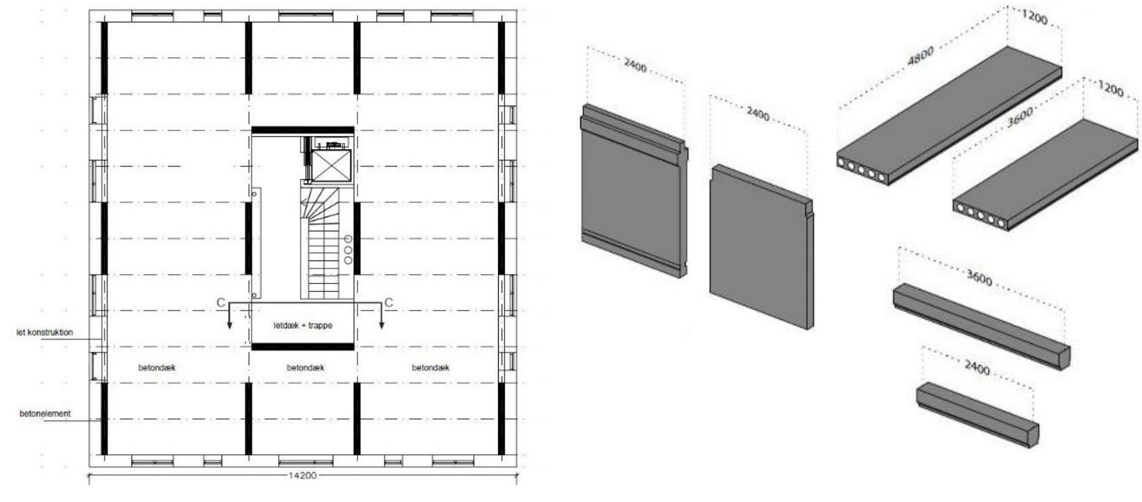


Fig. 16. Circle House. Plan of structure and concrete modules. The structural system consists in 3 module types with 2 sizes for type (structural walls, slabs and beams) (Source: Vandkusnten 2017s).

To prevent the breakthrough, spawning, and milling of concrete, the design is based in "soft" dots, which can be penetrated to install the wooden deck in the staircase, and wooden walls where installations placed in the apartments. (Vandkusnten 2017 s)

Fig. 17. Circle House. Façade study for three storey building (Height may vary from three to five storey). Façade elements and cladding in steel and wood.

Fig. 18. Circle House. Visualization of façade system- Beton element, thermic insolation element and wood cladding (Source: GXN 2017)

*Interior design*

The interior design of Circle House is characterized by visible and assembly details and plumbing installations, and electrical cables placed in the panels. All installations are placed in the staircase to facilitate maintenance, repairs, and replacement.

Surface treatments that are environmentally harmful or difficult to clean are tied up. "*It's a whole new aesthetic we must learn to love, a showdown with the Nordic tradition of clean lines and white faces*. (…) *But it is a necessary step towards a more sustainable building practice*" says Katrine West Kristensen, architect at Fallestegnestuen (Vandkunsten 2017 s).

Fig. 19. Circle House. Visualization of interior finishing materials. The wall finishing panels and beams are fixed to structural elements by screws and threads. Bolts and gaskets are made visible.

*Circular building principles and products life-span*

Essentially all elements and products in the Circle House must be able to separate from each other after use. Therefore, this is reflected in the order in which the parts of the building are installed. In accordance with the principles of design for Product-Life Extension (see 3.1.2) the materials with longest lifespan must be placed at internal layers of the shell and vice versa

The internal processes of design and construction of Circle House, including the visions, network of participants and the learning processes, are further analysed in the section 4.1.3.

# 4. Analysis and Discussion

This chapter aims to analyse and discuss the dynamics of changes in the building sector and the ways in which local initiatives based on circular design and construction can contribute to a transition towards the circular economy. The analysis section reports the findings of the study based on the methodology introduced in Chapter 2 to gather information. The analysis is also guided by the research questions introduced in Section 1.3. The discussion section interprets and describes the significance of the results presented in the previous section to explain new understandings and insights about the problem and, ultimately, answer the research question.

## 4.1 Analysis

The analysis is divided into two main sections. The first section analyses the building sector in terms of its different aspects, aiming to obtain a comprehensive understanding of its characteristics and dynamics of change. The analysis covers three historical periods, the contemporary 'regime'[4] with its local and global trends, and the barriers and drivers of change towards a circular building sector. The second section focuses on analysing the experimental activities from a niche perspective. Special emphasis is given to the illustrative case—the Circle House. The aim of this section is to understand the dynamics and interaction among these experimental initiatives and how they possibly contribute to a niche formation.

### 4.1.1 The Danish building regime

This section focuses on analysing the building sector through the lenses of MLP, aiming to understand the regime shifts and the dynamics of the building sector, including innovations, path dependencies, and transitions. First, a description of the mainstream building process practice is provided, aiming to introduce main activities, actors, and their interactions. Second, by considering an evolutionary perspective of the Danish building sector, the differences and similarities between historically distinct periods are analysed—including the building system dynamics and the main characteristics and dynamics of change. This section also introduces several societal and technological trends that may exert pressure on the existing regime. Finally, the barriers to the transition to a circular building sector and the drivers paving the way to this transition are both analysed.

#### 4.1.1.1 A building sector framework

The building sector consists of organizations and agents engaged in a heterogeneity of orders (e.g. construction, improvement, transformation, repair, maintenance and management, and demolishing) for a diversity of structures of built environment (e.g. dwellings, offices, shops, factories, schools, roads, bridges, tunnels, etc.). Carcassus (2004) defines the building sector:

> "*(...) the organised complex of commercial and non-commercial relationships, between productive and institutional actors, taking part in the production and the management of services provided by the structures used, throughout their life cycle, as the living and working environment of a population"* (p. 10).

The construction sector differs from other sectors in terms of both the complexity of its product and the involvement of an extensive range of stakeholders. Buildings have a long lifespan—usually more than 50 years—making it difficult to predict the entire lifecycle of a building. Moreover, buildings are subject to various alterations during their lifespan due to natural

[4] The contemporary status of the building sector does not show characteristics that allow calling it a regime. The least it can be called is an 'in flux' regime. Nevertheless, in order to make it easier to understand, I it call here the contemporary 'regime'.

occurrences or human use, but also due to deliberate changes that alter its function and form to a certain extent. The building industry has a complex stakeholder field with many players. Most businesses in the building industry in Denmark are SMEs and small companies, including craftsmen, contractors involved in building and construction, consultant companies, architects and engineers who use drawings and calculations to ensure that the building meets its performance expectations during its lifecycle. Furthermore, there are also material producers who produce and deliver the building materials and components and finally the actors who subsequently manage the operation and maintenance of the building (Smith Innovation 2016).

Data from Statistics Denmark show that the construction industry, excluding material producers, consisted of approx. 31,300 active companies employing 165,000 people (Statistics Denmark 2017). This fragmented structure implies that multiple companies frequently join together for the realization of building projects. This can occur through partnerships and subcontracting, in which the general contractor leads and coordinates the design and construction.

Due to the social implications of built environment structures, the sector system is mediated by a large number of institutional regulations, norms, and standards concerning the structures (building permits, construction codes, product and service certification), the firms (firm standards, labour management, prices), and the environment of the firms (procurement methods, funding, tax, R&D support, education and training). Also, they are defined and applied by a complex system of public (international, national, regional, local) and private institutions (industrial, unions, consumer organizations) (Carassus 2004).

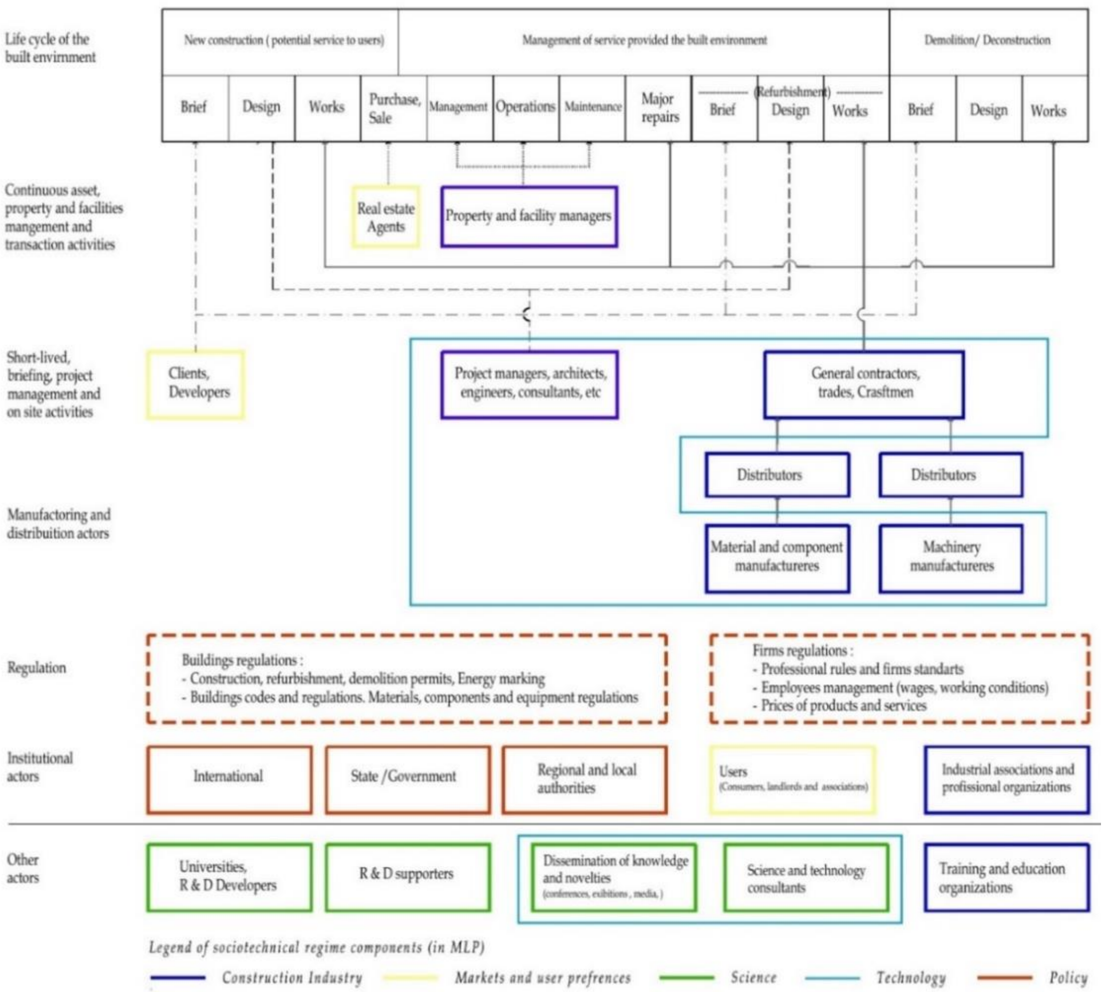


Fig. 20. A building sector framework of actors and processes. Adapted from Carcassus (2004) and Ruddock (2008).

The figure above (Fig. 20). shows an organizational chart of main actor and activities involved in the building sector's. This framework builds on this organizational model of construction sector as an economic system, as developed by Carassus (2004), as well as on the socio-technical regime model from MLP (Section 2.1.1)

This framework includes the groups of activities and actors involved in all the stages of a building lifecycle—from the short-lived activities to the continuous aspects of the building sector. It also provides an integration of these aspects into the building regime components, including the industry, markets, and the consumer preferences, science, and policies. The technology component has been also considered; however, it has not been attributed to only one specific group of activities and actors. The same applies to the culture component. Figure 8 sums up the main functions, regulations actors, and components considered in this building sector framework.

#### 4.1.1.2 Dynamics in the building regime

This section provides a long-term analysis of the dynamics of the building regime, focusing on key social dimensions of the regime, such as technology, industry, markets/customers, policy, culture, and research and education, in the premodern, modern, and postmodern periods, followed by insights into the current dynamics of the contemporary building 'regime'. The analysis is partly based on insights into the building sector development in Denmark provided by Kristiansen et al. (2005), Gottlieb (2010), Thuesen et al. (2011), and Jensen el al.( 2011).

**The premodern period**

This period extends approximately until World War II, and is characterized by a growing urbanization, a shortcoming of housing and the emergence of a dwelling market. This rapid increase urban population, is mainly related with the concentration of trade and manufacturing in cities. As an example, the city of Copenhagen, in the years 1850 to 1920, grew in population from app. 130.000 inhabitants to more than 550.000 inhabitants (Gotlieb 2010). The new citizens are represented by a homogeneous group stemming from the countryside without any specific requirements for living rather than a job and a place to live. This rapid growth gave rise to problems (e.g. sanitation, water supply and social related housing problems) and made necessary the development of a number of policies and laws (Gotlieb 2010). In order to address the growing demand for housing, five-storey buildings have been developed around the medieval center of cities, such as the example illustrated in Figure 21.

Fig 21. Examples of two types of buildings from premodern regime. On the left, the figure shows a type of building that is a direct continuation of the building type that developed in the densely populated cities from the 1700s. On the right, the figure shows a type of building that is common from the late 1800-1920. This building type differs from the previous by having main partitions and walls of solid masonry, internal double brick walls, iron beams, and

concrete casting in wheat areas. Both buildings are characterized by with a variety of materials and details carried out by craftsmen. (Source: danskebygningsmodeller n.d)

### *Configuration of premodern regime*

Based on the MLP conceptualization of regime research from Thuesen et al. (2011) the premodern regime configuration read as follows:

### *Technology*

The building sector developed around well proven technologies/materials such as wood, bricks, tiles, copper, and glass. This development of technologies and materials was initially driven by major buildings such as churches, and later applied to other building typologies. For example, bricks have already been used in the 15th century but only in a small percentage of residential buildings and with a level of quality not always high enough (Thuesen et a. 2011). Precisely due to this lack of quality, a group of architects began in 1915 a new period in the Danish construction called Better building practice (Benævnt Bedre byggeskik, in danish), which extended until 1965 (Thuesen et al 2011).

### *"Industry"*

During this period, there was not really a building industry in the current sense of the term. The building was realized by professional craft guilds (e.g masons, joiners, carpenters) which have created out to stabilize a precarious construction market and to enhance social coherence and political support (Yang 2008). These low power communities evolved over time to unions with a major power. So much that employers also began to organize themselves in employer associations.

### *Market / customers*

As cities expanded due to progressive urbanization, wood as the primary building material was replaced by brick. This structural and finishing material became more and more popular in city architecture, particularly in what we know today as "*brokvarterene"*, the neighborhoods located outside of the original medieval city (Thuesen et al. 2011). Buildings with brick facades are significant for city landscape in Denmark and continue have great acceptance in new buildings market.

### *Policy*

The guilds provided the first guidelines for all craftsmen to follow the rules, but they exercised only their influence within a discipline. Only later, in 1790, emerged a real state regulation when tendering was made statutory. However, it was only in 1915 that the first direct construction's regulation took place when the Ministry of Public Works issued the "*General Conditions for Work and Supplies*" that also included construction (Thuesen et al 2011).

### *Culture*

The culture here is essentially related to the building culture. This culture was based on oral transmission of technical knowledge and cultural values from experienced craftsman to apprentices.

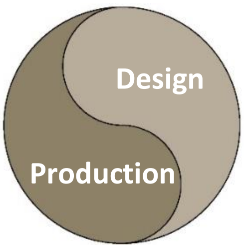


Fig. 22. Integration between design and production in pre-modern building. Source: Thuesen et al. (2011)

In the same way, experience and tradition were also crucial factors in terms of integration between design and execution. This integration was made possible by master artisans who had the power to design buildings (Thuesen 2017). They were responsible to drew up the main design based on the exact knowledge of the traditional methods, and using some few basic drawings showing plans, sections, and elevations. This drawing material was then given to craft masters who could carry out the work with methods that were used in all the building processes (Thuesen et al 2011). In this way, it was ensured that the design could be realized through traditional practices.

### *Research and education*

The codification of knowledge through drawings or descriptions played a minor role in this period. The interpretation of the sparse drawing material was made possible by a silent and embodied knowledge, anchored particularly in the form of rules of thumb (such as 2xtrin height + step length = 2 feet). According to Thuesen (2017) this knowledge is characterized by: "…*it is tacit, embodied, and thereby is not directly communicable*" (p. 6). The building knowledge was transferred from master to apprentice, and from design to production, through apprentice learning principles. Later, as better building skills were developed, best practices and solutions were then disseminated by all the technical community (Thuesen et al 2011).

## The modern period

The development of modern construction must be seen in the context of social changes occurred in the period of the post-war to the mid-70s. This period is characterized by high a high demand of housing due to the increasing relocation of population from countryside to cities. Thuessen (2017) found that: "*In 1945 the Ministry´s Committee on Construction estimated that in the period until 1976 was to be built 1,5 million dwellings, and assessment subsequently proved to be on the low side*" ( p. 6). However, this desperate need for new housing could not be solved through the existing building practice, mainly due to the lack of qualified craftsmen. There was thus a clear need to reconsider the construction technology, practices, and organization (Thuessen et al. 2011). The market need was then satisfied by the construction of multi-storey buildings with standardized homes in the suburbs of largest cities. The modern building was then enabled by construction niche technologies and materials such as concrete and steel, which "*had proved their durability in other markets like bridges, railways, port facilities and other major infrastructure projects*" (Thuesen 2017, p.6).

This period is also called" Montagebyggeri" or"utraditionel byggeri", which can be translated as "*prefabricated construction*" or "*non-traditional construction*" ( Kauschen 2012).

### *Configuration of modern regime*

The existence of a number of major societal challenges as well as a matured concrete technology, created the framework for a regime change in the building sector. According to Thuesen et al. (2011) the premises in period were: *"there were places to build, people to build and materials to build with"* (p.24).

### *Technology*

After the introduction of concrete in buildings, quickly it became an important material, if not the primary building material. However, changes were not jus at the material level but also the construction process.

Firstly, the standardization and modularization of construction components. In this period several subsystems of buildings were standardized such as concrete elements, and mechanical and electric installation components (Thuesen 2017). As a result, the focus in the construction practice changed from rules of thumb to precision, tolerances and measurements. (Thuesen et al. 2011).

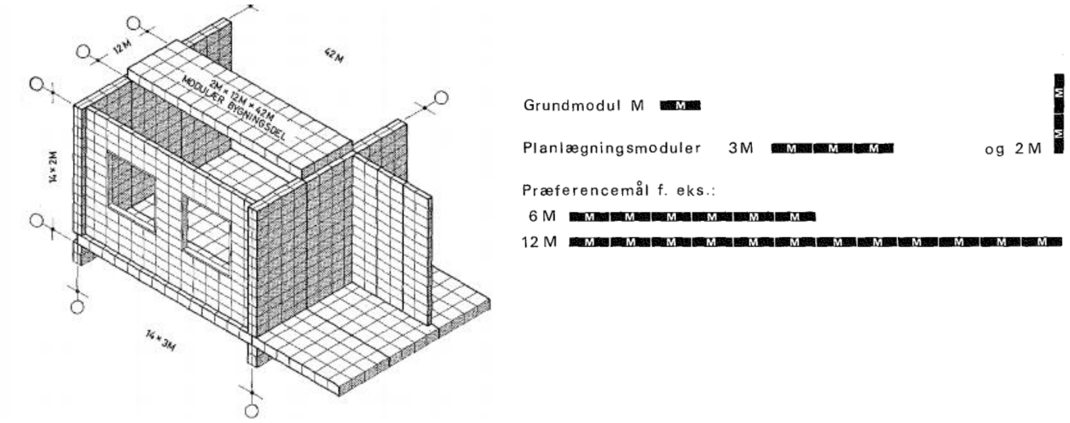


Fig 23. Example of module studies and construction assembly. On the left, the figure shows a drawing of model a housing module based on a system of modular parts. On the right, a scheme of basic module, planning module, and preferred dimensions, for dwellings (Source: Nissen (1975).

Secondly, the division between design and execution. This fundamental dissociation is symbolized by a phase model. It meant that drawings and documentation from playing a peripheral role in the pre-built building became important for communicating design decisions. All decisions about the design should then be taken in the design phase.

Finally, the industrialization of construction. This meant that the construction process became the subject of a mechanization (e.g. through the use of cranes). The cranes were necessary to mount the heavy concrete elements, but the consequence was that the design of houses was optimized in relation to the technological constraints of cranes. The result was that homes were designed to follow the traces of the crane – Crane track construction (Kransporsbyggerier, in Danish).

*Industry*

During this period, the organization of building industry underwent deep changes. As growing population in cities was largely unemployed they represented an unskilled resource. Thus, the large national contractors started employing on the basis of hourly paid work. The contractors were then the primary actors in the production of buildings, since they ensured a closed chain from the design and prefabrication of concrete elements until the assembly at the construction site. Central to address optimization and efficiency was the introduction of the planning engineer (Thuesen 2017). His role was to have a total overview of the building process, from design and prefabrication to the final assemblage. Hence, from being craft oriented the industry became science based.

*Market / customers*

Like in former regime the market in this period was for growing population in cities, however this time in much larger scale. According to Thuesen (2017), in 1945 the Interior Ministry's Construction Committee estimated that in the period up to 1976, 1.5 million homes should be built, an assessment that subsequently proved to be lower than demand.

*Policy*

The driver of development of modern construction practices was the state intervention in the building sector (Thuesen 2017). It started in 1947 with the creation of the first ministry Construction and Housing. Through a long series of laws and regulations, the ministry developed the government housing strategy and enforced the with industry. An example of this government policies is the "*Fast tid/pris cirkulæret*" ("Fixed Time / Price Circular), in 1960, which introduced key contract form for modern construction (Thuesen 2011)

Fig 24. Examples of buildings and new residential complexes developed on the outskirts of the Danish cities during the modern regime. On the left, Bellahøjhusene, by Kristensen, Heiberg, Buhl, Larsen, Fink and Petersen, 1951-1956. On the right, Høje Gladssaxe, by Hoof and Windinge, 1964 (Source: arkitekturbilleder.dk n.d)

### *Culture*

Cultural changes have also occurred in this period. In architecture and design the modern movement introduced, for example, the principle of "average men" (Corbusier's "le modulor" is the emblematic figure), that eventually became an imposition of a single model of Man. This design principle enabled the standardization of housing to work as a machine for the satisfaction of general human needs and to be produced massively. The industrialization of construction was introduced in the early 1920' by architects such as Walter Gropius, who advocate standardization in architecture, and mass construction of "*rationality-designed*" apartment blocks for factory workers (Giedion, 1956). This helped to develop the "myth" that standardized construction is a transparent process which make possible to plan the construction in detail from start to finish (Thuesen 2017). Although in this building process, design and production became separated in clearly distinct phases, as illustrated in the figure below (Thuesen 2011).

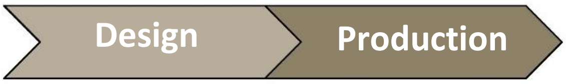


Fig 25 . Separation between design and production in modern building. Source Thuesen et al. (2011)

### *Research and education*

The development of the modern construction was driven by a scientific building construction. Thus, the system should be supported through research and training of architects and engineers based on academic and theoretical education. For this purpose, the State Building Research Institute (SBi) was established.

## The postmodern period

After the modern building system have solved the shortcoming of housing apparently, in the early 1970's, there was no central problem to be solved (Thuesen et al. 2011). Moreover, the dictates of costs and efficiency (particularly important in periods of masses of affluent populations to cities), coupled with organizational and technological constraints began to play a minor role (Harvey 1990). However, the oil crisis in 1973 introduced the challenge of reduction of energy consumption in buildings. At the same time grassroots started to challenge the modern practices of standardization and assembly-line uniformity (Thuesen 2017)

| Modern social trends | Postmodern social trends |
|---|---|
| Expansive economy (continuous growth periods) | Contractive economy (frequent crises) |
| Keynesianism, subvention economy | Neo-liberalism, market as driving force |
| Active, radical state intervention | Re-active, adaptive state intervention |
| National regulation frameworks | National deregulation, globalisation |
| Scarcity of skilled manpower resources | Scarcity of natural resources |
| Fulfilment of basic social and material needs | Fulfilment of spiritual demands |
| Industrialisation as mass production | Consumer oriented production, service society |
| Collectivism, conformity | Individualism, flexibility |

Table 1: Key social trends that set the framework for the transition from modern to postmodern construction- Adapted Thuesen et al. (2011).

Although the aforementioned trends help to establish the framework of postmodern socio-technical regime, it is however important to highlight the emergence of individualism as key tendency. If in the modern period the engine of identity was collectivism and uniformity, later it was replaced by individualism and flexibility. The flourishing of individualism was also seen in the building sector, particularly in the wake of the May 68-uprising[6], when various grassroots emerged for a variety of types of accommodation facilities. The consequence was "*that there was no longer 'a' market for standardized construction, but a change in preferences because the majority wanted to put their own stamp on their homes* "(Thuesen et al 2011, p. 29).

This social flow had repercussions also in architecture as the ideas of CIAM, Le Corbusier, and other apostles of 'high modernism', increasingly gave way before an offensive of a variety of possibilities, such as those presented the influential "Learning from Las Vegas" by Robert Venturi, Denise Scott Brown, and Steven Izenour (1972). The point of this book and many other emerging books and journals in the 1970s was that architects had more to learn from the study of popular, vernacular, and historical landscapes than from the search for abstract, theoretical, and doctrinal ideals (Harvey 1990). In this new cultural flow, the architectural practices were focused on design context-dependent and individual buildings and urban spaces, as well as in the restoration of older urban fabric and its rehabilitation to new uses (Thuesen et al 2011; Harvey 1990).

However, the disintegration of rationalization, which has been the main characteristic of modern regime, did not generate immediate alternatives to establish an alternative building sector (Jensen et al. 2011).

### *Configuration of postmodern regime*

In the following we will look at the configuration of postmodern building regime that starts approximately in the 1970s:

### *Technology*

On the technological front, the postmodern building is characterized by an enormous diversity of new building materials and technical complexity either to meet the demand for unique wishes from customers, or to lower the energy consumption (Thuesen 2017). One of the strategies for dealing with complexity of solutions has been the adoption of information technology, especially programs such as CAD for design, and Project Web for planning. But also, social techniques and

[6] The uprising of May 1968- a student revolt that began in a suburb of Paris- is usually used as the event that marks the beginning of end of post-war order and initiates a transformation of society, in Europe and elsewhere.

approaches around new forms of governance, cooperation and negotiation to deal with the complexity of planning processes (Gotlieb 2010).

During this period initial steps have been taken to promote recycling and cleaner technology in the building and construction sector. The technological development focused on new methods of degradation of buildings and facilities for the recycling of construction waste as well as the development of source separation systems, which later became characterized as selective demolition (DEPA 2017).

### *Industry*

The industry organization has also undergone changes in the postmodern period, particularly due to new roles in construction such as client advisers. Unlike the modern construction, in which contractors had direct contact with the developer, the contractors in the postmodern regime rarely have contact with the main customer. This role is taken primarily by the architect, or client advisers, who help the customer to identify his needs (Thuesen 2017).

The consequences of this developments have also been felt within major contractor companies. Contractors such as Rasmussen & Schiøtz which integrated a substantial part of building value chain became under pressure and ended up selling their material-producing sections. Also, companies like NCC and Skanska have been acquired by larger international contracting groups. As a result, building industry today is characterized by having a fragmented value chain (Thuesen et al 2011).

Conversely, for companies providing energy efficient solutions, the consequence was a consistent growth and their internationalization, so that companies like Rockwool and Velux are worldwide companies employing more than 10.000 people (Thuesen 2017).

The internationalization has also undergone consultant companies and architects which started orienting the practice towards international competitions and opening offices abroad (Thuesen et al 2011).

### *Market/ Customers*

The postmodern market is based on a wide variation of typologies and scales of buildings and characterized by being heterogeneously affected by major cyclical economic fluctuations (Thuesen et al 2011).


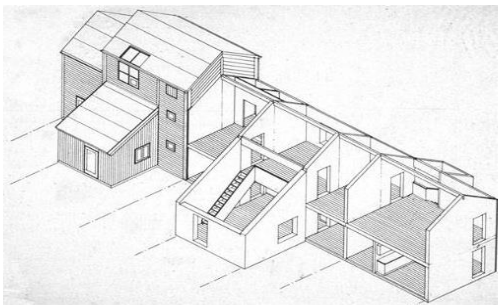

Fig 26. Example housing buildings diversity in the postmodern regime. The figure shows a builging façade and an theTinggården, in Herfølge, from 1978. The project by Vandkunsten tegnstuen, is general housing experiment. (Source: arkitekturbilleder.dk n.d)

### *Policy*

After meeting the social need to address a large unemployment of unskilled people and providing housing for growing urban populations, the housing industry was no longer a key social tool (Thuesen 2017). This meant that efforts to regulate industry should be focused on the entire building industry and not just on the housing construction industry. Based on studies in the 1990s showing that building industry became a business sector with low productivity compared with other industries, the government developed initiatives focusing on improving productivity (Thuesen 2017).

This development also had organizational consequences. From having been a ministry with a strong social agenda on modern building, the housing ministry was successively losing its relevance and ended up closing in 2001. The new regulatory agendas for energy efficiency and resource development continued in the Erhvervs og Byggestyrelsen (EBST) (Danish Enterprise and Construction Agency) (Thuesen et al. 2017).

*Culture*

The concepts of individuality and exclusivity has played central roles in building culture in postmodern regime. As afore mentioned architecture shifted from the rationality principles of modernism, which meant focusing on imagination rather than function. The consequence has been that architects and designers were rather more interested in constantly explore new architectural possibilities than in buildings functionality performance. To handle the key challenge of complexity of postmodern building new professions were introduced, and also new technologies. As a result, the design process and the production process were successively blown away (Thuesen et al. 2007)

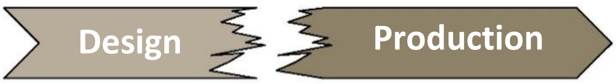


Fig. 27. Full separation between design and production in postmodern building. Source Thuesen et al. (2011)

*Research and education*

Postmodern construction also demands new skills in construction. While the modern construction 'scientified' the building on the basis of knowledge on statics and material strength, and scientific management, the postmodern demanded the ability to control and navigate in the "chaotic" / complex design and construction process. This has resulted in new developments for knowledge on building physics and project management replacing scientific Management as management philosophy (Thuesen et al. 2011). The development has continued in this direction with the focus on realizing the unique buildings through cooperation and negotiation (Thuesen et al. 2011)

At the same time, the role of the knowledge institutions as policy advisors has changed as part of university reform. The research sector was then included in the university system, e.g. SBi was merged with Aalborg University (Thuesen et al. 2011).

## Dynamics in contemporary building sector

Throughout the previous sections we have seen the dynamics of building sector and reconfigurations changes from one regime to the other, as responses to major societal changes and challenges in the different regime areas (i.e. MLP regime components). Although the dynamics of the current regime are resulting from to the prevalence of previous regimes (e.g. craftsmen, and bricks, prefabrication), they are due also and to emerging features at the local level and global trends and social flows exerted from the landscape.

This section presents the analyses of the internal dynamics at the regime level in its different aspects, and the pressures exerted by the social flows and trends (landscape level) over the building sector.

## 1- Configuration of contemporary regime:

### *Technology*

The need to improve productivity in the building industry and reduce waste, and the continued demand for customized products, are gradually leading to the emergence of innovative building technologies and management and software tools such as Lean construction and Building Information Modelling (BIM), among others.

In 1999, under the governmental programme Project House, the Danish building sector became aware of the work within the Lean Construction network. The main challenge of Project House in the industry was to produce double value for half the cost over the next 10 years—an objective quite close to the objective set in Lean Construction by Lauri Koskela (2000): Maximize value and minimize waste.

### *Industry*

Until the mid-1990s, subcontracting was a widespread practice. However, this practice gradually began to change as the large Danish contractors (defined as having more than 500 employees) grew at the expense of their medium-sized competitors (defined as having 100–500 employees), and also through the purchase of installation firms, building material, carpentry firms, and other trades/crafts (Kristiansen et al. 2005). A good example is MT Højgaard, the largest Danish-owned contracting company, which grew through a process of mergers and acquisitions. This concentration process also led the big Swedish contractors Skanska and NCC to acquire into the Danish market by purchasing existing contractors. This growth process—often called 'nordification'—was followed by the adoption of new strategies, ranging from more aggressive marketing to the adoption of management innovations such as lean construction and partnering (Kristiansen et al. 2005). In addition, the market leaders developed strategies and actions to control the whole value chain: : "*The subsidiaries of the two Swedish multinationals and the largest Danish company use the strategy of having in-house control of the whole process, from buying up land to renting out the building"* (Lubansky 2003, p.92) .

These changes represented a challenge for the smaller firms operating in the sector. According to Kristiansen et al. (2005), small construction firms that survived had given up the normal contracting role and were trying to specialize and improve their competences to be accepted as partners by the large contractors (e.g. some small contractor firms became specialist sub-contractors and installers of products from major producers for the large contractors).

Changes also occurred on the manufacturers side. On the one hand, there were changes at the level of small producers of building materials that opted for specialization—some of them decided to produce only one product such as staircases, doors, etc. On the other hand, there were changes at the level of major manufacturers aiming to increase the integration of value chain. As described by the Building Sector Development Council (Byggeeriets Udviklingsråd, or BUR), several of the large manufacturers of building materials began working together with engineers and architects in order to deliver more complete solutions such as roofs (instead of roof cladding materials), facade solutions (instead of windows), and complete house structures/systems (instead of concrete components): '*essentially a package approach based on strategic alliancing*' (Kristiansen et al. 2005, p. 507).

In this context, two aspects are commonly mentioned as characteristics of the current building industry:

a) an atomized value chain in which consultants and wholesalers represent a large part of the sector (Delloite 2013)

b) a division of labour between the contractors and subcontractors, which leads to a loss of productivity, despite an effective training system (Lubanski 2003)

According to Lubanski (2003) the lack of productivity and industrialization are dominant themes since the 1990s reflecting an international trend of criticizing construction activity for not following the modernization of other industries such cars or computers.


Fig 28. Labor productivity by industry, unit cost, and time (index 1966=100, 1966-price level chian figures). Source: Statistics Bank NATP 23 and Kristiansen et al. (2005)

The diagram above shows how productivity in the construction industry has declined and stagnated since the late 1980s until 2011, thus moving away from the growth trends of the Danish industry and economy.

This period coincides with the postmodern period and the international economic crisis, in which housing production went down and the demand changed towards variation and customized products (e.g. distinctive architecture, function, quality, timeframe, and environment), making it difficult to reconcile with traditional industrialization (standardization, mass production). Moreover, during this period, there was an increase in building repair, renovation, and maintenance (Nielsen et al. 2017).

In addition, changes in regulations related to CDW have led the industry to develop new practices and processes. Selective demolition—despite being more expensive and time-consuming than traditional demolition methods—has become an established practice, creating thereby new business models. Recycled materials such as crushed tiles, concrete, and asphalt, which are the largest fractions of construction and demolition waste, are seen as products with several uses in the construction sector (Montecinos & Holda 2006). As in Denmark, there is no outlet for reprocessed construction and demolition waste; generally, the marketing of recyclable construction and demolition waste is done by demolition contractors (Montecinos & Holda 2006).

Various actors in the building industry, such as architects, engineers, consultants, and manufacturers, have been gradually raising awareness about sustainability and sustainable construction; practices oriented towards developing sustainable solutions have been increasing in recent years. Apart from various dissemination events (e.g. conferences, exhibitions, seminars, fairs, etc.), professional associations like Foreningen for Byggeriets Samfundsansvar (Danish Association of Construction), FRI (the Danish Association of Consulting Engineers), and Danskark (Danish Association of Architectural Firms) are also conducting activities to raise awareness about sustainability and rebuild the skills of their members.

*Market/ Customers*

The main current market segments that can be distinguished in the building sector include new construction of residential and non-residential buildings and repair/renovation or maintenance of buildings. Although the market for new buildings continues to have a considerable weight within the Danish building sector, the demand has decreased significantly in last decade. In contrast, the renovation and maintenance markets have undergone a slight but consistent growth.

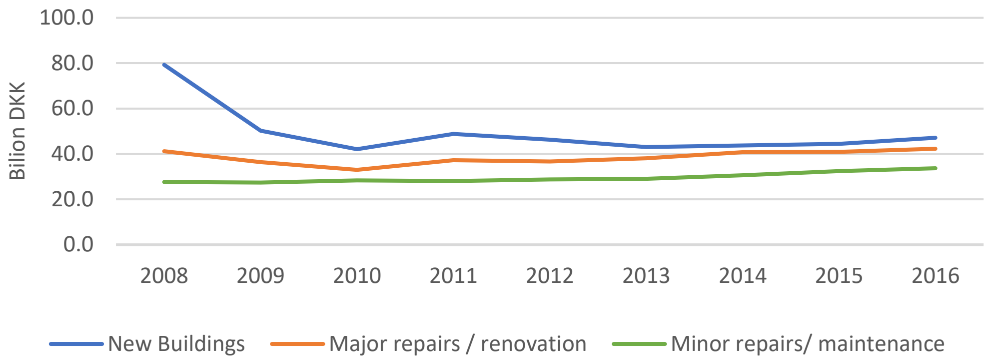


Fig. 29: Production value in the construction sector, 2008-2017,in billion DKK. Adapted from Statistics Denmark and Dansk Byggeri, (2016)

The graph above shows that the production value of new buildings had a sharp decrease between 2008 and 2010 and has remained relatively stable since then. At the level of major repairs or renovation and maintenance or minor repair, despite a slight decrease in 2010, the tendency has been one of consistent growth. Through the economic crisis years (from late 2008 to 2013 approx.), the construction of public buildings has helped to keep the new construction sector stable (Dansk Byggeri 2016). After 2013, the construction of private buildings returned to a growth trajectory, which is expected to continue in the next few years. This trend is closely followed by an increase in the renovation or repairs of existing buildings (Dansk Byggeri 2016).

According to the data from Statistics Denmark (….), housing construction has faced substantial fluctuations since the 1990s, in detached houses, semidetached houses, and multi-dwelling houses. The maximum values of housing construction or renovation were achieved in 2006 and the minimum in 2009, when the economic crisis had its greatest impact. However, after this period, not all types of private housing have had the same recovery trajectories. While detached houses and semidetached houses remained essentially unchanged after the crisis, the sector of multi-dwelling buildings has been growing consistently in recent years and is expected to continue to grow.

Along with the growing demand for sustainable neighbourhoods and sustainable construction, property developers and pension funds are reorienting their strategies and business models in order to optimize their construction and building portfolio for the demand of future tenants and investors for sustainable buildings and operations (Ejendomsforeningen Danmark 2017). Most of these market operators have begun to feel the global trend for sustainable buildings and its potential social economic and environmental benefits, such as:

> "*better indoor climate and work environment, which increases health, well-being and productivity,* [and]*create value in relation to the company's CSR policy and objectives, such as less environmental impacts in energy and waste that reduce CO2 emissions."* (PensionDnnamark, parag. 5)

In this context, investors are also raising awareness about the advantages of value creation by sustainability certification systems such as DGNB, BREEAM, or LEED (Ejendomsforeningen Danmark 2017). While certified green buildings are usually rewarded with positive sale and rental trends, brown discounts are emerging for non-certified properties (Allianz 2015)

### *Policy*

In the last two decades, several policies have contributed to the creation of new dynamics in the building sector. These include policies aiming to increase quality and productivity in the sector, as well as policies predominantly related to changes in production and sustainable development.

In relation to productivity, the government's Building Action 1998 aimed to improve quality and productivity in the building industry through the development of new and more flexible forms of cooperation, thus contributing to improve the organization and management of the building process (Lubanski, 2003).

Reducing energy consumption through increased energy efficiency and energy savings has been a priority in Denmark since the wake of the oil crises in the 1970s and is still an important part of the Danish energy policy. In recent decades, the climate dimension was added to this area as a response to the global high emission levels of greenhouse gases, which cause global climate change.

The Danish Government has a long-term objective of being free of fossil fuels by 2050; a crucial element in this objective is to improve energy efficiency. In 2012, the Danish energy agreement established that gross energy consumption in 2020 will be reduced by 12% compared to 2006. It also emphasizes energy renovation of existing buildings and energy-saving by energy companies as the two primary national instruments to drive energy efficiency (DEA 2016)

Following the EU's Buildings directive, the energy requirements for new buildings have been strengthened considerably the last two decades These building codes are strong instruments to promote innovation and low-energy usage in new buildings and component renovation in existing buildings (DEA 2016).

In regard to energy-saving in existing buildings, energy labelling was implemented by government and introduced into Danish law. The purpose is to make the energy specifications of buildings visible for owners and buyers and indicate the potential energy reduction. In addition, the Danish Government, in May 2014, adopted a strategy for the energy renovation of buildings, containing a set of initiatives to promote the renovation of the Danish building stocks and to ensure that energy efficiency measures are implemented. The strategy includes, among others, the following initiatives:

> "*Revision and upgrade of building regulations and energy requirements* [...] *New requirements to the energy efficiency of windows* [...] *Revision of the energy certificates scheme to improve the efficiency of the scheme* [...] *Measures to improve professional training to craftsmen and engineers in the building sector* (DEA 2016, p16).

As the building sector is considered by the government to have a huge potential in terms of the fulfilment of climate goals, political initiatives have been taken to reduce waste and resource consumption and to promote sustainable construction (DenOffentlige 2014). A first step, according to the Climate, Energy, and Building Minister, Rasmus Helveg Petersen, is a voluntary sustainability class "(...) *to give the entire construction sector a common understanding of when a building is sustainable. At the same time, the initiative will inspire the industry to build more sustainable in the future*"(DenOffentlige 2014, para. 2). Although today, in Denmark, there is a private certification scheme to ensure sustainable buildings and construction, the DGNB assessment system, according to government construction industry actors, has also demanded a more official definition of sustainability, which would facilitate the various actors in the construction industry (DenOffentlige 2014). In 2014, the Minister for Climate, Energy, and Building presented his initiative regarding the voluntary sustainability classes for the building sector as part of the government's overall construction policy strategy. This initiative has also been developed by representatives from the Ministry of Environment and the Ministry of Urban, Rural, and Rural Affairs, as well as representatives of the industry and relevant knowledge institutions.

Construction and demolition waste (CDW) was identified as a priority in the Danish government's policies on waste in the 1990s. The first national Danish Waste Plan 1993–1997 targeted substantial reduction of landfills, maintenance of incineration levels, and an increase in recycling (DEPA n.d). Since then, several policies have been developed to reduce incineration and waste. In 2015, two new strategies were adopted to cover waste management with emphasis on increased recycling and the efficient use of resources: '*Denmark Without Waste—Recycle More, Incinerate Less*', and '*Denmark Without Waste II—Strategy for Waste Prevention*'. The waste prevention strategy (Denmark Without Waste II) focuses on increased resource efficiency in companies in general and has a focus on construction waste, among other waste streams. This strategy emphasizes the essential role of collaboration for the optimal utilization of resources in the construction sector, the need for changing from energy optimization to resource optimization, and attractive solutions in terms of material costs (DG 2016). This strategy constitutes the first decisive step in the transition policies towards resource efficiency, and is further analysed.

### *Culture*

The cultural organization of the building sector is based on professions that are sustained by differentiated education institutions and apprenticeship learning processes (e.g. crafts) (Thuesen & Koch 2011a). At the same time, the building industry is characterized by a fragmented value chain and a strong separation between design and production, favouring the development of a silo culture (Billman 2015). In this long-established silo culture (i.e. professional silos, timeline silos, and languages) architects, engineers, consultants, suppliers, contractors, and other players operate in relatively autonomous environments and engage to provide what they think is the best for their clients, and in doing so, to protect their own interests (Billman 2015). However, there is an emerging rhetoric in the building sector for a break away from these silos and a future development of the sector that is more focused on collaboration. According to Billman (2015), the rationales for this emerging collaboration culture in the building sector are based on the following aspects:

- Productivity and competitiveness

  Transition from low to high productivity generates positive social and economic impacts.

  Increased competitiveness in the building sector maintains the Danish construction industry on the edge of international scene.

- Technological change

  Technological change (e.g. 3D building design and simulation tools) has positive impacts on both product and processes and provide platforms for decision-making.

  Unique solutions can be avoided in areas where tried and tested solutions already exist.

- Sustainability

  Implementation of sustainability visions and long-term solutions involve extensive stakeholder participation since early stages of building process.

However, this new culture of collaboration faces several challenges posed by the existing silo culture and trade-off.

### *Research and education*

The organization and division of labour in the building sector are reflected in the Danish educational system, which varies from the tacit and embodied cultural knowledge situated in crafts (which currently includes training in the vocational educational system) to the explicit and scientific knowledge of the academic professions (Thuesen & Koch 2011a). There are a large number of education programmes in the building sector (Delloite 2013):

- Vocational training: consists of a basic and a main training course for crafts (e.g. education in building electrical and plumbing area).
- Professional academy: aims to train experts such as specialized installers, construction technicians, and energy technicians.
- Higher education: include areas such as civil engineering and architectural education. The education programme consists of a three-year bachelor's degree and a two-year master's degree programme and is offered at most of the country's universities.
- Continuing education: the purpose is to develop staff skills to match the demands of a changeable labour market. The programmes are offered under the auspices of the labour market education—AMU.

Executive research in Building and Construction takes place mainly in nine universities and research institutions, including the Danish Building Research Institute (SBi), Technological Institute, Aalborg University (AAU), Danish Technical University (DTU), Copenhagen Business School (CBS), Copenhagen University (KU), Roskilde University (RUC), the Royal Academy of Fine Arts (KADK), and Aarhus University. Apart from this, research is carried out in private firms, such as consulting and architecture firms, contractors, developers, etc. (NORDEN 2007).

Although there are different research agendas among the research institutions, in general they are integrated into the Structure of Danish Research and Innovation. The government strategy, launched in 2012, 'Denmark—*a Nation of Innovation*', focuses on societal instead of technological challenge areas. The idea is that '*this will kick-start the demand for new solutions and thereby drive innovation*' (ICDK 2015, p. 3). In this context, there are several programmes and initiatives, as well as innovation networks and clusters related to the building sector, of which it is possible select the following: Innovation Network—InnoBYG, Innovation Network for Environmental Technology—InnoMT, Danish Material Network—DmnNET, and Innovation Network for Climate/Sustainability—Vandibyer.

Among the diversity of building and construction research topics, there is, however, a wide range that is part of government's long-term goal to make Denmark independent of fossil fuel supply by 2050—particularly with two major societal challenges (MER 2016):

1. Reducing energy consumption in existing and new buildings to meet energy supply based on renewable energy.
2. Achieving an effective interaction between buildings and the energy system.

In addition, there are also a number of research programmes related to sustainable buildings, as well as specific technological R&D programmes such as building process and innovation (SBi), certification (SBi), indoor health impacts (SBi), universal design an accessibility (SBi), BIM (DTU), new materials and structural elements (e.g. DTU´s programmes *Zero Waste Byg and Sustainable Light Concrete Structures),* sustainable building heritage (KADK), architecture and mass customization (KADK/CINARK), and use of robotics in buildings manufacturing (KADK).

For a summary of the various aforementioned aspects to describe the configuration of contemporary building sector, see Table 2.

| Dimensions | Pre-modern regime | Modern regime | Postmodern regime | Contemporary regime |
|---|---|---|---|---|
| *Technology* | • Bricks, wood | • Concrete elements, glass<br>• Prefabrication<br>• Mechanization<br>• Detailed drawings, phase models, and documents<br>• Standardization | • Diversity of materials and building systems<br>• Insulation materials, double glazed windows for energy efficiency<br>• Complex construction systems<br>• CAD and ProjectWeb<br>• Scheduling and collaboration technics | • Technologies to improve productivity and reduce waste.<br>• Lean construction<br>• BIM |
| *Industry* | • Craftsmen and guilds<br>• Unions and Employers associations | • Large contractor companies<br>• Industrialization of production. Concrete components and other building materials<br>• Mechanization | • Fragmented value chain<br>• Emergence of manufacturing companies for diversity of materials and products<br>• Energy efficiency oriented products<br>• Relation with the client – Through advisor or the architect | • Atomized value chain- consultants and wholesalers are the major part of the sector.<br>• Specialised manufacturers to deliver complete solutions (e.g. roof solutions)<br>• Division of labour between contractors and specialized subcontractors<br>• Lack of productivity<br>• Selective demolition and CDW management.<br>• Recycled materials (e.g Downcycling of tiles, bricks, concrete)<br>• Emerging awareness of sustainability dimensions (eg. Architects, engineers and consultants) |
| *Market/ Customers* | • Mainly private investment. | | • Demand driven<br>• Heterogeneous<br>• Cyclical<br>• Market niches (e.g. eco-houses and eco-villges) | • Market segments:<br>○ slight increase of new buildings; continuing increase of renovation/ repairs and maintenance.<br>○ Decrease of detached houses; growth of multi-dwelling buildings<br>• Growing demand for sustainable neighbourhoods and buildings<br>• Raising awareness of investors of advantages of sustainability certification systems |
| *Policy* | • "*General Conditions for Works and deliveries*", types of contracts, tender models | • Building as a resource area, governed by framework conditions and common standards | • Initiatives focusing on improving productivity<br>• Development based on interaction between the construction partners<br>• Regulatory agendas for energy efficiency and resource development<br>• EBST (Danish Enterprise and Construction Agency) | • Policies to:<br>○ Increase productivity and quality in industry<br>○ Energy efficiency in building environment. Energy labelling and new regulations<br>○ Climate change agenda. Sustainable buildings and construction<br>○ CDW management. Increase of recycling and Waste prevention<br>○ Support of demonstration projects of eco-solutions (MUDP) |
| Culture | • Craftsmanship and masterpieces processes<br>• Brick facades<br>• Five storey buildings (city landscape) | • Science and technology supporting social and economic development.<br>• Standardization | • Plurality/ Diversity/ Innovation<br>• Fragmentation (e.g, design and production)<br>• Context integration (local, historical and vernacular)<br>• Respect to patterns of consumption and labour market<br>• Awake to Earth limits (resources and emissions).<br>• Specialization (new professions)<br>• Emerging network culture (cooperation) | • Professional "silos" and fragmented value chain.<br>• Continued strong separation between design and production<br>• Emerging rhetoric for the need of more collaboration to:<br>○ Productivity and competitiveness<br>○ Technological change<br>○ Sustainability |
| *Research and education* | • Silent and bodily knowledge<br>• Rules of thumb | • National building research (SBi)<br>• Scientific and technological education (Architecture, building physics, and scientific management) | • Scientific and technological education to elaborate, control and navigate complex and unique design and construction processes.<br>• Project management studies oriented cooperation and negotiation | • Education based on: Vocational training; Professional Academy; Higher education; Continuing education<br>• Research in building and construction: 9 Universities, SBi, Technological Institute, CINARK.<br>• Knowledge transfer through innovation networks: InnoBYG,, InnoMT, DmnNET,Vandibyer. |

Table 2. Summary of contemporary building regime. Some aspects of past regimes prevail, and new elements emerge as a result of contemporary tendencies.

2- Global social flows and trends:

The global social flows and trends constitute the external context that exerts influence on the building sector and enables and constrains the possibilities for regime change. This corresponds to the driving forces situated at the landscape level, as mentioned in Section 2.1.1. The analysis is based on a qualitative collection of ongoing trends that seem to have the greatest impact on the building sector (Results from Trends and Technology Timeline 2010+ (….) Debacker et al. (2016) Buildings Performance Institute Europe (BPIE 2016) and sources referred in Section 1.1). Table 3 summarizes the global trends and social flow in four dimensions—society, sustainability, globalization, and technology.

| **Dimensions** | **Global trends and social flows** | |
|---|---|---|
| *Society* | • Continued world population growth<br>• Increase of urban population<br>• Individualization of building<br>• Dissemination of social media<br>• Sharing of assets and services | • Need for affordable housing globally<br>• Dwellings for elderly people<br>• Increase of small and blended families<br>• Building vacancy (market changes) |
| *Sustainability* | • Climate change<br>• Renewable energies<br>• Reduction of GHG emission<br>• Changes in consumer patterns | • Shortage of natural resources<br>• New eco materials and solutions<br>• Downcycling<br>• **Circular economy** |
| *Globalization* | • Global markets<br>• Global trends | • Global competition<br>• International standards |
| *Technology* | • Digitalization of design and construction processes (e.g. Building information modelling – BIM; Virtual design construction – VDC)<br>• Smart buildings and robot management | • Robot management<br>• Nano materials and technologies<br>• New materials (e.g biology based) |

Table 3. Summary of global trends and social flows that may exert pressure on the building sector and enable changes.

While these trends are important for the Sector, it is worth noting the relevance of *circular economy* which is an umbrella for the circular building and a circular building sector we will address next.

### 4.1.1.4 Building sector and the circular economy

With ever-increasing pressure on the building sector to recover more value from construction materials in the waste stream or preferably to not let it become waste in the first place, the circular economy (CE) is increasingly attracting attention. Although the CE provides multiple value-creation mechanisms to decouple consumption from the increased use of finite resources, it also represents an opportunity and a major challenge for the Danish building sector.

This section first focuses on what the circular building sector would look like and what these developments would entail, and then identifies some of the most recognized barriers and drivers for the transition of Danish building to the CE.

#### 4.1.1.4.1 A circular building sector

An exhaustive and ideal definition of the circular building sector does not exist yet. Some visions for the sector such as ‘circular construction’ by ABN-AMRO (2014) are particularly focused on the economic aspects of circularity. However, some principles are commonly mentioned when the CE is related to the building sector—e.g. as a lifecycle approach, preservation of natural resources, enhancing of existing resource, and fostering of building system effectiveness (EMF 2015).

From the perspective of processes and considering the forms of ownership in the value chain according to (ABN-AMRO (2014), this might involve the following:

1. Design that optimizes the useful life of a building or construction, giving priority to the high value of reuse components and resources that are recovered in an End of Life phase (i.e. considering circular design concepts—design for product life extension, design for adaptability, and design for disassembly).
2. Supply chain based on a new model of ownership, in which the resources are no longer sold to a developer and the final 'product' (e.g. a building or building fraction) is no longer sold to an owner.
3. Provision of services of living and working, for instance, by a consortium, while the different producers of all materials and components still own resources that are temporarily stored in the building (i.e. Buildings as material banks or BAM).
4. Management and maintenance of the construction, building envelope, and installation techniques included in the contract.
5. Sharing information within the value chain based on technological platforms.
6. New forms of funding with other paybacks and residual values.

In terms of the roles of different players across the construction sector, according to ARUP & BAM (2017) and DEPA (2017) they could include:

- Investors, developers, and building owners will take a longer-term view, focusing on the lifecycle of buildings and maintaining ownership of the resources. That means, for instance, deploy sufficient time for preliminary investigations and planning demolition; establish requirements in the procurement for use of recycled materials and for waste disposal; and reward circular solutions that take into account the entire life of the building (absence of problematic substances, "design for disassembly");
- Tenants will require very differently occupancy forms of the equivalent buildings today, but impact of these changes in tenancy agreements needs to be explored. Nevertheless, trends indicate that for example in office buildings, tenants will tend to privilege flexibility and rapid changes, and rather renting floor space, they will rent workspace. In commercial buildings uses also will be more flexible (i.e. with the possibility of providing space for housing or care) thus bringing new tenant types as working cultures and needs change;
- Authorities (European Union, government, and local authorities) play and important role in easing the transition to a circular building sector, through policies around taxation of consumption, legal structures, industrial strategy, building code regulation and standards. Moreover, assessment methods like DGNB, BREAAM and LEED will have wide application following policy high standards such as energy neutral buildings by 2020;
- Industry role in circular value chain will be based in different types of circular business models (CBM) that will interact and work together at different stages of buildings lifecycle. The implementation of these business models involves designers, suppliers, service providers, contractors and end-of-life companies by sharing materials, systems, as well as information and services. This CBM will allow:

  " - *Control of resource streams through the value chain so the added value can be identified and captured.*
  - *Innovation through the supply chain so new entities can be generated such as business in waste handling, refurbishment and reverse logistics.*
  - *Enhanced collaboration within the supply chain amongst all actors.*
  - *Creation of services that capture valuable products / resources"* (ARUP & BAM 2017, p.20)

In terms of specific tasks related with circular building for the different stakeholders it may include:

| Stakeholders | Tasks |
|---|---|
| Consultants / Architects | • Inform the developer about state-of-the-art in relation to optimal utilization of resources<br>• Find out resources for deploying resources, including local reuse / recycling opportunities;<br>• Provide planning and design for components, systems and ultimately the full asset in order to improve its service life.<br>• Specific solutions to improve how the asset is maintained repaired, upgraded and refurbished or remanufactured.<br>• Bring new knowledge into the process |
| Contractors (construction/ demolition) | • Provide solutions to extend the service life of products, components and systems.<br>• Avoid purchases of "extra" building materials, and store building materials appropriately to avoid weather damage.<br>• Recycle interim materials in multiple projects.<br>• Separate the waste into several fractions. |
| Manufacturers/ Suppliers | • Develop building materials, consumables, spare parts and add-ons to support the lifecycle of long-lasting products/buildings.<br>• Sell a product/service on the basis that it will be purchased back after a period of time. |

Table 4. Tasks of stakeholders in circular building regime.

- Technology will play a significant role in a circular building sector. It will be used to share and store information about in-use materials and components to reuse. This includes suitable material databases and materials passports[10], and BIM. Combined with other digital platforms and simulation tools, these technologies will enable sharing information from different stakeholders, reduce waste in production, drive efficiency, improve performance, and demonstrate residual value of materials at buildings end of life. In addition product passports, 3D printers and tagging sensors will also contribute to alter the building lifecycle process.

In short, and inspired by ARUP & BAM (2017) concept circular business models (CBM), it could be said that a circular building sector will shift the focus to sourcing sustainably, maintaining material productivity over the lifecycle of developments, and reducing losses of non-renewable materials. This will produce financial, social and environmental benefits.

#### 4.1.1.1.2 Barriers and Drivers

This section aims to identify the barriers and drivers that may respectively hinder or promote the transition to a circular building sector. As in previous sections, the following analysis is based on the MLP approach for sociotechnical regime and therefore the various barriers and drivers are analysed for each component of the building sector.

##### *Barriers*

The analysis of specific barriers within the following chapters aims to identify and analyse the key obstacles that may hinder the development of CE in the building sector. Based on the framework of building regime, this task goes beyond the broad understanding of building sector

[10] The emergence of materials passports and the use of Radio-frequency identification (RFID) labels make materials traceable through the entire chain. This gives insight for each material into its origin, supply and environmental performance.

dynamics in Section 4.1.1.2 and focuses on the most significant barriers identified in various documents and interviews.

*Technology*

While the application of technology in construction has progressed significantly in recent years, (e.g. BIM, lean construction, industrial production of modules), other technologies that are also critical for the development of circular business models are still often at the conceptual or early commercial stage. These technologies include LCA, LCC, 3D Printers, material passports/RFID, circular design, sustainable and alternative materials (e.g. bio-based building materials), and sharing of buildings. They would need further development to be economic at a large scale and be able to compete with more standard methods, particularly bound by more traditional practices (EMF 2015a).

*Industry*

At the industry level, for some reason it remains profitable for companies to pursue the linear model (Søren Nilesen 2107). Many players in the construction industry are unwilling to change long-established business models and extensive subcontracting, which is related to fragmented and overspecialized knowledge and capabilities (RUC n.d).

Beyond obligation to perform environmental impact assessment (EIA) in the case of large constructions and CDW handling (e.g. waste separation), contractors usually do not pay much attention to environmental issues. The industry lacks a clear vision on environmental objectives and the authorities place no regulatory pressure on the industry (RUC n.d). This is partly explained by the industry's reaction to the imposition of regulations related to the CE. According to Michael H. Nielsen, CEO of Danish Construction Association, the final success of the transition to CE depends not so much on regulation but on the capacity of industry to gradually adapt to new business models over time and to maintain and develop productivity and profitability:

> *"Engine for realizing the ambitions (genuine transition to circular economy) must be economics and business based. (…) It will take time to convert the industry to this and it is important to ensure objective assessments rather hasty regulation"* (DanskByggeri 2017, parag. 3 )

Since designing for circularity requires some alignment of incentives to close the loop in the value chain, lack of such incentives makes it difficult to make an economic case for reuse. In addition, the capital intensity of the industrial facilities makes the production of modules a challenge for the industry in Denmark, as it is made up of a large number of SMEs (EMF 2015a).

The fragmentation of the industry also leads to barriers of transaction costs and imperfect flow of information; the resources necessary to provide a system of circular design and construction are difficult to achieve.

Another barrier is the lack of definition about who owns the responsibility for product delivery of reused/recycled materials and products, but also about the overall buildings where these elements are integrated. In this respect, Anne Beim says:

*"I think some of the big industries already deal with waste handling and they try to boost in the design phases reduce the amount of waste and if they have waste they recycle it in different ways.* […] *but from an overall building construction industry in total there are various barriers in the sense of who will take the responsibility of all building that is going to be different. Who is going to take the responsibility in case of these* [used] *walls and windows are integrated into new building structures? This is the big issue at this moment"* (Anne Beim 2017, pers. comm, min 13:43).

*Market/ Customers*

For most developers and owners, major concerns are related to the short-term cost and benefit. According to Anne Beim, there is a lack of lifecycle perspective on the markets:

> *"they* [markets] *think: how many square meters do I get? What is the manufacturing cost of this particular building? For how much can I sell this building or lease? or how many times I need to clean facade and windows or if they should make conservation works in twenty years' time. They are not concerned about the circular economy thinking or recycling thinking or the life cycle of materials"* (Anne Beim 2017, pers. comm, min 17:06).

On the consumer side, homebuyers may also be unwilling to trust non-traditional building approaches (EMF 2015a). For example, in relation to the reuse of components and materials and the sharing and multi-purposing of buildings, the EMF´s report (2015a) mentions barriers such as the following:

- Imperfect information that negatively affects market decisions, such as asymmetric information
- Externalities (true costs) not fully reflected in market prices
- Insufficient competition/markets leading to lower quantity and higher prices than are socially desirable
- Custom and habit—ingrained patterns of behaviour by consumers and businesses

*Policy*

Policy and legal barriers to CE cover regulatory and non-regulatory aspects. These include European policies, directives, and regulations that hamper the transition to a CE, as well as national and local policies, standards, financial incentives, and certification mechanisms.

The barriers identified at the European level are related to the Circular Economy Action Plan and Construction Products Regulation and CE-marking:

- Action plan for the Circular Economy—Closing the Loop (COM 2015) states that '*the commission will develop targeted guidelines for the use of CDW. It will help* t*o spread best practices by developing voluntary recycling protocols based on the highest common standards for each waste stream*'. However, in contrast to the EU2020 package in 2007, in regard to energy targets for 2020, the CE action plan does not set mid- or long-term objectives and does not define common and unified performance indicators of circularity, which are needed as a motor for national policies for resource efficiency or circularity of construction and buildings (Backes 2017).
- Construction Products Regulation—EU Regulation 305/2011/EU (EU 2011) is based on a lifecycle perspective and establishes that the requirements to obtain the CE mark must cover the assessment of all phases of a product lifecycle. Despite the legislative progress represented by this regulation, there are, however, some regulatory failures such as the following:
    - Lack of specific conditions for evaluation of reused/recycled products. If tests are performed according to current regulations for new products and materials, it may be impossible to comply all the specific requirements for reused/recycled products and it is very costly to ensure the documentation (e.g. about purity and quality of materials) (SBi 2015).
    - Inhibition to new materials development, such as renewable biological materials, since the current fire requirements for CE marking extend the development of resource-saving building materials and indirectly provide incentives for using fire-resistant and energy-intensive materials such as concrete and steel.

At the national level, various kinds of policy and regulatory barriers can be identified concerning particularly the following points:

Information and awareness

- Policy interventions play an important role in increasing information and awareness on the CE among the public and business community, and particularly in the building sector. Such policies are critical '*to change ingrained patterns of behaviour and ways of thinking that companies and individuals have developed over long periods of time'* (EMF 2015a, p 66). However, it lacks policies oriented specifically towards raising awareness on CE issues and opportunities. Moreover, there is a lack of policies that contribute to developing collaboration throughout the building sector and between functional silos (EMF 2015a).

Regulatory Frameworks

- Regulations on CDW and building demolition/disassembling—Provisions on environmentally hazardous substances in construction waste are scattered among different laws, regulations, standards, and municipal systems and practices. In addition, there is a lack of standardized rules and regulations for how to demolish/disassemble buildings and the timeframes usually allocated to these tasks very short. On the one hand, these aspects create difficulties for players to get a clear overview of their roles and responsibilities in connection to a specific alteration, renovation, or demolition. On the other hand, it hampers methodological sorting which enables the reuse and recycle of resources from individual buildings (Vinterakademy 2016, Larsen 2016)
- Building regulations—The lack of harmonized building codes, standards, and clear rules in relation to reused/recycled materials hinders the development of both circular business and innovative design based on circularity principles (EMF 2015a, SBi 2015).
- Regulations on real estate sharing—there are regulatory issues related to real estate sharing need to be addressed before promoting it through pilots or partnerships, for example (EMF 2015a).

Assessment frameworks

- The use of holistic assessment methods to calculate sustainability performance of buildings (e.g DGNB, BREEAM, and LEED, and the application of life cycle analysis (LCA) for products have been increasing in recent years. According to Contreras (2016) these methods have the potential to: "*test impacts of circular business models, validate their assumptions and get feedback for improvement, [...] can help define targets and indicators to measure and foster circularity over time".* However, its application is voluntary in terms of building processes and there are no incentives to broaden its use or integration in the legal framework (Backes 2017)

Fiscal and economic instruments

- Fiscal instruments- Currently there are no fiscal instruments either to discourage non-circular activities on the one hand or explicitly support circular economy opportunities on the other. An example to follow, in the first case, may be the Danish tax system on landfilling, which led to pricing that includes negative externalities of waste. In the second case, incentives for consumers or businesses to become more resource-efficient could include value-added tax (VAT) or excise duty reductions for circular products and services, as well as tax shift from labour to resources (EASAC 2015)
- Public procurement- The role of public procurement in promoting circular economy is not yet fully exploited in Denmark, particularly in relation to buildings and construction. The Partnership for Public Green Procurement, established, some years ago, by the Ministry of Environment and Food (MEF) including twelve municipalities, two regions and a water supply

company has common goals for increasing circular procurement, but it is not current practice the procurement of circular building or reuse/ recycled construction products (NCM 2017).

### *Research and Education*

An increasing number of research studies dedicated to various sectors of CE, including the building sector, have been raising awareness in the research community to the CE issues. Despite slight progresses in research that may contribute to promoting CE among businesses and policy-makers, there are major barriers that hinder a paradigm shift in the educational and research segments. According to the EMF's report '*Delivering a circular economy—a toolkit for policy-makers*' (EMF 2015a), school and university curricula are still basically based in subject silos, while a transition to CE needs a paradigm shift to systems thinking and creative education. Moreover, according to the Danish Advisory board for CE (MFVM2017) CE is a new field in the Danish education system, and there are no bachelor's or master's programmes that contain significant elements of circular economics: *'There is currently only a small number of training modules in circular economy, as well as a number of existing education offers that contain relevant elements to a curriculum in circular economy'* (p. 15).

In addition, employees in the public sector and in Danish building sector companies generally lack the skills needed to translate the economic and environmental potentials of CE (MFVM2017).

### *Culture*

The cultural and institutional barriers to a circular building sector are related to the following aspects:

- Short-termism—one of the critical barriers that continues to be practised in policy-making in business and investment decisions is short-termism. A move to long-term thinking and planning, both in policy and in business, is a fundamental prerequisite for a CE (Reisch & Thøgersen 2015).
- Silo thinking—the 'silo-thinking' culture is commonly mentioned as responsible for hindering knowledge transfer (Bresnen et al., 2005), resisting acceptance of new technologies and vocabularies, and mismatches in management practices (Labuschagne and Brent, 2005). This silo mindset also constitutes a barrier to driving innovation and building momentum to CE transition. It also hampers collaboration between stakeholders in specific innovative projects and platforms involving public and private partnership (EMF 2015a).
- Reluctance to innovate—the learning process in the building industry is characterized by a project-to-project basis. This unsystematic process of building up knowledge leads to a reluctance in using unfamiliar technologies and materials, incremental change, and the slow diffusion of innovations (Giesekam et al. 2015).

## *Drivers*

There is a significant body of literature on the drivers of CE; however, research within the building sector, specifically in the Danish context, is still limited. Thus, the following paragraphs set out to indicate the possible measures aiming to drive circularity in the building sector. The analysis focuses on three streams of activities in the building sector—policy, industry, and research and knowledge transfer.

### *Policy*

European policy

In Denmark, policies related to the CE are anchored mainly in the EU Action Plan for Circular Economy adopted in 2017. This policy package consists of a series of proposals and initiatives to amend a number of previous waste directives. The package outlines the overall objectives and frameworks for US waste policy up to 2030 and will imply legal binding obligations for the Member States, thus including the municipalities.

### Government policy

A relevant document aimed at guiding policies towards the circular economy, is the aforementioned EMF's report "Delivering the circular economy – a toolkit for policymakers". In this document Denmark is the case study and includes a set of opportunities, policy recommendations and proposals for future action, particularly for the building sector.

In addition to these relevant drivers, mention should be made to three government initiatives that can assist in the transition to the circular economy: Report from the "*Advisory Board for Circular Economy - Recommendations to the Government* (MFVM 2017); *Waste prevention in construction* - Preliminary project (MST 2017), and the Danish Eco-Innovation Program – MUDP (MFVM 2017a). These are described below.

- Advisory Board for Circular Economy - Recommendations to the Government

The report from the Advisory Board for Circular Economy brings together a set of recommendations to give Danish companies a competitive advantage and open up new markets by developing new solutions and building know-how that can be exported.

Assuming the need to take immediate actions in the transition to a circular economy the Advisory Board points out four basic principles and claims: *" It is time for action and a reconsideration of our business models and welfare societies based on the following formula: Reduce. Reuse. Recycle. Rethink."* (MFVM 2017, p. 5),

The report includes five concrete objectives, four overall benchmarks, and 27 recommendations for concrete efforts that can strengthen the transition to a circular economy. Although a large number of recommendations are commonly applicable across different sectors, there are, however, six recommendations that are specifically related to the building sector. These are as outlined above in the Annexe 1. .

As regards to the transition process to circular economy the Advisory Board points out some important warnings and recommendations such as the following:

> "*A shift to a circular economy is an inclusive process, which will have to be phased in over several years. The extent of the effort should not be underestimated, and the confrontation with silo-thinking is crucial. The conversion requires collaboration between all stakeholders in the value chain - from designers and manufacturers across distributors and retailers to consumers and waste managers. This requires new collaborative relationships - for example between financial actors and production companies or between the economic and development departments of the individual company. It will also require new skills and research into smarter use of resources and materials. In order to adapt to a circular economy, individual citizens and public authorities, in Denmark, must be prepared for major changes in consumption patterns. The use-and-throw-away-culture has to be replaced with a new mindset*" (MFVM 2017, p. 11).

Despite the Advisory Board estimates that most of the recommended measures can be realized by 2020, in some cases such as the building sector this might be considered very optimistic (Lauritzen 2017).

- Waste prevention in construction - Preliminary project

The project Waste Prevention in Construction, Affaldsforebyggelse I byggeriet (DEPA 2017), is an initiative under the Danish waste prevention strategy Danish Without Waste II, established in 2015 by the Danish Environmental Protection Agency (DEPA 2015). Despite the projects focus is waste prevention and recycling in construction, renovation and demolition, it includes tangible measures to disseminate circularity in best practices to a wide range of players such as including developers, consultants/architects, contractors, producers and suppliers, waste handlers and authorities. The suggested measures and best practices are outlined in Table 6.

| **Players** | **Demolition projects** | **New buildings and renovation projects** |
|---|---|---|
| Developers | • allow sufficient time for proper demolition planning, maintain ownership and/share responsibility of the resultant waste. | • use of recycled materials and waste prevention measures, and demand that new buildings are designed to be easy demolished or disassembled at the end of life. |
| Consultants/architects | • drive knowledge of market potentials, conduct thorough resource mapping prior to demolition and recommend state of art recycling technologies. | • help spread knowledge about sustainable solutions, design for easy renovation, disassembly or recycling at end of life, as well as suggest recycled materials and prefabrication where possible and practical |
| Contractors | • develop new demolition methods that ease waste sorting into reusable/recyclable materials fractions | • avoid procuring excess materials, store materials properly, use return schemes where available, reuse process materials where possible and sort waste into fractions. |
| Producers and suppliers | • | • produce materials and products (prefabricated if possible) that are easy to recycle/reuse, take over-ordered material back, develop products based on recycled materials and help develop standards for these. |
| Waste handlers | • demand documentation of waste to improve traceability, demand better waste sorting on site and develop waste container solutions, and improve pre-processing of material for recycling. | • |
| The authorities | • improve implementation of relevant regulation, demand resource mapping before demolition, ensure clear and understandable limit values for problematic substances in recycling materials, demand certification of actors, and provide better information of relevant regulation.<br>• contribute with thorough analysis of the management of specific waste fractions, develop support and information tools for the use of recycled materials. | • help mapping the extent and nature of waste of constructions sites, and identify and modify legal barriers to recycling and reuse in new construction.<br>• development of quality standards and labelling, and support demonstration projects that can inspire and inform the sector. |

Table 5. Suggested measures and best practices

Danish Eco-Innovation Program (MUDP)

The Danish Eco-Innovation Program, *MUDP* (Miljøteknologiske Udviklings- og Demonstrationsprogram) (MUDP , is a program under the Ministry of Environment and Food, which supports development, testing and demonstration of environmentally efficient technology (MUDP 2017). The program supports projects such as water, climate change, air, as well as resources and waste. The prioritized projects are both development and demonstration projects and large lighthouse projects.

"*Through the lighthouse projects, companies are able to test full-scale solutions, and investors in Denmark and abroad are given the opportunity to see the best in green technology"* (Miljøstyrelsen 2017, parag.2).

One of the cases integrated in this program is the "Around Circle House - economically and environmentally sustainable construction" (Rundt on et cirkulært hus- Økonomisk og miljømæssigt bæredygtid byggeri). The project usually called Circle House will act as a national and international demonstration project. It has support from MUDP, Lejerbo and the architect GXN, in cooperation with several partners. This project will be further analysed section 4.1.2.

Local policy

At the local level mention should be made to the inspiration catalogue '*The Circular Municipality*' KL- Local Association of Danish Local Authorities (KL 2017). This document describes circular economy potentials in the local context and initiatives that could be launched locally. At the same time, it shows relevant cases and examples as inspiration for how the municipality can embrace the circular transformation in the future.

As municipalities together are one of country's largest builders (e.g schools, kindergartens, administrative building, clinics, cultural buildings, etc) KL is committed to move the agenda towards the circular construction. Accordingly, the inspiration catalogue suggests a number of ideas and examples included in following key points:

- Circular construction is the new sustainability stamp
- Design and knowledge of materials is the key
- Clear political line paves the way
- Mapping, smart design and multifunctionality
- Remember the circularity in municipal renovation and minor construction works
- Selective "and more intelligent" demolition
- Building materials must be back in the loop
- Sustainability certification and PPP as a lever.

KL's document provides a number of specific recommendations to municipalities with regard to circularity in municipal buildings such as monitoring sustainability requirements, set-up of a demolition strategy in the design phase and take ownership of demolition resources; stimulation of market for recycled materials, and inclusion of reuse/recycling materials in the tender.

As an example of circularity in municipalities is the "MBA2016 - Environmental Criteria for Building and Construction Projects" from Copenhagen municipality. The "criteria" was designed for municipal procurement of recycling and reuse materials for municipal buildings and construction. The MBA2016 is expected to lead to more recycling/reuse of building materials, and more efficient use of energy resources. The pilot projects conducted ahead of the MBA2016 indicate that there is a potential for environmental benefits and maybe also cost savings, in particular, if the full lifecycle costing is taken into consideration. In this context it is emphasized the reuse of old bricks taken from demolition of old hospital buildings into two building projects and renovating old schools. These pilot projects involved Gamle Mursten a firm with experience in cleaning and selling old bricks. Gamle Mursten also has demonstrated through LCA that using old bricks was a better and longer-lasting solution from an environmental point of view.

*Industry*

The drivers in the industry are mainly contractor and professional associations that see the potentials of circular economy such as DI – Confederation of Danish Industry (DI) and FBSA-

Danish Association for Responsible Construction (Foreningen for Byggeriets Samfundsansvar). These associations are committed at promoting circular economy among their members and influencing policies related with circular economy.

- DI

DI represents 10,000 companies and his voice is listened when it comes to social and economic aspects as well in relation to competitivity of Danish industry. It has been thus important to gain DI attention and progressive acceptance for transition to circular economy. Currently, DI is showing, in different ways, that is committed in doing "*what it takes to develop and produce competitive products and services resource-efficiently and in balance with both the economy and the environment"* (Kaae-Nielsen (2017). In this sense, DI formulated an environmental and resource policy focusing on the potential of circular economics. Moreover, it created the DI's circular economy network which is a platform for companies that are interested in, working with or wishing to be updated on a circular economy.

In relation to the building sector, DI point out some aspects in policies that must be taken in consideration. According to DI there is a need to proceed with the Recommendations from the Advisory Board (previouly mentioned in this section) in dialogue with the industry, particularly in what applies to the proposal to establish a sustainability class in the building code: "*Here it is necessary to clarify which elements of a sustainability class must contain and the time frame that is realistic"(*Kaae-Nielsen 2017, parag. 9) Hence, although DI's commitment with dissemination of circular economy business models, it has also a word to say in relation to policy details and transition pace towards a circular economy.

- FBSA

The Danish Association for Responsible Construction- FBSA (Foreningen for Byggeriets Samfundsansvar) has the main objective of developing and promoting social responsibility in the Danish real state and building sector. The Association also the aims to inspire good practice and to develop relevant instruments, and therefore it holds a series of workshops, meetings and seminars at which good practice is developed and discussed within current topics such as, for example, sustainability and sustainable productivity (FBSA n.d). In recent years the circular economy has been presented as relevant discussion topic and several cases have been presented such as the Circle House (outlined and further detailed in section 4.1.2.)

- MT Højgaard

MT Højgaard Group is one of the leading construction and civil engineering companies in the Nordic countries. Currently the company is shifting the focus from construction costs to the overall economy. For MT Højgaard's Sales Director, John Sommer Circular construction will be thriving business in the long term:

> *"Right now, it is not favourable, but it will be, because when the access to resources is limited then resources become still more expensive. Then the companies, which know how to increase resource productivity, will be the companies deriving a competitive advantage*" (Sommer 2017 v)

In addition, John Sommer argues that the building industry must find solutions to reduce the use of raw materials and the waste it generates:

> *"(...) if we do not find solutions ourselves it will be required from political side. Either in the industry comes to this itself, which we can actually prove* [by] *business models, or a still stronger political pressure will force the industry to act differently. When we see the world changing, we usually say that the best way to prepare for the future is to be part of creating it"* (Sommer 2017 v).

### *Research/ Education*

A number of research and academic institutions such as CINARK, DTUByg, SBi, and Tecnologisk Intstitut, have been contributing with knowledge and new tools to enhance circular economy. In terms of education it should highlight that KADK Royal Danish Academy of Fine Arts - Schools of Architecture, Design and Conservation is focused in preparing future architects to work circular solutions and technologies (InnoByg 2017). In the area of the area of knowledge transfer should be stressed the work developed by InnoByg, the building sector innovation network for sustainable construction.

- InnoByg

InnoByg is co-funded by the building industry and the Danish Agency for Institutions and Educational Grants – SIU (Styrelsen for Institutioner og Uddannelse). Among the diversity of activities related with the gain of knowledge on sustainable buildings and construction, Innobyg has also been involved in promoting circular thinking in construction. Below are outlined two catalogues aimed at inspiring circular construction solutions.

Idekatalog for Circular economy (KADK/CINARK &TI 2016)

This publication is one of the results of the 2-year InnoBYG project. Application and management of waste and resources in construction. The project is a collaboration between the two knowledge institutes Technological Institute (TI) and CINARK - Center for Industrial Architecture at the Royal Danish Academy of Fine Arts Academy in close dialogue with selected actors from the construction industry, such as Lendager Group and Tegnestuen Vandkunsten

The IdeaKatalog should provide inspiration for how to work with the development of strategies for increased recycling of materials in the building industry.

Through concrete examples of projects / strategies and interviews with actors from the construction industry, the catalog seeks to discuss and map the opportunities and barriers that exist within the field today.

Materialeatlas (TI & KADK/CINARK 2016)

The Materialeatlas was primarily developed by TI and KADK/CINARK in cooperation with relevant business partners. The atlas was designed as an overview of environmental possibilities and barriers associated with a wide range of building materials. The purpose is to work as a reference to quickly and easily find information about environmental issues associated with specific building materials. The Materialeatlas is intended to be part of preliminary studies of new design strategies for recycling building materials.

## *Synthesis of barriers and Drivers*

From previous analysis results, a number barriers and drivers to increasing circularity in the building sector, which are summarized in Table 7. The analysis enabled identify barriers and drivers in almost all dimensions analysed. Although, at the dimensions of technology, and market/customers, it was not possible to identify the drivers.

The table shows a long list of barriers and less of drivers. Barriers include both deep- rooted barriers and shortcomings. First are related with path dependencies or ingrained practices and habits, such as the cultural barriers. Second are a wide array of barriers concerning to a lack of incentives, information or definition. having thereby a greater probability to be addressed through specific measures. The analysis of drivers shows that much attention has been given to policy measures at all levels - European, national, and local. However, some of this policy drivers concern to recommendations and guidelines. The industry drivers involve promotion of CE and influencing policies. Finally, the dimension of research shows that academia and research are building knowledge and developing tool to enhance circularity. Although some of the important barriers don't have correspondent drivers.

| Dimensions | Barriers | Drivers |
|---|---|---|
| *Technology* | • Lack of development of innovative technologies that support circularity and can compete with existing technologies. | |
| *Industry* | • Lack of clear sustainability objectives on industry organizations<br>• Lack of financial capacity of SME to adopt new practices and introduce new production systems<br>• Lack of total-economy and long-term perspective from manufacturers<br>• Lack of capacity of contractors to adopt selective demolition/disassembly | • DI – Confederation of Danish Industry (DI) and FBSA- Danish Association for Responsible Construction (Foreningen for Byggeriets Samfundsansvar) initiatives to promote circular economy among their members and influencing policies related with circular economy<br>• Contractors such as MT Højgaard commitement tofind solutions to reduce the use of raw materials and the waste it generates |
| *Market/ Customers* | • Lack of definition about responsibility for delivery of reuse/recycled materials and products.<br>• Lack of long-term perspective from building developers<br>• Lack of information and awareness on circular economy among public and business | |
| *Policy* | • Lack of CE marking or other labelling scheme for reuse/recycled building products<br>• Lack of specific conditions to evaluate reuse/recycled materials<br>• Lack of fiscal incentives (e.g taxes) to circular products and services<br>• Lack of fiscal instruments that discourage non-circular activities (e.g. non-selective demolition)<br>• Lack of harmonized building codes (Building act) in relation to reuse/recycled<br>• Lack standardized rules and regulations for how demolish/disassemble | • EU Action plan action plan for circular economy.<br>• Governemnt's advisory board to circular economy. Set of recommendation to promote circular economy in Denmark including in the building sector. Proposal include: research development; testing and demonstration projects of circular solutions and technologies, product policy, building regulations, standardization and product passport, public procurement, and selective demolition.<br>• Waste prevention in construction- include tangible measures to disseminate circularity in best practices<br>• The Danish Eco-Innovation Program, MUDP supports development, testing and demonstration of "eco-solutions", including circular solutions.<br>• 'The Circular Municipality', (KL). shows relevant cases and of circular solution as inspiration for local context initiatives |
| *Culture* | • Short-termism<br>• Silo thinking<br>• Reluctance to innovate | • Science and technology supporting social and economic development.<br>• Standardization |
| *Research, education, and knowledge transfer* | • Lack of incentives to paradigm shift in from silo-thinking to systems-thinking<br>• Lack of bachelor and master's programs that contain significant elements of circular economy<br>• Lack of skills in public sector and to translate economic and environmental potentials of the circular economy | • CINARK, DTUByg, SBi, and Tecnologisk Intstitut,- Research and development of new tools to enhance circular products and construction<br>• Innobyg and other networks – Knowledge transfer on circularity to the industry. |

Table 6. Summary of barriers and drivers to circular economy in the building sector

### 4.1.1.5 Synthesis of Building sector analysis

In this chapter, the transition pathways of the Danish building sector have been analysed, covering first three periods—premodern, modern, and post-modern—and then the dynamics of contemporary regime. Also, the expressed barriers and drivers of the building sector's transition to CE have been analysed. Based on the MLP model (Geels 2004), Figure XX below illustrates the building sector's journey across successive historical regimes, the undefined contemporary regime, a variety of possible pathways to a circular building sector, and the trends and social flows from the landscape level.

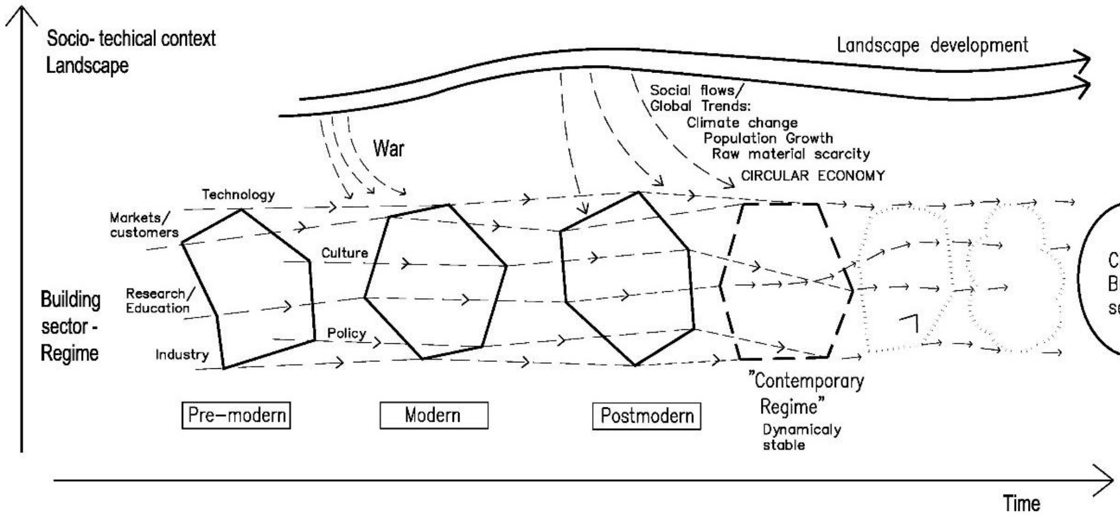


Fig 30. Building regime periods and dynamics. The figure shows the transition from one building sector regime to another as a consequence of landscape pressure. It shows also a variety of possible dynamics and patways towards a circular building sector including. Adapted from MLP model (Schot and Geels 2008)

In regard to the first three periods, it is possible to map sectors configuration and identify most of their relevant characteristics. However, mapping the contemporary stage is slightly more complex as the sector presents more diffuse characteristics. While on the one hand the sector tends to preserve and takes characteristics from earlier periods/regimes, on the other hand it reacts to some new perspectives stimulated by new socio-technical possibilities.

Regarding the transitions between regimes, there are different two different types: first, a quick and radical transition from the premodern to the modern period; second, a co-evolutive and slower transition from the modern to the postmodern period.

The first radical transition is triggered by the impact of an extreme event such as the World War II, and especially the extraordinary need of post-war housing. This extreme need thus constitutes a window of opportunity to a wide change from the pre-modern system based on crafts, individualized buildings, and rules of thumb, to a modern system with a building industry based on prefabrication, standardization, modularization, and mass-production. This involves a new integration between design and construction and the rise of a new actors in the planning processes such as the planning engineer. Also, this transition has led to the rise of new materials such as concrete and the dissemination of modern architecture based on functionality principles (e.g. based on experiments from W. Gropius since the early 1920s).

The second transition, started in the late 1970s and has developed over a longer period. It occurred due to several social events, including economic crises and the 1973 oil crisis, and the exhaustion of the factors that sustained the modern period. In contrast to rationality, uniformity, and 'uprooting' from history and context integration from the modern period, the postmodern period is characterized by diversity, plurality, fragmentation individuality, and experimentation.

The postmodern regime is characterized by the lack of single strategy for the sector, and a diversity in architecture, complex building systems, and new technologies such as the CAD and digital planning tools. In this context, the value chain is rather fragmented with several specialized contractors and manufacturers producing a wide range of material and products. Specialization is thus a distinctive aspect of this period. This links to the emergence of a network culture based on interdisciplinarity and cooperation, which has been a challenge due to the deep-routed silo culture since the premodern period.

Due to the increased awareness about resources and polluting emission limits, the postmodern period is also characterized by a set of environmental policies with impact on the building sector, such as landfill policy (see Section 1.1), and building energy efficiency. This period is also characterized by policies aiming for the real-life testing of building technologies and processes (e.g. demonstration projects), which are further discussed in Section 4.1.3.

As the contemporary 'regime' has several aspects of the previous regimes—mainly of post-modern regime—it is not possible identify a real transition. As mentioned in Section 4.1, the present corresponds to an 'in flux' stage in which several deep-rooted characteristics (e.g. craft practices and silo culture) contrast with advanced practices based on digitalization and collaborative processes (e.g. base digital construction, lean project and lean construction). It is also a period of a polarized and fragment value chain—on the one hand, a group of few large contractors and consultants growing and developing knowledge, aiming to achieve the global markets, on the other hand, a wide range of specialized medium-sized and small companies competing mostly in the local markets and tending to stability due to their lower capacity to fast developments. In this current status, the policies tend to diversify objectively— either just translating European directives to the national legislation or climate adaptation measure, or defining specific policies to address sector issues such as the lack of productivity and quality. Furthermore, the policies involve aspects such as waste prevention and increase in recycling, or the support of experiments in new construction technologies, eco-solutions based on the stimulation of cooperation, etc. This diversity can be seen in two perspectives. The first perspective is the government's generic policy to keep the number of firms, technologies, and options as broad as possible. The other is that diversity does not result from any strategy. This alternative is further developed in Section 4.1.3.

The trends and social flows situated at the landscape level cover various dimensions such as society, sustainability, globalization, and technology. This trend exerts pressure over the regime level and may enable processes of coevolution between the building sector and other sectors. The CE is one of the identified trends, it works as an umbrella for different forms of circularity, including initiatives of circular building at the regime level or experiments at the niche level.

A circular building sector is an idea that is attracting more and more followers, who consider it as a great business opportunity. There is not yet a common understanding of what a circular building sector should be, but there are some principles that can be emphasized, such as the lifecycle approach and the involvement of the whole value chain since the early stages in the building process.

The analysis of barriers and drivers to circular economy, showed a wide number of barriers, which in some cases are deep rooted, and a fair number of drivers in almost all dimensions analysed. The results indicate that an increasing attention is being given to the barriers and options for circular economy in the building sector, both at the political level and the building industry level.

The wide range policies, from directives to recommendations, indicate a growing interest in establishing the bases to the possible transition pathways towards circular economy. At the industry level, various associations are committed in promoting circular solutions among their members, and influencing policies growing understanding about the potential for circular construction and reuse/recycled products. Moreover, front-runners such as MT Højgaard are interested in developing circular business models and participating in experiments of circular construction. At the level of research and education level, universities, research institutes and networks are building knowledge and tools that can contribute to new policies and circular solutions.

Hence, in the contemporary regime, there are drivers creating visions and expectations to of circular economy to the sector, and contributing to promote the emergence of experimental activities and demonstration projects.

### 4.1.2 Circular building – analysis of niche dynamics

This section analyses the circular building from a niche perspective. The aim is to identify initiatives and experiments that may contribute to the creation of a circular building niche. The analysis is based on a summary of experiments, initiatives, and demonstration projects developed by a number of dedicated protected actors (i.e. shielded from competition, and with strong financial support). Particular emphasis is placed on the Circle House—a demonstration project that is currently under development and that aims to bring together knowledge and experiences of circular solutions from a broad network to build affordable circular housing.

The theoretical framework for the analysis of niche dynamics is the Strategic Niche Management (SMN), as outlined in Section 2.1.2. Given that a project does not emerge in a 'vacuum' but is based on a set of experiences, several projects and initiatives preceding the Circle House are analysed as they have provided valuable experience and knowledge. These initiatives are selected from the work developed by three architecture offices involved in CH, Vandkunsten, Lendager group, and GXN, due to their consistency in the application of principles of circular building. There are other initiatives of circular solutions, but the chosen ones are those that are the broadest or likely to have the most bearing.

#### 4.2.1.1 Rationales

Circular building is a part of CE in the building sector adapted to the building industry. The concept of circular building does not have a common understanding; it is difficult to specify which innovations and products could be covered. A common denominator could be that in circular buildings, the entire construction value chain needs to be involved for mutual gain, and products need to be designed with future uses in mind to achieve longer-term benefit and the highest residual value of buildings, components, and materials after every lifecycle (ARUP & BAM 2017).

In Denmark, circular building may be considered as an embryonic niche—a niche in the early stage of formation—as the accumulation of initiatives and experiments is still less and the market for circular products is small. This idea builds on Raven et al. (2008), who describe a niche formation as a process in which intermediaries distil lessons from current initiatives and offer transferable knowledge to new ones, which then re-interpret and apply it in their local contexts. This supports the consolidation of learnings and replication of successful practices, thereby increasing the influence of the niche on regime actors to adopt new solutions (Raven et al., 2008).

Circular building projects and initiatives are thus evolving in the Danish context through the participation of an increasing number of dedicated players acting in a protected environment and often supported by government programmes, NGOs, or major players in the building industry.

The reasons that are leading an increasing number of actors to be interested in circular building may include:

- Competitions favouring sustainable solutions of architecture and construction

- Encouragement and support from policies to promote demonstration projects based on CE principles
- Private initiative interested in being first runners in a market of circular solutions, which they foresee as having strong economic potential.

#### 4.2.1.2 Innovation projects and initiatives in local practices

In this section, a number innovation projects and experiments are introduced, as well as the actors developing activities within the circular building framework.

The objective is to map experiences and demonstration projects that may constitute the basis of knowledge and experience of relevant actors integrating the network of Circle House.

This analysis focuses on innovative solutions, projects, and products based on circular thinking, which have been developed by three partners in the Circle House. These actors have been selected from a wide range of stakeholders integrated in the network, because they are good examples of dedicated actors that have been contributing with circular solutions towards a circular building niche.

The examples include three architecture offices—Vandkunsten Tegnestuen, Lendager Group, and GXN (in partnership with MT Højgaard in one case).

#### Tegnestuen Vandkunsten

Tegnestuen Vandkunsten is Danish architecture firm established in 1970. Their work in residential architecture and housing developments has been described as characterized by "*convertibility, communality, residential involvement, dense-low rise, and sustainable development*" (Vandkunsten, 2017). Søren Nielsen is the architect specialist for the field of sustainability. He won a competition in 1995 about sustainable social housing and it was the beginning of his commitment to sustainable architecture and urban sustainability (Søren Nielsen, pers. comm.). The circular economy principles began to be implemented in the firm after 2010 when Søren Nielsen started is PhD research in industrial design and the office began to have internal research and collaborations with Technical Universities and architect schools (Søren Nielsen, pers. comm.). Regarding to research integrated in a architecture firm Søren Nielsen explains that: "*research is very powerful strategic tool* (…) *to make clear what to do to develop the field of interests"* (Søren Nielsen, pers. comm, min 9:21). Based on this strategic orientation to research the firm applied for granting founds from various institutions "*which made possible to develop some research projects".* For Søren Nielsen the result of this research cannot be implemented directly in the project commissions, however "*they are preparing or anticipating future situations, such as a more developed circular economy*" (Søren Nielsen, pers. comm., min 11:18). Below are introduced three projects/ proposals by Vandkunsten involving circular economy aspects.

- *Bolig+ : A change-based building culture*

Bolig+ was a competition proposal for 60 apartments in a 6-10 storey housing block in Aalborg. This proposal from 2009 represents for Vandkunsten the first application experience of circular economy aspects in competition projects. However, according to Søren Nielsen "*it was too early and we didn't win at that time.* (…). *because what we claimed in our proposal (…) was the need to include life cycle aspects"* (Søren Nielsen, pers. comm., min. 11:18). On the contrary the brief and the developers were orientated to saving energy on operation stages:

> *" (…) all the mindset of all the institutions collaborating this competition it was all about energy production in the building and it was about saving energy for operation but all the embodied energy it was completely ignored, but it was the routine at that time. Actually if you had asked an engineer*

*two year ago what is embodied energy he probably didn't say he never heard about it"* (Søren Nielsen, pers. comm., min. 13:31).

The proposal focuses on passive strategies: Insulation, heat-recovery and energy-storing capacity. It also focusses on the production system, and preserving the energy capital embedded in the building materials by regarding the entire lifecycle of the building (InnoByg 2016).

The principles used were: a high degree of general usability: a hierarchical assembly structure, allowing disassembly for purposes of maintenance and upgrade, identity change, or installation of new technical facilities.

According to Søren Nielsen, this circular economy principles in construction were relatively new at that time and were not part of sustainability agenda:

*"this project was before the concept of circular economy. Right now circular economy is a buzz word but before it was more about including the material flow in the energy sources, and in the construction processes, and in the operation and maintenance period"* (Søren Nielsen, pers. comm., min. 14:20).

- *Albertslund Syd: Renovation of the atrium houses (Gårdhusene)*

The project concerns to a competition won by Vandkunsten, in 2012, for the renovation of 1001 atrium houses in the non-profit housing complex of Albertslund Syd. The buildings are uniform in their configuration and materials and were built by industrialized processes with low technical quality. This is the reason why it has been necessary to improve the quality through numerous renovation processes, in the last decades. The Vandkunsten proposal, was developed under a main idea-*'change to preserve'* (Vandkusten 2017) which consists, basically, in modifying the public spaces /places for new kind of activities, and leave to the housing association and tenants the opportunity to pick and choose among a large assembly of options and coordinate solutions.

The greatest challenge in this project, acording Søren Nielsen (Vandkusten et al. 2016) was complete renewal of the ground slabs because it required 80.000 m2 of solid beech parquet flooring to be removed:

"*We proposed to convert the floor boards into a new interior wall cladding to cover the new highly insulating facade panels. The reused wood would so replace a standard interior cladding and in this way, reduce the total environmental impact. (...) The subsequent course of events showed us, however, that numerous barriers must be overcome in order for component reuse to become a common practice: The tenants did not like the proposed changes, furthermore these were mostly considered a burden to the tenant administrator, and finally the authorities had no regulations to follow in order to approve of the solutions*" ( Vandkusten et al. 2016, p.3)

The solution was thus an arrangement between the demolisher that was in charge to remove the flooring and the Danish recycling vendor Genbyg A/S that now sell the cleaned floor boards on their website.

According to Søren Nielsen ( Vandkusten et al. 2016) it was the Albertslund Syd experience that inspired the project team to go further and allocate part the commission funds to conduct a research in high-level component reuse, which will is analysed in the following.

- *Nordic Built Component Reuse*

The Nordic Built Component Reuse project (NBCR) is a project developed, in 2015, by an interdisciplinary team of architects, engineers and recycling merchants. Vandkunsten has led the project team with the recycling company Rebuild, and the Norwegian engineering company Asplan Viak, consultant Hjelness Consult and Swedish Malmö Technical University. The project explores, by means of 20 full-scale prototypes, new practices for high-level reuse of dismantled building components and materials at all product stages - sourcing, rehabilitation, design integration, construction, marketing, and disassembly (Vandkusten et al. 2016).

The aim of NBCR project was to stimulate the Nordic market for recycled components and inspire and assist the development of the circular economy, leading thus to energy saving while creating profitable businesses and architectural identity. Furthermore, the project had the objective to improve methods and quality of environmental evaluations of reused materials through the use of flow charts and expanded LCA work.

According to Vandkunsten et al (2016) there is an increasing commercial interest in products and methods designed from reuse/recycled materials, and projects such as NBCR are important contributes to promote reused/ recycled products: *"the interest in prototypes and open-source dissemination of results will hopefully inspire the construction sector and users for further cultural development and implementation"* (p. 3)

For Søren Nielsen (pers. comm) this project and other competition projects are ways to contribute to change the existing mind-set in relation to reuse/ recycle materials:

> *"We are primarily interested in being capable of finding solutions in circular technology which is related with circular economy, but technology is basis for economy. So, our role it is to show that something can be done (min 22:36). (...) the only way that we as architects can find to be part of this development (...) it's by through competitions and contacts with some more progressive clients [because] we don't have access to large decision makers, we don't play golf.... We accept to take small steps and I think this way we can make the difference"* (Søren Nielsen, pers. comm., min. 37:13).

### Lendager group

Lendager Group is an interdisciplinary corporate group that aims to develop and disseminate circular economy solutions for sustainable cities, buildings, and businesses (Lendager Group n.d). The group as a triangle is composed by three following companies: Lendager Architects is the architecture practice and has the role to deliver specialized sustainability solutions, circular construction solutions, and upcycle materials solutions; Lendager Strategy explores potentials and develops sustainability-based strategies for organizations. Lendager Up delivers upcycle building materials.
Anders Lendager is an architect and founder and partner of Lendager Group. His long-term goal is "*making Lendager Group globally the market leader in circular economy and resource efficiency in three areas: architecture and urban development, strategy and analysis, and upcycle product development*" (Lendager Group n.d, parag. 9)
Lendager group have been working in several innovation experiments and initiatives in the last few years. For the present study it is worth mention the following two for the contribute to dissemination of circular construction options: the *Upcycle House*, a demonstration project; and the *Wasteland – From waste to architecture,* an exhibition.

- *Upcycling house*

The Upcycle House is a single-family house demonstration project based on the principle of upcycling. It has been supported by Realdania City and Byg who developed and carried out the construction The project's purpose was exposing potential carbon-emission reductions through the use of recycled and upcycled building materials (Lendager Group n.d a).

The final result of this experiment was that $CO_2$ reduction has been even higher than expected initially. Based on the results Anders Lendager comments and raise some questions:

> "*We initially thought that a reduction of 65% $CO_2$ was unrealistic, but when we ran the LCA (Life Cycle Assessment) on all materials throughout the entire project, it turned out that we had reduced the $CO_2$ emissions associated with construction with 86%, compared to a benchmark house. With that in mind, we are surprised that no one else is working on this.*

*Why is it not included in everything we do as architects? Why is it not included in the building code that a certain percentage of building materials have to be recycled*? (Arch-daily 2013, Parag.11)

The demonstration of upcycling potentials of this projects and the questions that arise, have been a base for debate discussed in several forums, such the exhibition that follows.

*Wasteland – From waste to architecture*

The Lendager Group's exhibition of Wasteland – from waste to architecture took place Danish Architecture Center in Copenhagen (DAC), in January 2017. The exhibition took as departure point the current global and local challenges, such as population growth, and the increasing demand for raw materials, waste and emissions. These challenges are seen by Lendager Group as opportunities for change in the way we build and live in our buildings and cities. (Lendager Group n-d. b)

The exhibition displayed existing examples of possible synergy options between design, production, consumption, and resource, such as building facades of old newspapers, floors of cork stoppers, and houses ready for demolition being moved from abandoned regions to big cities. The aesthetics and design principles e.g. "*beauty and detail-rich of buildings and cities*" were also considered central in this example. The exhibition was based on well-known materials namely, plastic, wood, concrete, brick, glass, and metal.

From this exhibition Lendager Group expects: "*Our hope is that this exhibition contributes to a new understanding of waste as a valuable resource in the development of our common future*" (Lendager Group n-d. b, parag. 3)

## *GXN Innovation*

GXN Innovation was established in 2007 as an internal innovation unit to 3XN architects, and have been working with applied architectural research in green materials and building technologies. Kasper Guldager Jensen is the senior partner and the one of main promoters of innovation projects and research related with sustainability and circular economy. In addition, he his member of government's Advisory Board for circular economy.

Beyond several projects commissions and exibitions GXN have been a main partner in funded research projects such as: The Biological House (MUDP); Building a Circular Future, (MUDP); Cradle to Cradle Manual (RD); Urban Green Biotopes (MUDP); Green Energy Window (EUDP); User Driven Innovation (EBST); Heat Dynamic Materials (PSO); Biobased Building Systems (EU).

In the following are outlined two research/ demonstration projects which have contributed to circular building development: The Biological House and Building a Circular Future.

- *Biological House*

The Biological House is an experimental project that explores the upcycling of leftover materials from agricultural industry to be transformed into construction components. The project has been developed based on circular economy principles that secure building's separability, and the possibility to preserve materials, elements and components in a closed loop over time (GXN n.d ).

The Biological House is aimed to be built using composite materials based on innovative building concept -a digital production technology that ensures an effective as well as flexible system minimizing waste. The house is also designed to disassemble in order to guarantee both a fast construction and dismantling. The simplified production and its modular design makes future adaptation and change of the construction less complicated and less costly.

- “*Building a Circular Future”*
  *Case study - office building 'De fire styrelser “(The four agencies)*

Building a Circular Future is a book that is the result of a demonstration project and one-year research project supported by the Danish Environmental Agency's Innovation Program (MUDP). The contents have been developed through extensive research, knowledge sharing and workshops between 3XN Innovation and 3XN Architects (architects), MT Højgaard (contractors), Kingo Karlsen (demolitioners), VIA University College (constructing architects), and Cradle to Cradle Denmark. The research relied also in studies made by two master students, Leonora Malabi Larsen and Sara Diraoui, to their master thesis developed at MT Højgaard. The project was leaded by Kasper Guldager Jensen, Director at GXN John Sommer, Sales Director at MT Højgaard. (GXN et al. n.d)

The project aimed at demonstrating that it is possible in practice to design buildings that allow building materials to be disassembled and used in future building projects with their current properties—and that such solutions can produce considerable resource and CO2 emission savings. (DTU 2017)

The project included also a case study, an office building project for 'De fire styrelser “(The four agencies). The project was based in specific design concepts included in circular economy, such as design for disassembly, material passport, and two important tools for intelligent design and construction: Building Information Modelling (BIM) and Virtual Design and Construction (VDC). The project also took into account social changes from ownership of buildings to lease/ rent by demand (GXN n.d a).

The conclusion of this project, according to Kasper Guldager Jensen and John Sommer (DTU 2017) was that success of a circular economy requires some important factors:

1. all building materials must be designed for disassembly. This involves architects, engineers, contractors, and manufacturers.

2. the circular mindset must be widespread, as it at happen for example with electric cars that now have a specific infrastructure for recharging. At the same time, to adopt a circular approach, it is necessary to create a market involving supply and demand and very large number of actors

3. a well-organized digital infrastructure must be established for selling and transporting the reusable building elements.

4. materials must be of a high quality to withstand assembly and disassembly. High quality materials are expensive but what determines the outcome are the costs throughout the building's life.

### 4.2.1.3 The Circle house

The Circle House project consists of 60 general housing units in Lisbjerg the largest urban development project in Aarhus. The projected is expected to be completed by 2020.

As a demonstration project it is funded by the Danish Environmental Protection Agency Development Danish Environmental Protection Agency (DEPA) through the Danish Eco-Innovation Program (Miljøteknologiske Udviklings- og Demonstrationsprogram - MUDP), and Realdania's [11]Innovation Program in Construction.The municipality of Aarhus contributes providing the land in Lisbjerg,

[11] Realdania is an independent philanthropic foundation that “*initiate and promote ideas and practical solutions in the built environment that have the capacity to drive development and change”* (Realdania 2015).

## *Building of social network*

According to Kasper Guldager Jensen, architect and direktør of GXN, since the project inception the process of network formation was facilitated by a wide acceptance of actors in entire value chain:

> *"The Association for Building Social Responsibility came in spring 2016 to interview us about the book[12]. When they left again, we had the idea of Circle House and after a couple of weeks, Lejerbo, the Building Research Institute and the City of Aarhus were included. Similarly, all the other companies in the project have joined. It has been a lot of enthusiasm all around. (…) We have gathered all the companies from the entire industry that are needed to make such a construction. Together we will devise the new circular solutions"* (Lejerbo 2017b).

The scheme below depicts the convergence of knowledge and competencies drawn from different participants in the Circle House.

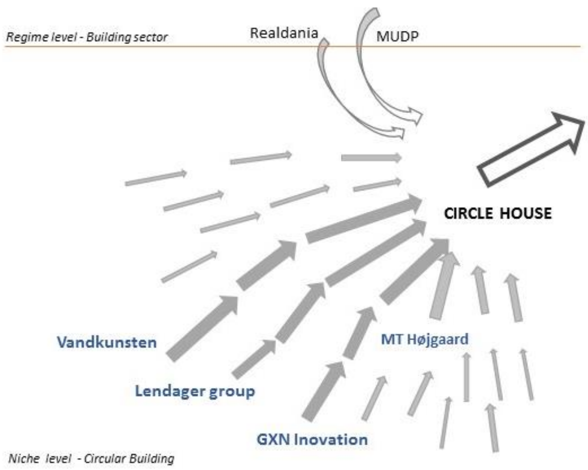


Fig.31. Convergence of actors and projects to a circular building niche formation (own creation)

The empirical data collected (see section 3.2) shows that the social network is in place and it is broad, covering the entire value chain with a combination of actors coming from previously unconnected fields and disciplines. It is also possible verify that its formation has taken place within a relatively short time. It has, however, not been possible verify the social network stability and the regularity of interaction between network participants. Considering, thus the criteria for a good network, as indicated by Raven (2010), it appears that criteria such as broadness and stability are fulfilled, but there is not enough data about the regularity of interaction between network participants.

## *Voicing and shaping of visons and expectations*

The process of expressing expectations and shaping the vision are relevant criteria when analysing chances of success for an innovation project. According to Raven (2010), the process will be much richer and more productive when an increasing number of participants share the same expectations which in turn are converging to a shared vision. In the Circle House the main major ambition of participants is to build the first general housing construction according to circular principles. This means, among other things, that the construction can be separated again, and the used items can be recycled almost without losing value (DanskArk 2017).

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12 Kasper Guldager Jensen has, along with John Sommer from MT Højgaard, written the book "Building a Circular Future". The book is about the technique and business model behind a shed house designed according to circular principles.

Although, it was not possible to find clear data about this vision was built, collected data indicates a reasonable level of alignment of between participants the main goals to the Circle house. At the very beginning, it has been this vision that most likely served as a stimulus to gather the most relevant players across the building value chain.

It is, however, possible verifying some small variations in expectations according to interests of participants. As the project is still under development it is likely that some of these expectations, and others, will become more specific as tangible results arise. The table 8 below summarizes some of these expectations that participants expressed so far.

| **Participant** | **Subject** | **Expectation** |
|---|---|---|
| Lejerbo (Developer) | Circular affordable housing | The project will serve as a national and international demonstration model to provide knowledge and experience in circular housing construction (Lejerbo 2017a) |
| FBSA (Monitoring team) | Circular solutions to building industry | *"It is our hope that the industry will bring along what we have achieved. We do not offer complete solutions or the final solution. We provide some steps on the road to achieve an open broad discussion within the industry on how to build differently, how to do a different kind of business, and how to draw up framework conditions for a better support of reuse and design for disassembly"* (Lange 2017 v) |
| GXN Innovation (Technical and stakeholder conductor | Circular system solution | *"At Circle house we try to demonstrate what circular construction is about. How far can we go and how can we provide circular system solutions at market terms. Circle house will be an important proof of concept that circular building is possible today" (Jensen 2017 v)* |
| Fællestejnestuen (Architects) | Flexibility | *"The advantage for the users of Circle House is that the flexibility of the house is a mean to vary in size (eg. Extra room or change combination of the house larger or smaller) as well as relatively easy access to the installations" (Lendager 2017 v)* |
| Fællestejnestuen (Architects) | Aesthetic in circular building | *"when creating the Circle House, we wish to take advantage of the opportunity to demonstrate that it can look differently, for example visible assemblies instead of hidden assemblies" (Nielsen 2017 v)* |
| M T Højgaard (contractor/ demonstrator) | Quality | *"Circle House project is important because it will be a demonstrator of how construct buildings of elements which have a second and third life without degenerating"*(Sommer 2017) |
| Komproment (Manufacturer - facades) | Market scalability | *We know hour facades are already circular because they are certified Cradle to Cradle [*but] *if we can cause a ripple effect, some more developers, municipalities etc will understand that circular building means (*Heidtmann 2017v) |
| Peiko (Manufacturer - Precast concrete components) | Circular solutions and products | *"Circle house is a very interesting project for us since we have a unique opportunity to develop new solutions and new products which enable the developers to design circular constructions and in the long term to allow to disassemble and recycle*" (Hog 2017v) |

Table 7. Summary of expectations that participants expressed so far.

## *Learning processes*

In SNM, it is argued by Raven (2006) should be orientated to creating alignment between sociotechnical aspects such as a technological development, the development of a user context, societal and environmental impact, industrial development and government policy. In addition, learning can also be orientated towards learning about the effectiveness of a specific technology to achieve a specific goal, about underlying assumptions and norms, or changing the rules of the games.

In the Circle House large number of actors have been involved in a dialogue process aiming at creating alignments on specific technological solutions to achieve the goals for the first circular housing construction (Lejerbo 2017). The learning process is thus based on this dialogue which in turn is enriched by previous experiences and knowledge of different actors.

An important factor that contributes to the deepening the learning process is the junction of three architecture practices in a common office, the Fællestegnestuen. This cooperation aims at developing a single project, the Circle House, but it also constitutes a learning platform to foster the exchange of information, knowledge, and experiences of circular building.

Another important contribution to the learning process is the hold of workshops. Until now several workshops have been held providing attendants with opportunities to discuss subjects as the architectural concept and principles of circular building to adopt; possibilities for building both circular, flexible and less expensive housing than the framework of the Public Housing Act (Almenboliglovens). This means approx. DKK 20,000 per square meter. (Lejerbo 2017c)

Concerning the concepts, the project will focus on the circular building concept of disassembly. According to Søren Nielsen, from Fællestgenestuen, during the initial meetings and workshops other solutions have been briefly discussed, such as i.e design for durability, but the chosen option has been the one that allows materials to be dismantled, and the use of recycled materials by almost the same value (Nielsen pers. comm.).

Before the assembly workshop, other workshops were held with different manufacturers and suppliers to search for possible reusable product solutions and materials that can be reused without having to be crushed. (FSBA n.d.)

> *"Options using concrete are a challenge that the project partners are particularly aware, because the construction uses so much concrete. If the concrete cannot be reused, it will be difficult to balance the Danish building's overall sustainability accounting"* (Lejerbo 2017).

The question of whether to build in concrete or solid wood remains open. In the innovation phase industry companies, together are discussing possible innovative solutions considering that "*the market for circular building products can become so large and diversified that the products will also be attractive in mainstream construction*" (FSBA 2017)

Another important question discussed in workshops have been the flexibility of buildings. The challenge for participants is that construction must so flexible that housing units can be changed as needed.

> *"For example, a wear facade can also be released and turned so that the other side can give the facade longer life. This type of costs of installation flexibility, and thus innovation in this particular field, is crucial in allowing construction to achieve economic objectives"* (Lejerbo 2017 c).

On this subject, architects proposed to use smaller and identical concrete walls, to allow large functional flexibility in construction. This idea created a lively discussion about the consequences of such design, such as the additional boost it would cause in construction if compared with relatively larger concrete units. (Lejerbo 2017b)

> "*Solutions were drawn on the blackboard, argued and composed in a joint effort to explore effective ways to realize the architect's' idea. Can the smaller items be stacked and mounted in series? 'Can any machines be used other than those we usually use and if yes which?' The question went around the table, and both engineers, contractors, and others laid their minds softly and contributed with solutions*" (Lejerbo 2017b).

Façade solutions have been also discussed. It was proposed the use of wear facade that can be released and turned so that the other side can give the facade a longer life. In this respect Gerti Axelsen, Head of Construction and Development at Lejerbo, explains:

> *"Since the many parts of a house have very different lifetimes, it gives a very good economic sense if you can take the parts down separately without destroying the others. We are renovating the buildings continuously*"(Lejerbo 2017d).

Another raised subject was the tong-term gains when Circle House is to be taken down. In this respect the flexibility costs were seen by participants as crucial for the construction to achieve its goals within the economic framework (Lejerbo 2017d).

The results of these discussions and the many solutions that are being developed will be attached to Circle House's tender in 2018. This will allow the bidding parties to get full insight into the discussions and solutions of innovation phase (Lejerbo 2017b).

*Summary of Circle House internal processes*

The analysis of Circle House as a demonstration project has been limited to a scarce empirical data. Firstly, because the design process is still ongoing, and secondly, due to the lack of access to data on the processes and information from participants. Therefore, the analyses of dynamics in network formation, expectations, and learning, run the risk of being considered incomplete, incorrect or missing.

Nevertheless, the internal processes observed indicate the following:

- A broad social network across the building sector value chain with high alignment is enabling a continuous development;
- A broad set of expectations is enabling the building process development in accordance with circular building principles. Although there are some variations in expectations among participants, these are still consistent with main goals. In addition, some expectations will more specific as tangible results arise with the project development;
- The learning process is enabling stabilization of solutions and is being made through exchange of knowledge and experiences mostly in Fællestegnestuen and in workshops. The alignment that has been created has enabled alignment between sociotechnical aspects such as the technological development, the user context, the industrial development.

In all these internal processes is possible verify long-terms gains from collaboration.

#### 4.2.1.4 Synthesis of niche dynamics analysis

Following a tendency to detach development from a continuous use of natural resources and downcycling waste, a number of experiments have emerged in Denmark, in recent years, aiming to close the loop of materials and construction products.

Initially, circular solutions were proposed by architects in competitions or commissioned projects aiming to explore the potential of buildings to save resources and energy through reuse/recycling of materials. The select proposals, mainly from Vandkusten Tegnestuen, described above, represent a shift from linear to a circular thinking in construction, and because it was too early they haven't been totally accepted. The reasons were either because they have not complied strictly with architecture competition rules (e.g Bolig+), or due to user's preference (e.g. Albertslund Syd). In this last case, however, the solution to reuse wood floors was accepted, which made possible creating a new business model for the initial product supplier (Nielsen 2017, person com.).

In a second phase, various initiatives emerged related to research, explorative experiments and demonstration projects based on circular building principles. Although in this phase, architects have a relevant role to play, the networks are broader and include engineers, researchers, contractors, product manufacturers and material suppliers. In addition, these initiatives started to have the financial support from government and private associations programmes which are directed to sustainable innovation and circular economy development. The niche dynamics during this phase have occurred in three separated strands represented each one by one main actor, respectively: 1) Vandkunsten Tegnestuen; 2) Lendager Group; 3) GXN Innovation (in partnership with MT Højgaard in one case). The table 9 summarizes a set of initiatives developed during this second phase, including explorative experiments, demonstration projects and exhibitions, and the corresponding objectives, networks, and physical results.

| Stream / Main actors | Concept/ technology | Initiative/ Type/ Funding | Objectives | Social network | Physical results |
|---|---|---|---|---|---|
| 1) Vandkunsten Tegnestuen | Upcycling<br>Design for disassemble<br>*Re-beauty* | ***Nordic Built Component Reuse***<br>Explorative experiment<br>Nordic Built | Stimulate the Nordic market for reuse/ recycled components.<br>Inspire and assist new practices for reuse of dismantled building components | Architects, engineers and recycling merchants | 20 full-scale prototypes |
| 2) Lendager Group | Upcycling | ***Upcycle house***<br>Demonstration project<br>Realdania | Demonstrate that the use of the upcycle principle also has economic benefits | Engineers (MOE) | Detached house with 86% upcycling materials |
| | Upcycling | ***Wasteland***<br>Exhibition<br>Realdania, Dreyers Fund, State Art Foundation | Show how CDW can be regarded as a resource involved in the production of architectural features, new buildings, and modern urban development. | Consultants, DAC (Danish Architecture Center), and funding organizations | Samples and mock-ups of upcycled material experiments.<br>Architecture projects and models. |
| 3) GXN Inovation | Upcycling<br>Design for disassemble<br>Digital production<br>Prefabrication | ***Biological House***<br>Explorative experiment<br>MUDP | Explore and demonstrate that leftover materials from agricultural industry can be upcycled into modular components of construction. | Architects, researchers, engineers, and economic consultants | Samples of upcycled panels.<br>Architecture project |
| GXN Inovation<br>+<br>M T Højgaard | Design for disassemble<br>Digital production - BIM and VDC<br>Prefabrication<br>Material passport<br>Buildings as material banks | ***Building a Circular Future***<br>Demonstration project | Inspire future buildings that are designed and constructed so that they can be dismantled without significant impairment and loss of resources. | Architects, researchers, engineers, general contractor, demolition contractor and Cradle to Cradle Denmark | Book and open-source publication |

Table 9. Circle House. Summary of initiatives developed during this second phase

The results in the table above show innovation journeys from the three different streams are been based on variations either in relation to circular building principles and technologies or the other parameters analyzed: Vandkusnten is focused in exploring the aesthetics aspects of design modules for disassemble using upcycled construction. The aim is to create beauty (i.e. re-beauty) through reused materials and keep construction components in a closed loop; Lendager Group focuses in exploring the potentials of upcycled inorganic waste from different sources including construction and demolition waste. The objective is to demonstrate trough the design the functional, aesthetic and economic potentials; GXN Innovation, in a first stage, has explored the potentials the concept of cradle to cradle, design for disassembly and prefabrication, creating solutions with upcycled agricultural industry waste. Recently, in partnership with MT Højgaard, has extended the concepts and technologies to digital design and production, and the networks have been enriched by an increasing number of actors.

Despite the differences highlighted, the increased experience has contributed to the *aggregation of learning* in two levels. The first level represents the knowledge that is transferred from project to project within the same stream. The second level is the level of an embryonic niche where learning from a variety of experiences is shared as well as circular building principles, rules, technical models and expectations, as depicted in figure XX.

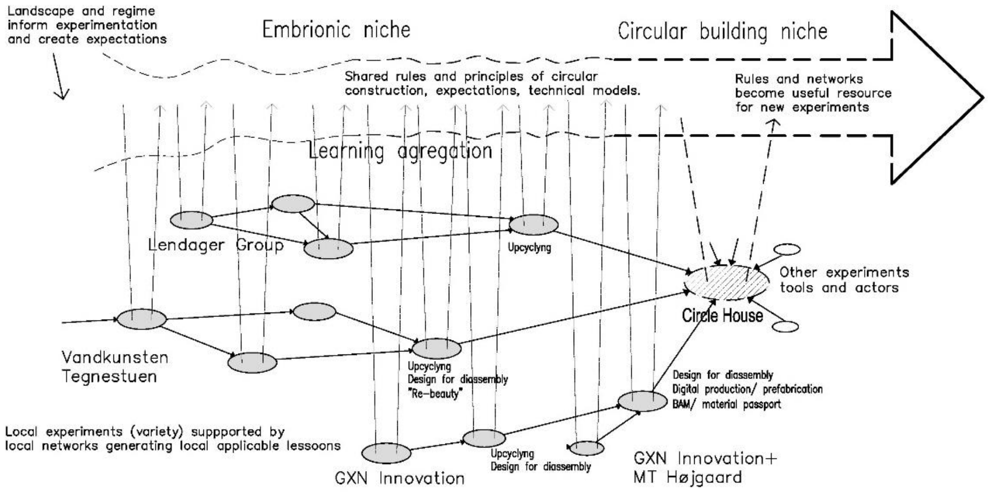


Figure 32. Trajectory of local experiments and dynamics in circular building niche formation. The figure shows a variety of local experiments contributing to niche formation. First, learning aggregation contributing to an embryonic niche. Second, by network formation, common expectations and learning enabled by the Circle House. Adapted from SMN model - Emerging technical trajectory carried out in local projects (Geels and Raven 2006)

The point where these three streams are brought together is the Circle house, through a common architectural office the Fællestejnestuen. The network involves also a diversity of other relevant participants from the entire value chain. The aim is to demonstrate through 60 urban dwellings the feasibility of building affordable housing based on design disassembly in which 90% of construction elements can be separated and reused without losing significant value. The project involves also technologies such BIM and VDC, and material passport and BAM.

As the Circle House is ongoing process the analysis only focused on internal process including the work formation, vision and expectations and learning process. The preliminary results indicate that participants in social network are aligned with broad set of expectations, despite particular interests. The learning process is based on exchange of previous experiences in workshops enabling gradual stabilization for the buildings life cycle.

For its scale, social network involved, and high expectations the Circle House represents an opportunity to demonstrate the technological, economic and environmental potential of circular building. Although it also allows to show how is to live in a social housing build according to principles of design for disassembly. Through this real-life experiment, will be possible to develop new niche rules and networks established can then become a useful resource for future niche experiences.

### 4.1.3 Discussion

The discussion section interprets and describes the significance of results presented in the previous section in order to explain new understandings and insights about the problem and, ultimately, answer the research question.

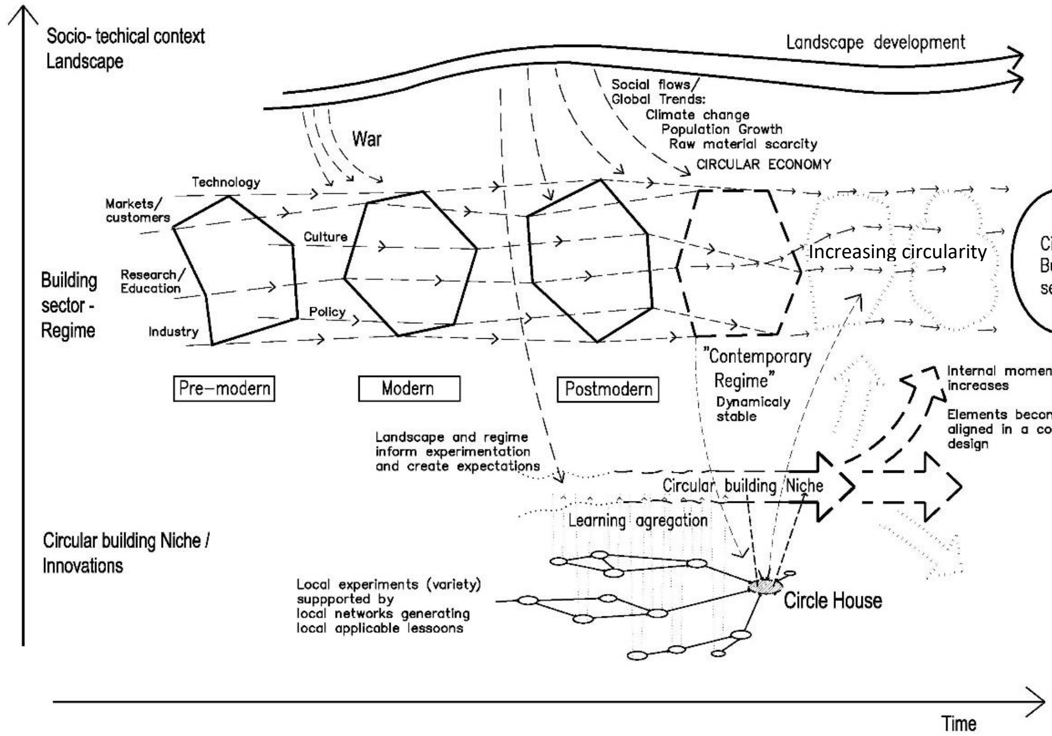


Figure 33. Synthesis of dynamics in the regime and niche level towards a circular building regime. The figure shows firstly the evolution of building sector regime and the trajectory of local experiments to the Circle house. It shows a possible contribution of Circle House and circular building niche as well to increasing circularity in the regime trajectory towards a circular building sector.

According to Raven (2010) experimental activities at the niche level are important to replace existing practices in the regime level. Although experiments are relevant to transition pathways, they are often limited to local contexts, failing thus a possible contribution to transitions at the regime level. According to Verbong & Geels (2008), this is because "*they are not situated in a broader regime analysis that takes into account the inertia of the existing system and deep structural trends*" (Verbong & Geels 2008, p. 208).

Against this background and considering the analyses results, the following discussion revolves around possible answers to the research question of this thesis.

In the following are discussed the challenges of demonstration projects in general, and the Circle House in particular, transition pathways. Two lines of discussion are followed. First, is related to the challenge of dissemination and influencing the structures of building sector. This line of discussion builds mainly on Jensen & Bronke (2011) analysis of experimental activities contribution to Danish contemporary sector development. Second, revolves around the challenge of establishing a framework for circular demonstration projects that facilitates the formation, or stabilization, of a circular building niche. This challenge is discussed in light of two different types of studies of demonstration projects: 1) the analysis demonstration projects in the Danish building sector, by Clausen (2002); 2) analysis of documented demonstration projects in the energy sector by Klitkou et al. (2013) and Bossink (2017).

*Experimental activities for the development of Danish building sector*

Experimental building (Forsøgsbyggeri) has a long tradition in the Danish context. It started after WW2 with experimental building schemes as part of a governmental programme aimed to address housing needs through a radical socio-technological change in the building sector (Clausen 2002). In this period, experimental activities were also part of the broad sectoral reorganization from the traditional craftsmanship system towards an industrialized building sector (Jensen & Bronke 2011). The role of experiments was then to contribute to the rationalization of construction process, enabling it to be controlled and optimized from a single point of planning. This rationalized system, however, began to disintegrate in the 1970s due to a combination of reasons— the economic recession resulting from the 1973 oil crisis, the apparent housing shortcoming, and societal changes (Jensen & Bronke 2011).

Therefore, in the late 1970s, the government started supporting a different type of experimental activities related to concrete experimental building projects.

In the first stage from the1970s to mid-1990s, experiments were mainly linked to the state's development programmes, involving general housing construction and specific programmes for new housing, building renovation, and urban renewal. Although this support has become an increasingly important element in the state's policy for technology barriers in the building sector, experiments only diffused marginally beyond their local settings in this stage (Jensen & Bronke 2011). This may be attributed to several factors. According to Jensen and Bronke (2011), this can be explained by the opacity regarding the strategic role of the building sector during this period:

> "*The argument that the learning from the experimental concretizations activities in the 1990ties did not diffuse because of impeding framework conditions thus appears to be a somewhat jumpy conclusion. The problem was as much that the concretization activities themselves generated a situation of strategic opaqueness. The development activities of the 1990ties thus failed to generate a coherent and attractive strategic configuration of theorization, concretization and institutionalization processes which was able to build collective capacity for coordinated sectorial change*" (Jensen & Bronke 2011, p.112)

Another explanation could be a diversity of societal changes that occurred in this period. The emergence of neoliberal political models, the urban expansion to the outskirts, new neighbourhoods with detached houses, and the demand for diversification of building models and materials might have been some of the reasons that the learning from experimental building activities did not disseminate widely.

In the late 1990s, the attempts to re-establish the building industry as an important sectoral object of development led experimental activities to play a relevant role too. According to Jensen and Bronke (2011), in this new stage, experimental activities aimed to exploit very different possibilities and strategies, drawing on '*new planning technologies, new materials, new product architectures and new forms of inter-organizational collaboration*' (p. 112). Moreover, the challenges of international competition, lack of productivity, and innovation and cooperation due to organizational fragmentation were also decisive for establishing the objectives of experimental projects and the network involving a broad range of actors from the building sector. The four experimental programmes were Casa Nova[13] (wood-house tower blocks), Confort House (integration of architecture and industrial production), Habitat (industrialization by modularizing into prefabricated elements), and PPU (new processes of planning and construction) (Jensen & Bronke 2011). The wide range of local experiences generated by these programmes did not succeed in terms of generating a new sector configuration. Instead, as stated by Jensen &

[13] Casa Nova is a demonstration project that includes the development of first wood-based industrialized system for apartment buildings. The project took advantage of new contractual arrangements and vertical integration, using IT/CAD to facilitate the coordination of the project team (Miozzo & Dewick 2004).

Bronke (2011), '*they turned into an increasingly dense patchwork of local specific productions, capable only of generating local and mutually uncoordinated effects' (p. 110).*

In the post-2001 period, sector development activities became more organized, although the sector configuration was not defined by a single strategic orientation. It can rather be '*perceived by an ongoing interplay between the structure or grammar of sector problematization*' (Jensen & Bronke 2011, p. 211). The expression of this variation of diagnosis of the sectoral lock-in and the possible solutions is represented by experimental programmes such as Digital Construction (DC) and Building Lab DK. The DC programme, hosted by the government, aimed to establish an integrated and digital information and production process. Building Lab DK, hosted by Realdania, was inspired by ideas of industrialization, modularization, and 'delivery system', and was oriented towards configurable system deliverances, independent individual construction, and organizational specialization (Jensen & Bronke 2011). In both cases, the visions for a stabilized sector based on their strategic orientations was not convincingly achieved. According to Jensen and Bronke (2011), the reasons for these failures may vary from case to case—DC because of its inability to stabilize a coherent strategic operational approach, Building Lab because of its lack of learning across the consortium/network and for paying too little attention to the support from vested interests to institutions and organizations.

Against this background, one could say that the challenge for Circle House to diffuse beyond the circular building niche is limited. If we consider that the existence of a single sectoral strategy is the main factor for a broad diffusion of experimental activities, demonstration projects would have more opportunities to disseminate beyond the local context. This would mean that circular building experiments are unlikely to make a sectoral breakthrough towards closed loops if they are not part of a single sectoral strategy. In this case, the current diversity of competing strategies and agendas in the building sector (e.g. increasing productivity, energy efficiency through renovation, sustainable buildings, digitalization of construction processes, industry internationalization) would make impossible a direct contribution of circular building experiments to a circular building sector. Moreover, even if projects such as the Circle House succeed in demonstrating the possibility to build affordable circular housing, the sector would not change significantly.

However, as stated by (Geels 2005), '*transitions are complex processes that cannot be steered from one single point of view*' (p. 453). The contribution of emergent outcomes of demonstration projects to increasing circularity in the building sector cannot be seen as an easy or a linear process. The absence of a single strategy does not make easy the challenge of changing institutionalized structures, path dependencies, or building practices.

The possible difference between the aforementioned markedly unsuccessful cases and the Circle could be the fact that the latter involves a wide range of relevant of actors from all value chains, which are also interested in being front-runners and determining the 'running pace' of the CE. According to John Sommer (2016 v) (DT):

> *'Either in the industry comes to this itself, which we can actually prove the business in this, or a still stronger political pressure will force the industry to act differently. When we see the world changing, we usually say that the best way to prepare for the future is to be part of creating it'*

Hence, the interlinkages between the building regime level and the niche level, through relevant actors from the building industry, housing market, and the research field, constitute an important contribution to a wider dissemination than in previous experimental activities. But of course, it is the result of demonstration projects by itself that is the best way to influence practices and consumer preferences in the medium term

## The role of Circle House as a demonstration project

As seen in the analysis chapter, the Circle house is considered to have the potential to become a milestone in the pathway of a circular building niche. However, it is at an early stage of development (i.e. design stage); hence, it is premature to predict the roles it plays as a demonstration project in its area of circular building. The following section discusses the possible roles of Circle House in light of results from studies of demonstration projects of construction in Denmark and the demonstration projects in transition processes to sustainable energy and transport.

As mentioned in the previous section, the experimental activities in Denmark involving demonstration within the building project context began in the 1970s. Depending on the historical and social context, these demonstration projects had different purposes. Starting from an observation of two case cases in the Danish building sector—Casa Nova and PPU Consortium[14] Clausen (2002) identified four roles of demonstration projects: *'(1) Demonstration projects as the creation of a 'learning arena', (2) demonstration projects as regulation of conflicts and cooperation, (3) demonstration projects as the mobilization of resources for innovation, and (4) demonstration projects as reduction of uncertainty.*'

According to this study, the first role of demonstration projects is to establish a forum for shared learning among project participants:

> *'Experimental building brings together the necessary complementary skills to implement systemic innovation, [...]. Experimental building can create a shared understanding of problems and solutions in development projects and also serve as a medium for disseminating "silent" knowledge, that is, the law of unprecedented knowledge that is a prerequisite for the skills of the employees' (Clausen 2002, p. 242).*

The issue, for some companies, relates to their learning situation and the long timespan of projects, which can be fragile on the one hand due to their innovation productivity dilemma, and on the other hand because it involves learning continuous work, which is sometimes inconsistent with short-term perspective of firms. In the two analysed cases, the project participants tended to leave the new collaboration in the design process and return to well-known and proved behaviour.

The second role of demonstration projects is related to the regulation of conflicts and cooperation. Experimental buildings have the potential to become a 'forum' during the development process for the redistribution of tasks and the mediation of different interests and goals. They allow the development of project participants and provide a basis for new organizational experiments that would otherwise not be possible.

The third role concerns the mobilization of resources and incentives. This role is related not only to the support from ministerial programmes but also the mobilization of internal funds and allocation of resources and attention within the development project organization.

The fourth role of the demonstration project is the reduction of uncertainty by allowing troubleshooting of technological issues and tracking of system failures. This means both testing innovations against the surrounding system and sanctioning of new technology. In this respect, Clausen (2002) stresses:

> *'Experimental building thus gets a function as "paradigmatic" (or exemplary) case, which means that it may appear as a metaphor for future development, or may form a school for the case study area. What has previously been an uncertain direction of development, or*

[14] PPU Consortium is an innovation project concerning '*Co-operation in the design process*'. The development work was carried out by a consortium of three firms—Arkitektgruppen i Århus (architect), Rambøll (consulting engineer), and Højgaard & Schultz (main contractor). '*The innovation project focuses on process innovation including a reorganised design process, the shaping of a new and more integrative collaboration between architects, consulting engineers and contractors, and furthermore, an early involvement of trade contractors and manufacturers in the design process*' (Clausen 2002, p. 17).

*perhaps even something "unthinkable" and "inexhaustible" now appears as a real possibility. The uncertainty is thereby reduced' (DT) (p. 244).*

Some important lessons from Clausen's theorization are that demonstration projects allow the testing and demonstration of not only innovation' functionality and coherence (associated with the technical success), but also the social surrounding system (associated with the business success). In addition, demonstration projects are likely to constitute platforms for future developments in construction technology and future partnerships based on the established atmosphere of confidence among the partners.

In regard to the Circle House, in spite of major differences in terms of stage of project development, objectives, stakeholders, and others, it can be said that there are some common points with the roles played by the aforementioned demonstration projects.

In relation to the first role, *creation of a 'learning arena'*, the Circle House analysis suggests that the common architecture practice, the Fællestegnestuen, and the workshops constitute important platforms for the discussion of ideas, experiences, and knowledge. These spaces are important forums for the discussion and dissemination of experience and knowledge. It is worth noting, however, that the whole demonstration project constitutes an opportunity for learning and creating a common understanding about problems and solutions among partners, as has happened in the cases of Casa Nova and PPB.

In regard to the role of *regulation of conflicts and co-operation*, it is to a certain extent related to the previous role, as workshops and other forums of discussion are part of a wide platform for collaboration where conflicts are thus mediated and regulated. The project as an organization allows this cooperation, but it is worth noting that it depends on an organizational structure and on the agency where mediators and spokesman represent an important role. Such structure and agency are particularly important in the Circle House due to its wide network of actors with different interests, agendas, and specific objectives.

In addition, this role is also important for creating a network of collaboration that may constitute the base for future partnerships in innovation projects. This can be seen, for example, in the Circle House network that integrates actors from previous experimental activities, such as the demonstration project Building a Circular Future

The role of *mobilization of resources for innovation* also represents an important role for not only the demonstration project in question but also future projects. The Circle House project was made possible by the vision and ambition that served as the basis for the mobilization of resources, whether funding or other. However, this experimental building will act as a catalyst for future funding and legitimatize the allocation resources if it demonstrates the potential and feasibility of the purported technology.

Finally, the role of "*reduction of uncertainty*" which means that uncertainty involving the implementation of circular building principles can be reduced through the Circle House. The complexity and uncertainty of circular building only can be reduced as the project goes from one stage to the next (e.g using quantitative analysis and assessment tools such as LCA and LCC).

However, the reduction of the uncertainty in the Circle House project does not seem to encompass other stages in the buildings life cycle. This means that despite the project is based in life cycle thinking, the role of reduction of uncertainty does not cover stages such as post occupancy, or the end of life. Thus, the uncertainty related to the extent how residents adhere to circular design solutions is not covered. Also, the uncertainty related with the refurbishment phase (e.g minimal maintenance, easy repair and upgrade, adaptability and flexibility) and the End of life (e.g deconstruction, selective demolition, reuse of products and components, and recycling).

The roles of Circle House, as demonstration project of circular building, have thus some similarities to the roles investigated by Clausen (2002), although with some limitations such as the reduction of uncertainty in later stages of building's life ycle.

With regard to other roles that demonstration projects of circular building can play, it is worth mentioning for the present discussion the studies Klitkou (2016) and Bossink (2017), which analyse the effect of demonstration projects in the energy and transport.

Klitkou (2016) analysed 433 demonstration projects to sustainable energy and transport concerning the period 2002–2012, including 224 projects were in Denmark, 107 projects in Norway 107, and 102 projects in Sweden, and developed a taxonomy of demonstration project categorised by their aims and roles. The analysis of database allowed Klitkou (2016) to conclude the following:

> "*proving technical feasibility was the aim in more than half of the projects, while for one-third of the projects the following aims were: to reduce building, operating and maintenance costs, to prove feasibility in commercial applications, and to facilitate learning. In less than a quarter of the projects, the aim was to contribute to the formation of knowledge networks. The other aims were less prominent* (p.107).

Bossink (2017) analysed 229 publications on sustainable energy demonstration projects. The objective of this review study has been to develop a model of sustainable energy demonstration projects that identifies distinctive types of demonstration projects. The results indicate that learning is the major effect demonstration projects in sustainable energy. They enable participants to learn about: "*1. the technical aspect of a form of sustainable energy (…); 2. the organizational aspect of producing these prototype-based products (…); 3. the marketing aspect of introducing these prototype-based products to customers and users (…); 4. the policy aspect of supporting these prototype-based products in the marketplace"* (Bossink 2017, p 1359). In addition, the learning in demonstration projects increases the capability of participants "*to contribute to the (sustainable) energy (demonstration) projects they will be working on in the near future* "(Bossink 2017, p 1359). This study, however, found no evidence that prototypes of sustainable energy that are transformed for production and use on a larger scale will automatically become market products or services.

Both studies indicate that learning plays an important role. The differences, however, consist of the importance attributed to learning. While Klitkou's study indicates that proving feasibility is the first role for half the demonstration projects and that facilitation of learning is the role for just one-third of them, Bossink's analyses show that learning is the most relevant effect of demonstration projects. In this study, *learning* means learning at all levels of the project: technical, organizational, marketing and policy.

As observed in niche analyses and particularly in Circle House analysis of internal processes, learning seems to constitute an important role in all the circular building experiments that were analysed. Learning has been important not just for the development of each and every project but also for subsequent projects. This is what happens with the Circle House that gathers the learning and knowledge from previous experiments and facilitates learning while it is being developed, which will likely contribute to other projects in the near future.

Proving technical feasibility and contributing to network formation in circular construction are also important roles in the Circle House and projects. Although some projects and prototypes of upcycling from Lendager group are trying to be transformed into market products, there is not enough evidence that proving feasibility in commercial applications constitutes a major role of demonstration projects.

To summarize the preceding discussion, we can say that comparisons between the challenges and roles of demonstration projects should consider the context in which they emerge and the objectives that are established at the beginning.

It is possible for the Circle House to have the same unsuccessful history in contributing to changes in the building sector, but if lessons from the past have been learned, it is possible that there may be less constraint on its dissemination. The context of the contemporary building sector and the fact that relevant actors in the sector are involved in the Circle House suggest that it might be possible for the dissemination to be wider than in previous experimental activities. However, this is dependent on the consistency and transparency of the results and on the possibility of achieving a high initial ambition for the first circular affordable housing.

The comparison with the role of other demonstration projects also provides some useful insights despite the differences between demonstration projects in circular building and the other demonstration projects mentioned above. Thus, it can be said that demonstration projects have some particularities, but the roles of learning, proving technical feasibility and contributing to network formation are the most relevant.

# 5. Conclusion

The objective of this master thesis is to develop knowledge about circular building demonstration projects and their contribution to the building sector's transition to a circular economy. Based on this objective, this study asks a question regarding the ways in which demonstration projects in circular building such as the Circle House contribute to increasing circularity within the building sector. In this study, the answer to this question is firstly based on an evolutionary approach of the Danish building sector, in light of the multilevel perspective approach. Secondly, the study focuses on the analysis of local experiments (i.e. explorative experiments and demonstration projects) in circular construction. Finally, the discussion revolves around the interactions and effects of circular construction demonstration projects in the building regime and at the niche level.

The building sector analysis has shown that main transitions from one period to another are not caused by one single event or driver but are instead based on co-evolution processes and are restricted by path dependencies. Major events can represent a key role in radical transitions, as happened with the impact of World War II on the transition from the pre-modern to the modern period. Moreover, transitions are preceded by several development steps, which include research experiments and niche development. The rationalized building system and industrialization developed in the modern period were enabled by niche construction technologies based on concrete, steel and modularization. These previous developments were thus crucial for sector development, as well as the response to the social and economic need for massive construction. Conversely, the transition from the modern to the post-modern regime occurred during a longer time frame, thus reflecting a diversity of socio-economic trends and influences. The experimental activities during this period are therefore characterized by a diversity of responses and reactions to the outdated structures of the modern regime.

The analysis of regime dynamics was, however, unable to directly inform how experimental activities have contributed to changes in building sector configurations. Also, it was unable to reveal any possible existing strategies to reshape the existing regime as a circular building sector. However, it was possible to verify various trends in the circular economy at the landscape level and barriers to increasing circularity at the regime level, as well as opportunities and drivers of change to a circular economy.

The analysis of barriers and drivers indicates that increasing attention is being paid to the barriers and options for a circular economy in the building sector, at the political level and the building industry and research levels.

As for the 'niche' level, the analyses showed an ongoing process of niche formation based on several demonstration projects distributed by three different streams situated in three different groups of architects. The contributions of these projects are from learning aggregation, network formation and a vision of circular construction that is still subject to interpretation. It also showed that the Circle House may be crucial in strengthening and stabilizing a circular building niche.

Regarding the ways in which demonstration projects such as the Circle House may contribute to increasing circularity in the building sector, the study was unable to provide a concrete answer. Some possible explanations, however, can be put forward:

1. Although there are path dependencies and barriers in the building sector and the Circle House is just a promise at the moment, it is likely that it may be disseminated more widely than previous building experiments in Denmark. A strong vision or ambition and relevant actors from the building sector involved in the Circle House may constitute important factors for this possible dissemination. However, it may depend on the consistency and transparency results and the possibility to successfully achieve the high ambition of becoming the first circular affordable housing.

2. Although demonstration projects in circular construction have some particularities, such as a short life span compared to the relatively long lives of the buildings, it may be possible for the Circle House to perform important roles at the niche level that could be important for future demonstration projects. These possible roles are:

- Learning platform: Demonstration projects constitute forums for shared learning among project participants. They bring together complementary skills that are necessary to implement innovation in building systems innovation. Learning may involve various aspects: technical aspects of circular building; organizational aspects related to design and production; scale-up and marketing aspects of introducing the circular building technology, circular products, and reused/recycled materials in the market place; and policy and regulatory aspects of supporting circular building.
- Regulating conflicts and cooperation: Demonstration projects constitute bases for the collaboration and mediation of worldviews, interests and goals of the project's participants. They have the potential to strengthen the trust among project participants and contribute to changes to the silo thinking culture.
- Proving technical feasibility: Demonstration projects allow testing and sanction circular construction technologies and tracking of system failures.
- Contributing to network formation: Demonstration projects in circular construction can contribute to gathering a broad social network, including players across the building sector value chain, as seen in the Circle House. The network should also involve users in generating the second order of the learning process; however, their involvement is not always relevant for industrial niche projects such as the Circle House.

Further, due to the importance of understanding potential factors that hinder the nurturing phase of circular building and its dissemination, future research could ask how to transform concrete elements in the Circle House from old to new use and explore related market issues.

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# Annexe 1

Advisory Board for Circular Economy - Recommendations to the Government

| Recommendations to building sector | Description |
|---|---|
| 7. *Promote research, development, testing, demonstration and marketing of circular solutions and technologies* | This recommendation aims at allocating new funds to circular economy R&D through existing multi-annual funding schemes: Innovation Fund, Eco-Innovation Program- MUDP (Miljøteknologisk Udviklings- og Demonstrationsprogram), and Market Demand Fund. The Advisory Board also recommends enhanced collaboration between companies and research institutions, in order to ensured that results in solutions that can easily be transformed into practice, accelerating the transformation into circular economy. |
| 10. *Strengthen circular product policy in, among other things, eco-design directive.* | The current product regulation does not promote the market for circular solutions, but focuses primarily on energy consumption in the use phase. This means that companies do not have sufficient incentives to design circularly, and citizens have limited opportunities to choose circular products and services. As a result, products are not designed to be repaired, disassembled, recycled and recycled. The recommendation aims at promoting circular design through the EU Eco-design Directive, which is gradually expanded to include more product groups, particularly products designed according circular economy principles. In addition, the recommendation indicates that Denmark must participate actively in the EU's in the development of a new method for assessing environmental performance products (PEF) which include circularity differential indicators. |
| 12. *Draw up circular building regulations* | From 2020 all new buildings should comply with building regulation which include building information requirements such as information about material content, the amount of recycled, recycled and recyclable materials, as well as the amount and number of undesirable substances included in the building. Also in 2020, a voluntary sustainability class should be introduced, which will form the basis for a mandatory sustainability class from 2025. |
| 13. *Develop standardized building and product passport.* | The recommendation aims at developing a standardized digital and freely accessible building passport, as well as a product database for suppliers with digital information sheets for building products. In that sense, Danish Standard should establish and operate a secretariat or development of an international standard for product passports. |
| 17. *Build and buy into the public sector based on total economy and life cycle calculations.* | This recommendation on public building and procurement includes proposals for development of life cycle or total cost tools and the requirements for using full-cost tools as the primary economic allocation criterion for the purchase of selected products and total public construction over 5 million kr. |
| 26. *Expand selective demolition of construction* | The selective demolition is recommended either entire buildings or major renovations. Prior to selective demolition, a demolition plan should be prepared for mapping materials with problematic substances, materials to reuse/recycle and recycle value, as well as a description for how demolition should take place. The recommendation also points out that demolition plan must be prepared by a certified company or specially trained person. |

Table 8. Summary of Advisory Board's recommendations related with building sector