BAMB
BUILDINGS AS MATERIAL BANKS

D1 SYNTHESIS OF THE STATE-OF-THE-ART

Key barriers and opportunities for Materials Passports and Reversible Building Design in the current system

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CONTENT

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1 INTRODUCTION

1.1 The BAMB Project - Buildings As Material Banks

In BAMB, 16 partners from 8 European countries are working together with one mission – enabling a systemic shift in the building sector by investigating and creating circular solutions. Today, building materials end up as waste when no longer needed, meanwhile destroying ecosystems, increasing environmental costs, and creating risks of resource scarcity. To create a sustainable future, the building sector needs to move towards a circular system, a pattern in which buildings and building materials are used, reused, adapted and re-built over and over again. Whether an industry goes circular or not depends on the value of the materials within it – worthless materials are considered as waste, while valuable materials are reused or recycled. Increased value equals less waste, and that is what BAMB is creating – ways to maintain and increase the value of building materials.

BAMB will contribute to the enablement of a systemic shift where buildings designed for Change can be incorporated into a circular economy. Through design and circular value chains, materials in buildings maintain their value – in a sector producing less waste and using less virgin resources. Instead of being to-be waste, buildings will function as banks of valuable materials, building materials and building systems – conserving material value and functionality, so materials and building components can be reused, and thus decreasing the need for primary resource mining. The project is developing and integrating approaches, methods and tools that will enable the shift: Materials Passports and Reversible Building Design – supported by new business models, policy propositions, and management and decision-making models. During the course of the project, these new approaches will be demonstrated and refined with input from 6 pilots. The BAMB project started in September 2015 and will progress for 3.5 years as an innovation action within the EU funded Horizon 2020 program.

Activities within the BAMB project are divided in the following work packages:

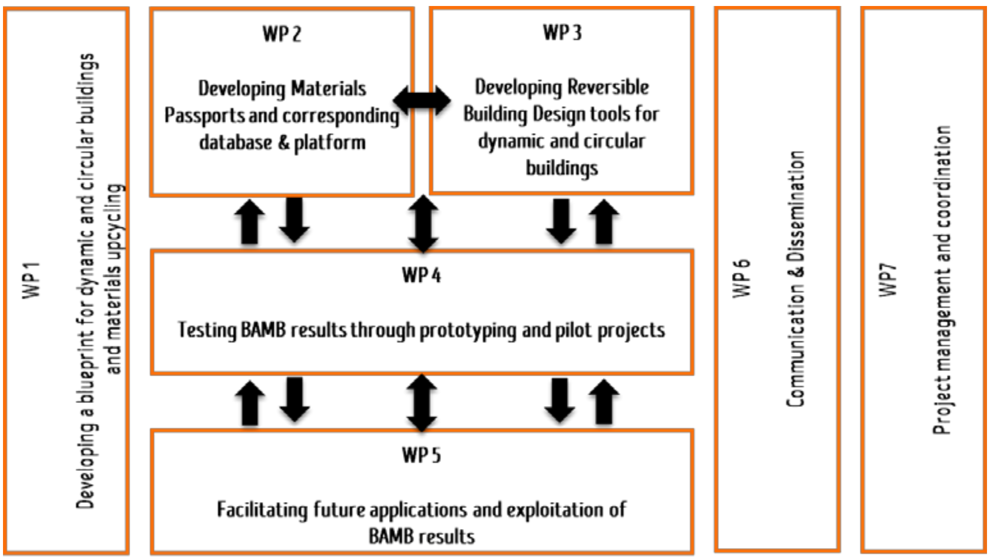

Figure 1: work package structure within the BAMB project

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1.2 Description of WP1 activities

Within the first work package of the BAMB project (WP1), the current built environment is investigated, barriers and opportunities are identified and a shared vision and blueprint for a future system configuration is being developed. Through participative reflexive monitoring, the essential backgrounds and outcomes of BAMB are enriched. WP1 accumulates lessons from all content related work packages (i.e.WP2 to WP5), in order to identify barriers and opportunities for a transition towards an envisioned systemic innovation[1]. Reflexive monitoring of the pilot projects within WP4 is an important source of information, as the pilot projects involve real-life developments and external stakeholders 'in the field'. Participation of all involved partners is crucial to (1) align, connect and integrate different visions and approaches and (2) to (inter)actively learn from each other's actions and results. A learning and monitoring framework is gradually being developed, mostly through interactive, interdisciplinary and co-creative workshops and exchange. These workshops are also used to give feedback to all BAMB partners about the most important insights gathered during WP1 activities, such as the monitoring of the pilot cases, enriching the developments of each work package.

1.3 Why this report?

This report is the result of joint efforts within the BAMB consortium, describing and/or analysing Business as Usual (BaU) and also niche activities within the partners' discipline(s). These interdisciplinary activities made it possible to answer the following key questions:

- *Why are Design/Build for Change and Circular Economy not yet (fully) integrated in the current building practice and related policy?*
- *What are the main barriers and opportunities within the current system for implementing Materials Passports and Reversible Building Design Protocols?*

This synthesis report (D1) is a *snapshot* of the current system, mainly based on desk research and available expertise within the BAMB consortium. As forthcoming BAMB activities (especially linked to the pilots and the business modelling) and interactions with stakeholders outside the BAMB consortium will bring along new insights, as well as new opportunities and barriers, modelling of the current system will be refined on a regular basis during the BAMB project. The outcome of this learning process will be detailed in deliverable D3.

1.4 Link with other BAMB activities

This synthesis report and related documents serve as a basis for:

- the development of a shared vision and setting up a blueprint for a desired/future system (WP1-Task 4 & D2), as well as a refined description of opportunities and barriers (+refined blueprint) at the end of the project (WP1-Task 9 & D3)

[1] A **systemic innovation** is a fundamental change in the way society's needs are provided for. Systemic innovations include co-aligned changes in deeply ingrained patterns of behaviour within the structures they are embedded. The term here is used as synonym for transition. (http://transitiepraktijk.nl/nl/experiment/definitions)

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- the user requirement analysis related to Materials Passports (WP2-Task 1 and D4[2])
- the identification of indicators for reuse and disassembly potential (*WP3-Task 1*) and criteria for measuring building and system transformation capacity (*WP2-Task 8*), and related user requirement analysis (*WP3-Tasks 4 and 16*)
- the identification of data requirements for measuring resource productivity (*WP5-Action 1-Task 1*) and user requirement analysis related to a Building Level Integrated Decision Making Model (*WP5-Action 1-Task 2*)
- the elaboration on business needs and opportunities for Materials Passports and Reversible Building Design (*WP5-Action 2-Tasks 2 and 3*)
- the identification of key policy measures and standards impeding or facilitating the implementation of circular and reversible building design (*WP5-Action 3-Task 1*)

1.5 Outline of the report

In Chapter 2, a methodologic framework is revealed in order to analyse the main research questions presented in section 1.3. This methodologic framework is built on two pillars: i.e. state-of-the-art analysis and transition management. In Chapter 3, some near past, current and upcoming trends – pressuring business-as-usual activities/actors and announcing a systemic change – are elaborated on. Business-as-usual and leading activities are further characterized in Chapter 4 from a process perspective as well as from a value network point of view. In Chapter 5, niche activities within the development of Materials Passports and Reversible Building Design Protocols – as potential enablers for a systemic change – are investigated. Furthermore, an idealized value network – with new relations between existing and also new actors – is created if we would consider a complete integration of Design/Build for Change and Circular Economy within the built environment. Based on this, opportunities and barriers for the further development of Materials Passports and Reversible Design Protocols are grouped from a systemic perspective within Chapter 6. Within Chapter 7 the parts of the puzzle are put together, in order to answer (partly) the research questions presented in section 1.3. Within the Annexes the executive summaries of the underlying state-of-the-art reports are provided.

Important notice: the underlying state-of-the-art reports are not part of this deliverable and will accordingly not be made public.

[2] Deliverable D4 has successfully been delivered to the European Commission in June 2016

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2 METHODOLOGY

2.1 State-of-the-art reporting

Most input for the research questions presented within the Introduction has been provided through desk research and collaboration with experts with different fields of expertise. Business-as-usual and current niche activities have been described within different State-of-the-Art reports on the following subjects:

- Materials Passports and their role within circular economy (*link with WP2*)
- Analysis of the existing building stock within some European countries, related to construction types & methods, causes for demolition and major refurbishment actions, and construction and demolition waste (*link with WP3*)
- Overview of existing policy and standards facilitating or impeding circular and reversible building design within European Union and some European countries and regions (*link with WP5-Action 3*)
- current situation of Building Information Modelling (*link with WP5 Action 1*)
- Value chain and value network mapping at building product and building level (*link with WP5 Action 2*)

Executive summaries of these underlying State-of-the-Art reports are provided within Annex A of this document.

Due to the **interdisciplinary character** of this research action, interactions between the different authors and specialists have been stimulated in order to couple the different domains (and related research question) with each other. Although this resulted inevitably in overlap between the different underlying reports, important insights have been highlighted by the authors – and the BAMB consortium in general – for further use in other activities within the BAMB project.

2.2 Transition management and system thinking

Besides the state-of-the art reporting, this synthesis report is also based on the knowledge that a full implementation of Circular Economy and Design/Build for Change within the building practice and policy will only be made possible through a series of radical and structural changes within the built environment – not only involving the creation of new construction systems and building product, but also related to policy, financing, business and value creation and legal affairs. These 'transitions' are long-term processes that try to handle the inherent complexity and insecurity of societal systems. Although transition (management) approaches are not to be considered as a silver bullet methodology for actually solving issues on lack of sustainability, we use it as a framework to co-develop effective sustainability approaches.

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Transitions[3] play simultaneously at different levels of structure, scale, organisation and action (possibilities) for influence. This co-evolution characteristic is expressed in the '**multi-level perspective**' that distinguishes landscapes, regimes and niches. More information about the multi-level perspective is given in Box 1.

Because of the complex structure of the current built environment and the interactions between society, science, state and market, a reductionist approach – only looking at these socio-technical system elements individually – is insufficient to tackle the research questions presented in the Introduction. Instead, a systemic approach is suggested, looking at the interactions within and outside the built environment in order to induce systemic changes within the current regime.

In order to have a better understanding of the current built environment – allowing us to answer the research questions presented in the introduction – landscape trends and niche activities pressuring the current regime needs to be analysed. This is respectively done in Chapters 3 and 5.

[3] A **transition** is a fundamental change in the way society's needs are provided for. Transitions include co-aligned changes in deeply ingrained patterns of behaviour within the structures they are embedded. The term here is used as synonym for systemic innovation. (http://transitiepraktijk.nl/nl/experiment/definitions)

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Box 1: Multi-level perspective, based on VITO (2013)

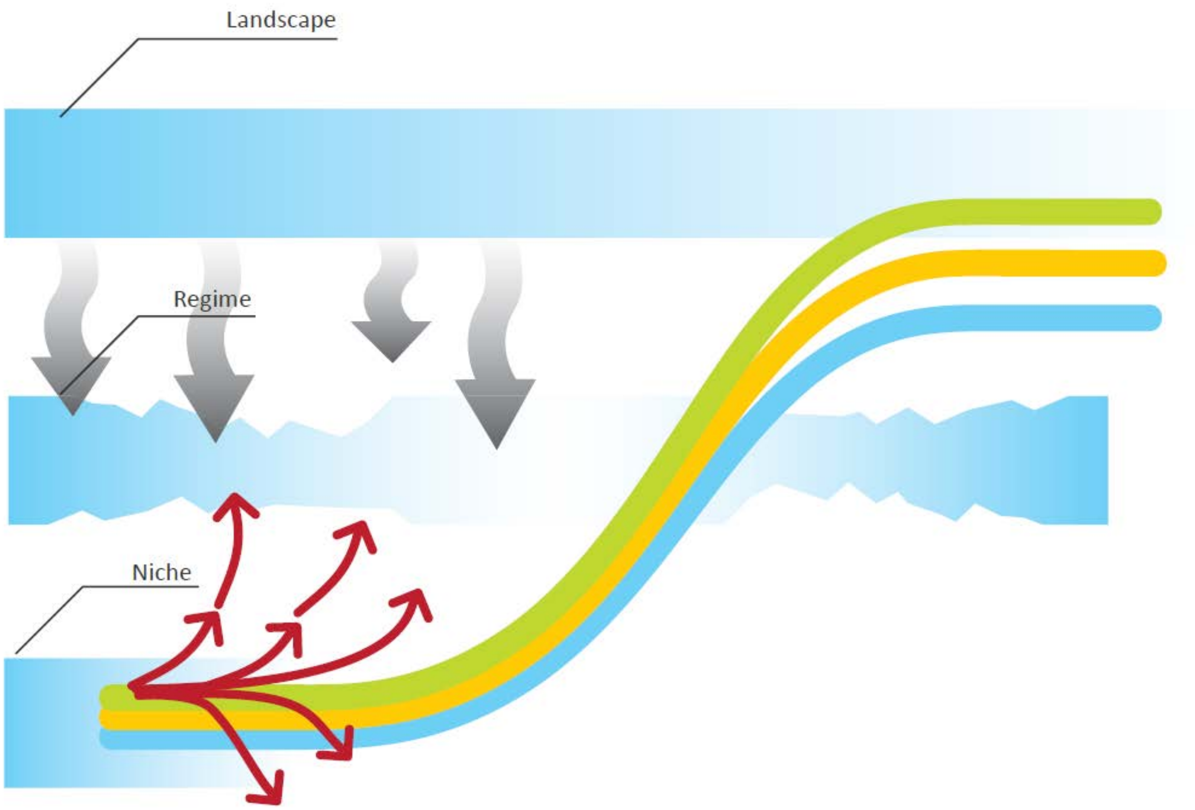

Figure 2: multi-level perspective, based on VITO (2013)

At the **landscape** level 'gradients of force' are in play: 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…). However, these prevailing evolutions and trends exert external pressure on the systems in place.

A **regime** refers to the dominant culture, structure and practice embodied in physical and immaterial infrastructures (e.g. roads, power grids, routines, actor-networks, regulations, government and policy …). Regimes are the backbone of the stability of ruling societal systems and they have a characteristic rigidity that typically prevents innovations from altering the standing structures fundamentally.

Niches are often little visible small scale segments in society. In such protected environments, novelties and innovations are created and tested. These novelties can be (combinations of) new technologies, new rules and legislation, new concepts, new organizations, innovative business models and financing mechanisms… Niches accommodate incubators for transition experiments and proofs of concept of radical innovations.

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3 Landscape trends

In this chapter an overview is given of some landscape trends (see section 2.2 for further explanation) pressuring the current regime activities and agents. In fact, landscape trends announce a systemic change. The main input of this chapter is provided by the underlying state-of-the-art reports (see section 2.1 for an overview and Annex A for executive summaries), explaining why the focus is given on European countries and regions addressed within the BAMB project. Additional information (including statistics and examples) providing evidences of these trends are clearly referenced.

3.1 Increasing awareness of sustainability and circular economy

In 2008, the world reached a unique, yet invisible milestone: i.e. for the first time in history **more than half of mankind lived in urban areas**. By 2030, urbanisation is expected to rise to 75-80% compared to the situation in 2008 (Debacker, 2009). Cities are big energy consumers and responsible for 80% of CO_2 emissions. Each day, a city with a million inhabitants consumes on average 9500 tonnes fossil fuel, 625.000 tonnes water, 32.000 tonnes oxygen, emits 29.000 tonnes CO_2 and dumps 500.000 tonnes used water (Battle, 2007). Although urban areas have an important part in environmental issues, policy-makers and experts increasingly recognise the **potential value of cities to long-term sustainability**. For example, the City of London is a model of transport efficiency with over 95% of all commuters using rail, bus or the underground to get to work (UNFPA; 2008).

At EU level, the construction industry is one of the largest industry sectors (10% of the GDP of the EU and 20 million jobs (CEN, 2015). This industry is also responsible for 40% of greenhouse gas emissions in Europe and uses more than 50% of the materials taken from the earth's crust. Construction and Demolition (C&D) waste[4] and building manufacturers generate more than 45% of the total controlled waste. (EIB, 2015; EEA, 2001; Eurostat 2006, McCormick, 2016)

Undeniably, the **built environment is a big consumer of resources and is responsible for a dominant share of global greenhouse gas emissions**: not only in relation to electricity and heat production for buildings, but also related to manufacturing and construction processes. From all industrial processes, cement and steel production – two pillars of the European building industry – are responsible for half of GHG emissions. Most emission reductions from manufacturing industries were achieved by 1993, due to efficiency improvements and a fuel shift from carbon intensive solid fuels to less carbon intensive gaseous fuels. (EEA, 2006; Debacker 2009)

Based on studies of the IPCC (2007), **the building sector has the biggest potential to mitigate GHG emissions at the lowest cost** (see Figure 3); over 80% of the buildings potential can be identified at 'negative cost'. According to IPCC (2007) about 30% of the projected CO_2 emissions could be avoided by 2030 with net economic benefit, by means of energy efficiency options for new and existing buildings. However, with increasing population growth and wealth, energy efficiency measures alone will not be enough. Effective measures, such as the use of

[4] More information on the generation of C&D waste is given in section 3.2.

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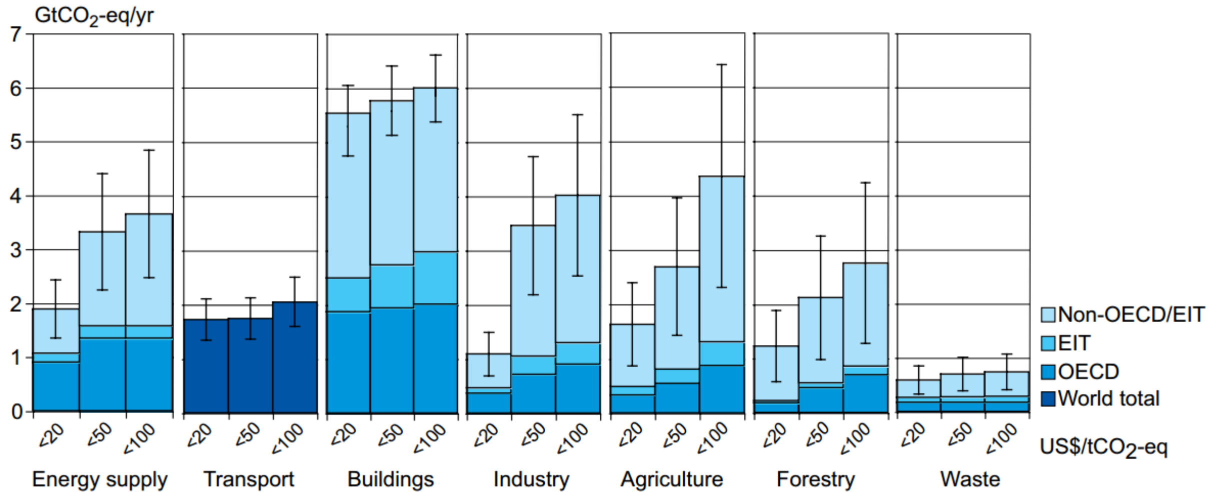
renewable energy sources, are necessary to support carbon neutral or even carbon negative processes, in buildings as well as in the manufacturing industry. (Debacker, 2009)



(potential at <US\$100/ tCO_2-eq: 2.4 - 4.7 Gt CO_2-eq/yr)	(potential at <US\$100/ tCO_2-eq: 1.6 - 2.5 Gt CO_2-eq/yr)	(potential at <US\$100/ tCO_2-eq: 5.3 -6.7 Gt CO_2-eq/yr)	(potential at <US\$100/ tCO_2-eq: 2.5 - 5.5 Gt CO_2-eq/yr)	(potential at <US\$100/ tCO_2-eq: 2.3 -6.4 Gt CO_2-eq/yr)	(potential at <US\$100/ tCO_2-eq: 1.3 - 4.2 Gt CO_2-eq/yr)	(potential at <US\$100/ tCO_2-eq: 0.4 - 1 Gt CO_2-eq/yr)

Figure 3: estimated sectoral economic potential for global mitigation for different regions as a function of carbon price in 2030, based on IPCC (2007)

Although Europe has been a standard-bearer of environmental consciousness, **the global economic crisis, soaring commodity prices and growing awareness of the human impact on the environment have pushed the circular economy agenda into mainstream policy debate**. In Europe today, circular economy measures can be found in various environmental and economic policies. The EU has established resource-related policy goals, extending as far ahead as 2050, as part of its Europe 2020 strategy (EC, 2015; EC, 2011a; 2011b). In many cases, these goals are accompanied by relevant targets and indicators to track implementation. (EMF et al., 2014)

Besides governmental measures, also **societal and commercial initiatives emerge, supporting circular economy** ideas. In 2010, The Ellen MacArthur Foundation (EMF) was established with the aim of accelerating the transition to the circular economy. Since its creation, the foundation has emerged as a global thought leader, establishing circular economy on the agenda of decision makers across business, government and academia. (EMF, 2015)

According to EMF et al. (2014), other trends indicate that the linear model is reaching its limits:

- In modern manufacturing processes, **opportunities to increase efficiency** still exist, but the gains **are largely incremental and insufficient to generate real competitive advantage or differentiation**.

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- An unintended consequence of eco-efficiency has been **accelerating energy use and resource depletion due to the 'rebound effect'[5],** which has negative impacts when improvements to energy and resource efficiency drive increases in the real amounts of materials and energy used.
- **Agricultural productivity is growing more slowly than ever before**, and soil fertility and even the nutritional value of foods are declining.
- The **risk to supply security and safety** associated with long, elaborately optimised global supply chains **appears to be increasing**.[6]
- Many **production sites with excessive requirements for virgin resources**—water, land or atmosphere—**are struggling to renew their licence to operate** as they compete in sensitive local resource markets.

3.2 Down-cycling of construction and demolition waste and landfilling practices

According to the European Environment Agency (EEA), quantity of waste is defined as an indicator of material efficiency of society; it represents an enormous loss of resources in the form of materials and energy. Excessive quantities can result from inefficient production processes, poor durability of goods, excessive consumption patterns, but also due to short term and inadequate design. (EEA, 2001)

The building and construction sector generates about one third[7] of all waste in the EU (Bio Intelligence et al., 2011). On member state level, similar figures are observed: e.g. 36.7% in Belgium, 41.6% in The Netherlands and 41.5% in the UK (based on weight), as shown in Figure 4 (Statistics Belgium, 2016; CBS, 2015a; DEFRA, 2015). Although other sectors may have a different level of importance, **construction and demolition (C&D) waste remains to have a dominant share of the yearly total waste production**. Based on a study performed by Bio Intelligence et al.(2011), the composition of C&D waste (excluded excavation material) for most studied EU member states is composed of concrete and masonry (ranging from 40% to 84%), asphalt[8] (ranging from 4% to 26%) and other mineral waste (2% to 9%); for some analysed North-Eastern European countries such as Finland and Estonia, metal (up to 40%) and wood (up to 41%) are the biggest contributors to the national C&D waste. An overview is given in Table 1.

[5] The **'rebound effect'** or **'take-back effect'** is the reduction in expected gains from new technologies that increase the efficiency of resource use, because of behavioural or other systemic responses. These responses usually tend to offset the beneficial effects of the new technology or other measures taken. While the literature on the rebound effect generally focuses on the effect of technological improvements on energy consumption, the theory can also be applied to the use of any natural resource or other input, such as labour. The rebound effect is generally expressed as a ratio of the lost benefit compared to the expected environmental benefit when holding consumption constant.

[6] There is also a trend to source products at best shore locations or nearby partners/ suppliers. These additional procurement and purchasing costs are quickly equalized by reduced transportation costs and reduced overall inventory levels.

[7] According to Bio Intelligence et al. (2011), current EU data on construction and demolition (C&D) waste does not allow for a good estimation of the total quantities in Europe, amongst others due to a lack of harmonised reporting mechanisms and clear definitions of construction and demolition waste. It is therefore more reliable to look at C&D waste for each member state separately.

[8] Asphalt waste fractions are generally attributed to road infrastructure and less to building demolition. However, most literature on C&D waste combine both perspectives; i.e. building and infrastructure.

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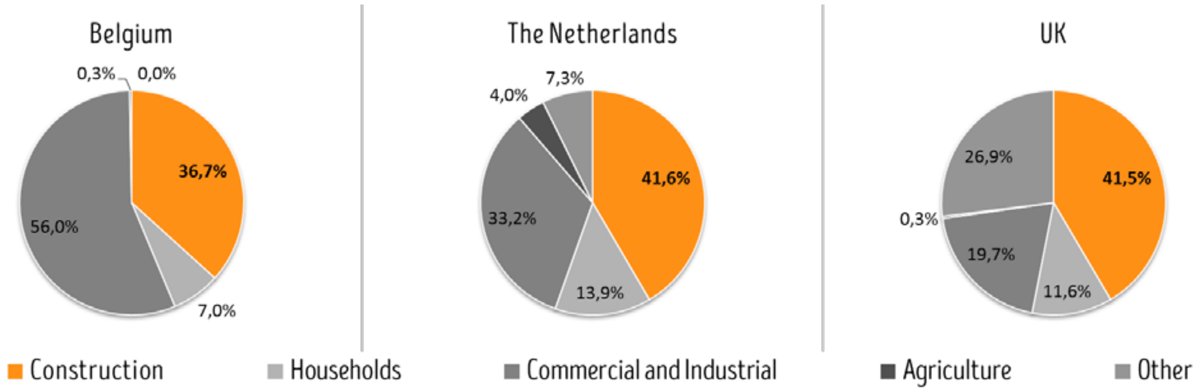

Figure 4: waste production per sector for Belgium, The Netherlands and the UK in the year 2012, based on Statistics Belgium (2016), CBS (2015a) and DEFRA (2015)

Table 1: material composition of C&D waste for some European countries and regions - without excavation material, based on Bio-Intelligence et al. (2011) and adapted from UBA (2008)[9]

Country	Netherlands	Flanders	Denmark	Estonia	Finland	Czech Republic	Ireland	Spain	Germany
Year	2001	2000	2003	2006	2006	2006	1996	2005	2007
Concrete	40%	41%	32%	17%	33%	33%	80%	12%	70%
Masonry	25%	43%	8%			35%		54%	
Other mineral waste	2%	-	0%	0%	-	-	0%	9%	-
Total mineral waste	**67%**	**84%**	**40%**	**17%**	**33%**	**68%**	**80%**	**75%**	**70%**
Asphalt	26%	12%	24%	9%	-	-	4%	5%	27%
Wood	2%	2%	-	-	41%	-	-	4%	-
Metal	1%	0,20%	-	40%	14%	-	4%	3%	-
Gypsum	-	0,30%	-	-	-	-	-	0,2%	0,4%
Plastics	-	0,10%	-	-	-	-	-	2%	-
Miscellaneous	7%	2%	36%	34%	12%	32%	12%	12%	3%

During the past 30 years, there have been an increasing number of initiatives to improve waste management, by the EU, governments, councils, NGOs and private companies, including programmes for reducing the quantities of waste. (Wolff, 2016; Lindblom, 2016, Paparella 2016; Debacker, 2009)

Small and densely built countries such as Belgium, the Netherlands and Denmark, have decades of experience in treating inert stony materials for other applications, primarily due to a lack of space (Debacker, 2009), leading first to high landfill taxes and also a disposal ban of stony and other fractions that could lead to useful applications, reuse and recycling. Other countries such Germany, the UK, Austria and Poland followed the example, thanks to focussed waste

[9] Bio-Intelligence et al. have corrected the figures highlighted in green to allow comparable data. Excavated materials have been excluded in the "other mineral waste" fraction for Denmark, Estonia and Ireland.

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management policies (Bio-Intelligence, 2011). On paper, all the above mentioned countries already fulfil the European Waste Framework Directive (EU, 2008) target to reuse, recycle – or other form of material recovery – 70% by weight of all non-hazardous national C&D waste (excluding excavated materials) by 2020. However, looking at current recycling and recovery techniques, **most stony C&D waste fractions, such as concrete and masonry, are down-cycled**. Only a small (selectively sorted) fraction is actually reused, e.g. as reclaimed clay bricks and tiles, or really used for material recycling, e.g. as secondary granulates for concrete. The bulk of demolition waste in the countries mentioned above is characterised by a mixed stony fraction that is usually broken down into granulates of different size and quality for a predominant use as filler material for road or building foundation works (Durmisevic et al., 2016). These **low grade applications are only a short-term solution, as they put a lot of pressure on the scarce space in Europe**. Knowing that the amount of space devoted to roads in Europe in 2002 was equal to the space of housing, and the two together compete with agriculture (McDonough, 2002), the increasing pace at which stony materials are down-cycled for transport infrastructure (and other low grade applications) is a scary thought; future generations will have to cope with less material and land resources due to decisions made now and in the past. (Debacker, 2009)

In other European countries, such as Bosnia Herzegovina (BiH), **C&D waste recovery and recycling is far from being a well-established practice**, because the **national waste management system is still based on disposing waste in regional sanitary landfills**. Similar trends are observed in other South and Central European countries such as Greece, Italy and Portugal (Bio-Intelligence, 2011). Recently, BiH passed a legal framework on waste management introducing the obligation to develop waste management plans for the purpose of building construction, reconstruction and demolition (Durmisevic et al., 2016). Also in Portugal, specific measures have been put into force to prevent and manage C&D waste. For public construction at least 5% pf recycled materials need to be used. Also, landfill taxes for inert C&D waste have been increased, with the main purpose to divert it from landfill disposal (Henrotay et al., 2016).

Despite the many (policy) efforts to reduce and prevent it, C&D waste still puts **a lot of pressure on the way we (re)use and try to protect our scarcely available material and spatial resources.** The situation will become even more complex, due to **upcoming composite waste fractions** such as thermal insulation (e.g. contaminating stony debris) and coatings (e.g. fixed to glass fractions) – used on a regular basis from the 1970s and installed in practically all new buildings due to energy performance regulations. Selective demolition and sorting of these upcoming waste fractions is in the majority of demolition cases seen as technically and/or financially unfeasible (EMIS 2016, OVAM 2012).

The underlying cause(s) of these pressures have to be predominantly found within the design of current and past buildings and building products. **Most modern and post-modern buildings and their constituent parts are not designed (and accordingly built) to change easily and building products were not designed (and manufactured accordingly) for recovery and reuse**. As will be detailed in section 3.3, it is often technically easier and less expensive to demolish current buildings or major parts of it. More than ever before, there is a need for Design strategies that will support Change (cf. Design for Change) within new and existing buildings, and circular/cascading solutions for new and existing building products.

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3.3 Building vacancy and premature demolition

Real-estate developers warn that existing building stock does not match with the unremitting and ever increasing changes in market demand. This difference in supply and demand results in huge building vacancy and consequently in loss of real estate value. (Planbureau voor de Leefomgeving, 2013; Durmisevic et al., 2016)

A study from the Dutch government has shown that 12.4% of the additions to the total residential buildings between January 2012 and July 2015 are transformations of non-residential buildings into residential (CBS, 2015e). This is mainly related to the transformation of offices into apartments due to a high vacancy rate of office spaces. In 2014 more than 8 million square meters of Dutch office space was vacant (Durmisevic et al., 2016). Despite the fact that the vacancy rate for offices in the Netherlands is exceptionally high – i.e. 10,7% of the total office stock of 69,5 million m² – new office buildings are still being built, indicating that current (office) buildings do not reflect the requirements of the end users (EIB, 2015). Only 25% of vacant offices have the capability to be transformed into dwellings. That gives a potential of 20.000 new homes in vacant offices (EIB, 2015). Major barriers related to transformation of offices into apartments are related to the reduction of natural light due to the width and depth of the building block, fire escape routes and number of staircases needed for apartment buildings. (Durmisevic et al., 2016)

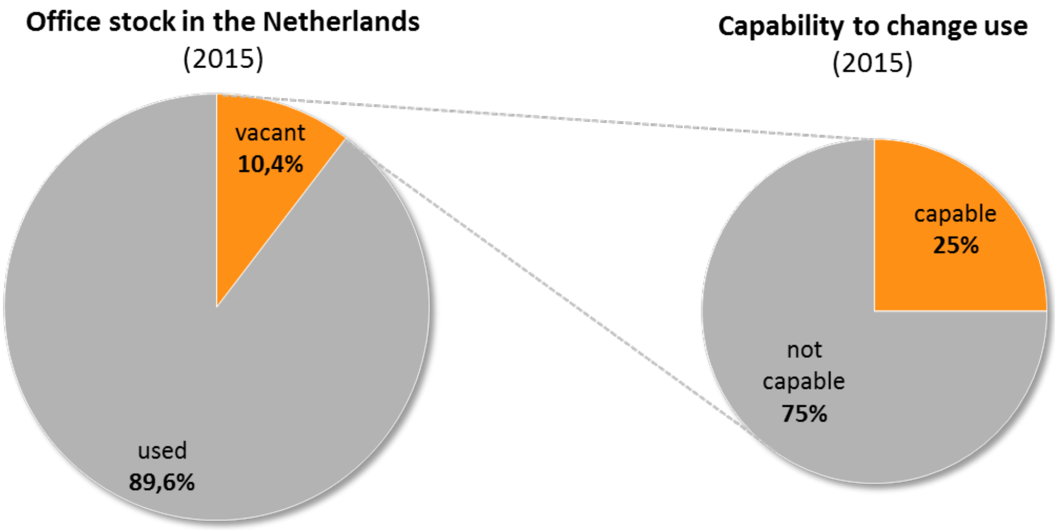

Figure 5: capability to change vacant office buildings in the Netherlands, based on EIB (2015) and Durmisevic et al. (2015)

Within the Brussels Capital Region (BCR) similar trends are visible. In 2014, 8.2% of the office space was vacant. If the hidden vacancy is taken into account as well, the average amount of empty office space increased even to 18% of the entire office stock in 2008 (Doornaert,2009). This **hidden vacancy includes the vacant office surface unavailable on the market** for example because buildings are abandoned or buildings have lost their original qualities. **The major part of this hidden vacancy is left for deterioration and has an uncertain future** (Vergauwen, 2011). Those office buildings often require intensive refurbishment activities in order to be used again (Doornaert 2009; Doornaert 2011). Despite a high vacancy rate, new

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office buildings are still being planned and constructed. These new buildings compete with the old office buildings due to higher energy performance and better locations (Jeanne Dekkers Architectuur, 2012). Due to the urgent lack of educational and residential facilities, the BCR creates opportunities for reconversion of vacant surfaces into new (mixed) functions, like schools, dwellings and other functions (Böhlke, 2007; Vergauwen, 2011). Until the nineties, vacant office buildings were barely transformed into dwellings. From then, the reconversion of obsolete office buildings has increased (CLI, 1997; BRAT, 2007) especially in areas with a high residential value. At the moment, (only) 45.000 m² office area is transformed into dwellings each year in the BCR (Doornaert et al., 2008). (Vandenbroucke and Paduart, 2016)

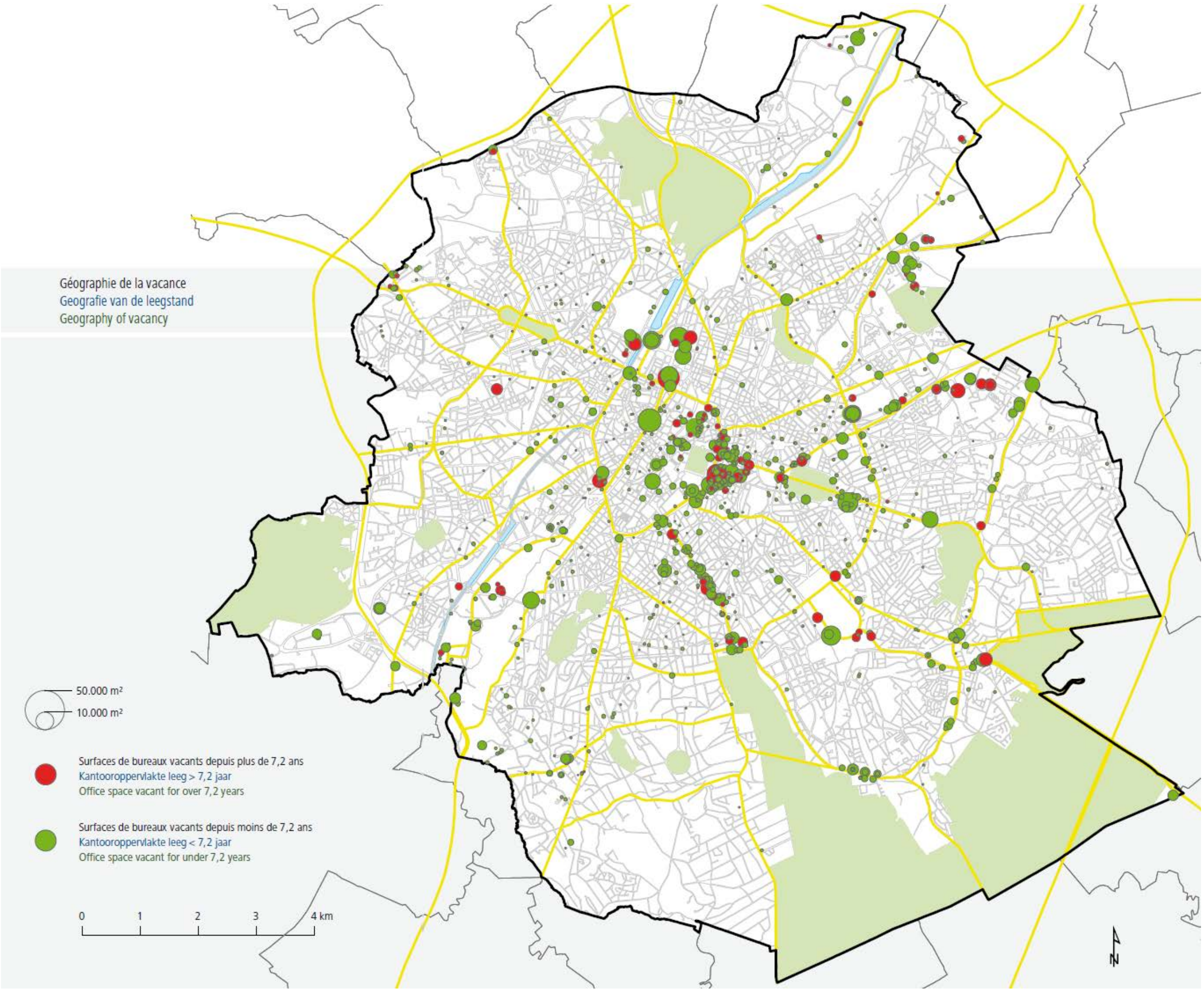

Figure 6: Map of BCR showing the distribution of vacant office surface in Brussels, based on (Brussel Stedelijke Ontwikkeling 2015)

Conventionally, the technical and functional service life of modern and post-modern buildings is approximately 50 to 75 years. Some buildings are actually demolished due to deterioration. Yet, today most buildings are being demolished to give way to new construction, because they do not meet the requirements of the end users. The average functional service life of a building is

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becoming shorter and this requires the return on investments to be shorter too (Durmisevic, 2006).

An example of this trend is the Fortis Bank Building in the centre of Amsterdam, which has become subject to redevelopment and demolition 18 years after construction. As illustrated in Figure 7 this has led to a value degradation of the building's components and materials.

Figure 7: representative example in Amsterdam where the building is demolished earlier than expected. (Durmisevic et al., 2016)

In 1972, the Dutch construction industry reached the highest amount of dwellings built in one year (155.000). After this peak there was a decline in the amount of constructed dwellings, because the large urban developments stopped and moved towards urban densification, small scale developments and urban renewal (Liebregts & van Nunen, 2014). This also led to **the end of the industrialised housing systems** that were most effective in large scale urban developments in the Netherlands.

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3.4 Digitalisation

Whilst the First and Second Industrial Revolution were about mass production, the Third Industrial Revolution is about the information economy. We have entered the '*Age of Information*' where data is traded, consumed and used continuously, forcing businesses and individuals to adapt or be left behind (Eynon, 2015).The number of Internet of Things (IoT) devices in buildings is rapidly increasing along with new requirements for flexible operations. By 2014, 16 billion devices were connected to the IoT. This figure is projected to grow to 50 billion by 2020, and 1 trillion by 2040 (Ericson, 2011). (McCormick, 2016)

In the 1980s and 1990s, **building automation** allowed real estate and facility management teams to visualize their buildings' key performance indexes through dashboards. However, these dashboards were static, historical and aggregated, and did not provide actionable insight. They could tell us which buildings produced most waste, but not why, or what to do about it. From the beginning of this millennium, **smart buildings** made their entrance, making it possible to link sensor specific information with analytical tools to create actionable insights at the room and asset-specific level. However, as it is only possible to analyse primary data points, and as few organizations have implemented tools to be able to analyse large amounts of unstructured data, insights are still at an aggregate level and limited to comparisons with historical metrics. (IBM Global Business Services 2016)

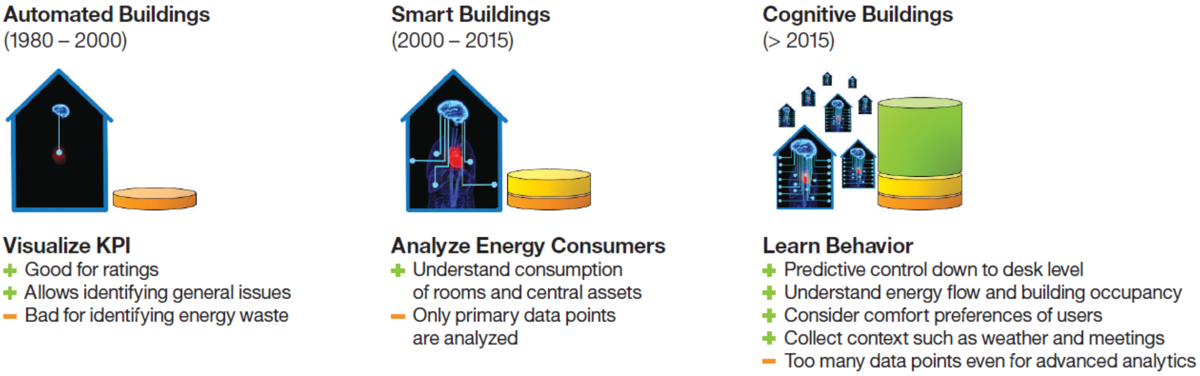

Figure 8: IBM's cognitive buildings Maturity Framework, presenting three maturity levels (from left to right): automated building, smart buildings and cognitive buildings, based on IBM Global Business Services (2016).

In its white paper "*Embracing the Internet of Things in the new era of cognitive buildings*" IBM believes that besides automated and smart building, **cognitive buildings** – autonomously integrating IoT devices and learning system and user behaviour to optimise building performance – will have the ability (1) to provide insights; (2) to learn, reason with purpose and interact naturally with humans and (3) to act and deploy changes to building operations. (IBM Global Business Services, 2016)

Closely linked to the digitalisation trend, **Building Information Modelling (BIM)** is considered as one of the most promising innovations in the modern era of the architecture, engineering, and construction (AEC) industry. "*BIM is essentially value creating collaboration through the entire life-cycle of an asset, underpinned by the creation, collation and exchange of shared 3D models and intelligent, structured data attached to them.*" (UK BIM Task Group, 2013). Already in 1975, Eastman suggests "*The use of computers instead of drawings in building design*", describing a working prototype "*Building Description*

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System (BDS)", which included ideas of parametric design[10], deriving drawings from a model, a "*single integrated database for visual and quantitative analyses*". He also suggests "*Contractors of large projects may find this representation advantageous for scheduling and materials ordering*". Eastman was describing "BIM" seven years before Autodesk was founded, and 25 years before the first version of Revit was released.

Today, BIM is used worldwide, although with a different rate of adoption (see Figure 9) and differences in regulation. For example, The UK, Netherlands, Denmark, Finland and Norway already require the use of BIM for publicly funded building projects, whereas other European countries rely on the private sector to push through BIM within their industries. (McCormick, 2016)

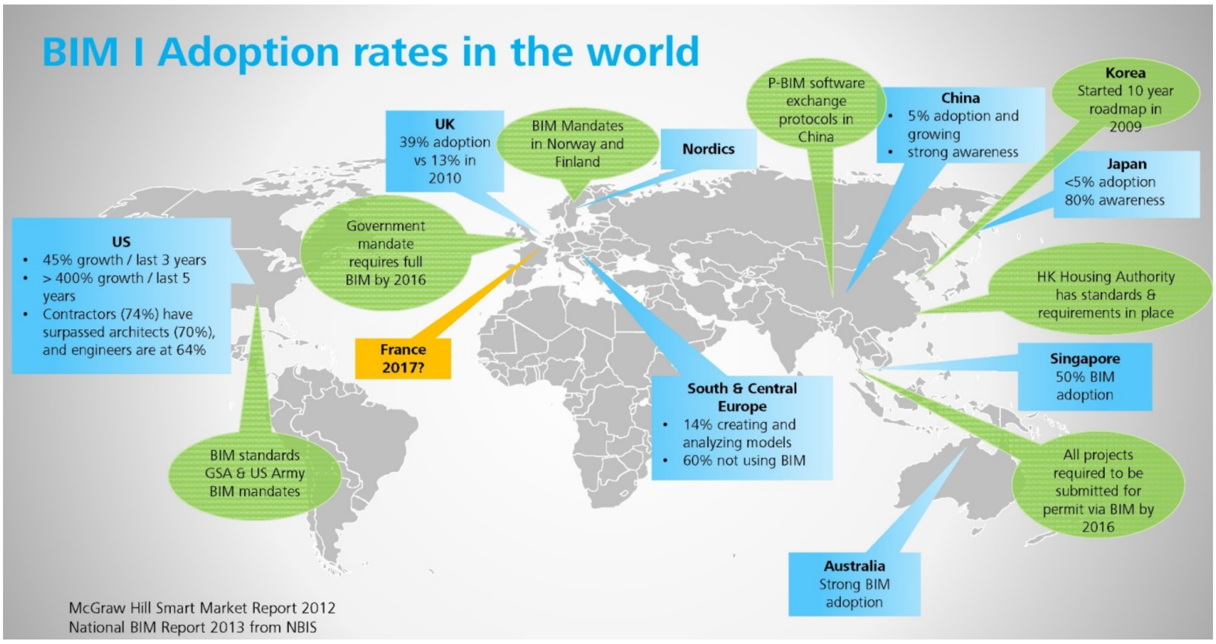

Figure 9: overview of adoption of Building Information modelling, based on McCormick (2016)

Within this third digitalisation wave, the extensive growth of data has been put forward. It is accordingly of crucial importance that the instruments using these data are user-friendly, in order to translate the huge amount of data into ready-to-use information by decision-makers.

[10] The ground of **parametric design** is the generation of geometry from the definition of a family of initial parameters and the design of the formal relations they keep with each other. It is about the use of variables and algorithms to generate a hierarchy of mathematical and geometric relations that allow you to generate a certain design, but to explore the whole range of possible solutions that the variability of the initial parameters may allow. (http://www.parametriccamp.com/en/what-is-parametric-design/)

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3.5 Increasing number of fragmented building regulation and building codes

The evolution of construction methods and the way materials have been used within the built environment are greatly related to the introduction of building regulations and building codes over time. Figure 10 illustrates the development of construction methods used in the Netherlands over the last 100 years. From the beginning of the 20th century, regulations focussed on improvement of basic living conditions, such as sanitary, useful space and moisture control. Post WWII construction introduced the standardisation of building components in order to speed up the construction process. The oil crises in the 1970's led to the regulation of higher insulation performance and reduction in energy needs. Even now, the importance of Energy Performance in Buildings Directive (EPBD) is very clear within the design and construction process. The EPBD has been a major driver for technology solutions for (nearly) energy zero buildings – at least for new buildings. The emergence of new policy documents on resource-efficient buildings and actions plans for the circular economy is a sign that the next wave of regulation and codes will focus on materials and the development of systems enabling closed (or continuous) cycles – systems that BAMB will largely contribute to. (Durmisevic et al. 2016)

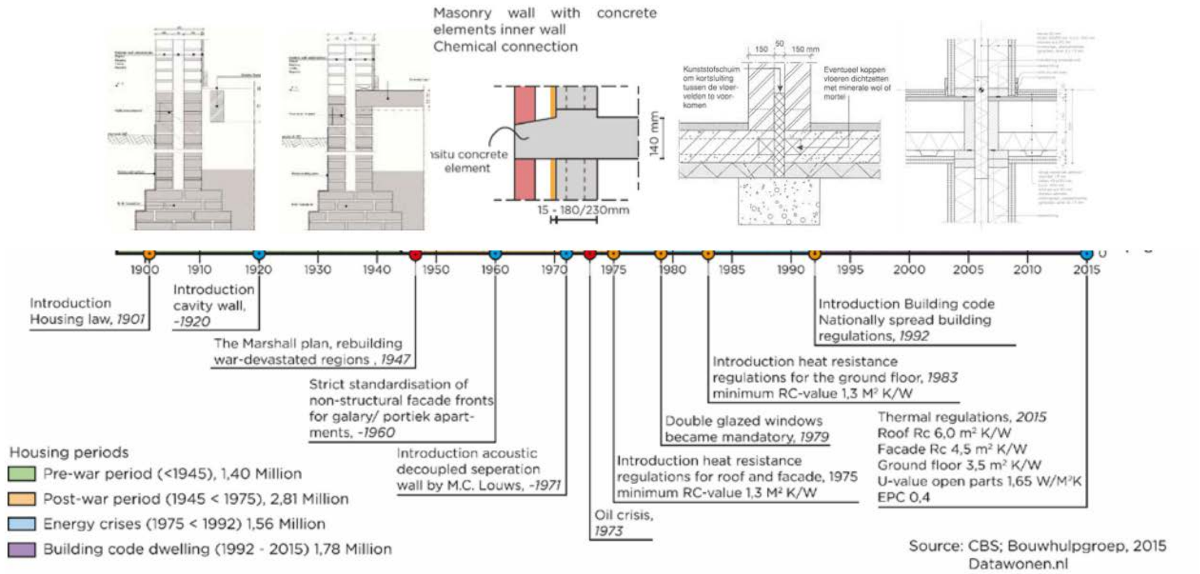

Figure 10: time-line of construction methods used in the Netherlands from 1900 to 2015 (Durmisevic et al., 2016)

Undeniably, the introduction of regulation and building codes has in general led to more building comfort and more sustainable building solutions. Nevertheless, **the growing number of EU, national and regional policy measures has also put pressure on manufacturing, architectural and engineering industries** – reluctant to take on even bigger responsibilities (Vandenbroucke, 2016). Conflicting regulations and legislation in different industries, connected to the construction industry, hinder circular models, calling for a more holistic approach when re-thinking the appropriate regulatory compliance rules (EMF, 2014).

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4 CHARACTERISATION OF THE CURRENT SYSTEM AND MAINSTREAM ACTORS

4.1 Describing the current system

This chapter focuses on the current ecosystem of the built environment. It describes the building phases, activities and milestones from a business-as-usual (BaU) perspective. Within each of the building phases the main actors and roles are defined (or groups of roles that are necessary to perform a certain set of activities) and the links and interactions between the different roles are described.

Apart from mainstream building practice, new initiatives are emerging that might pave the way towards a more circular building practice, if they would become more common practice. These state-of-the-art practices are also highlighted briefly.

In the analysis, 2 different viewpoints are used:

- **A process approach:** By taking a process view, the different activities and **sub stages** along the value chain of a building are defined to describe the construction process in more detail, based on questionnaires filled in by the BAMB partners (see following paragraphs). (Sub) stages are separated from each other by certain **milestones** and outputs which are required before a next phase can be started. Additionally the **actors** that are involved in each of these activities are listed.
- **A value network approach:** Actors (businesses, individuals, public bodies) can take different **roles** in the construction network, depending on the building phase and the interactions that occur. By using a value network approach (Peters et al., 2016) the complex construction ecosystem is described in terms of **relationships or links** between the different roles contributing to the value creation. These links represent interactions or flows (exchanges) between the participants, which can take the form of information exchange (for example regulatory bodies supply information in the form of rules, standards, laws…), financial exchange (contracts, payments), product/ material /labour exchange or a combination of these 3 exchange types. These interactions and flows have a dynamic nature: they change with time and are also dependent on the building phase. Also, flows can be multidirectional, which is characteristic for a network (in contrast to a 'chain'). The value creation can be defined in different areas such as societal value, financial value, environmental value and others. In this analysis we have focused only on the systemic value creation.

4.2 Building phases

The building process consists of several consecutive steps that can be divided in phases. Different ways of describing and grouping of activities are possible and their complexity and timeframe depends a lot on the type of building project (e.g. small private house or large public building) and on the common practices in individual countries (survey BAMB partners).

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This analysis distinguishes 4 main building phases:

1. **Design**: the phase where all the financing, designing, planning is specified.
2. **Build**: the phase where the building or infrastructure is realized.
3. **Use & Operate**: the phase where residents/ users/ occupants, etc. are using the building and the building is operated to maintain the service levels required by the occupants.
4. **Repurpose & demolition**: the phase where transformation is planned, and products and materials are extracted. However, currently repurposing is not common practice and most end-of-use options of buildings lead to partly or complete demolition (i.e. the building as a demolition liability).

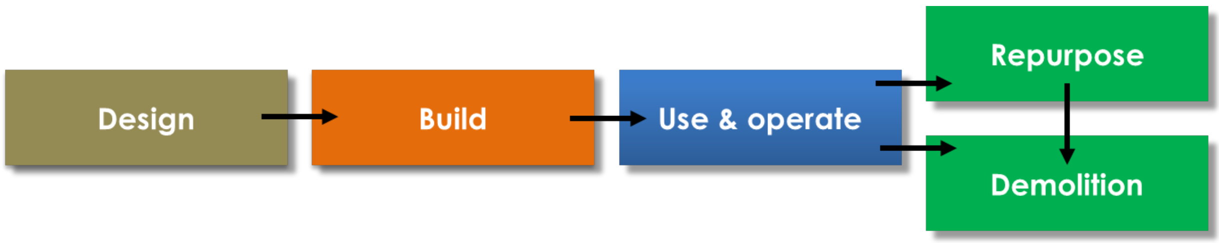

Figure 11: Building phases from a linear perspective, based on Peters et al., (2016)

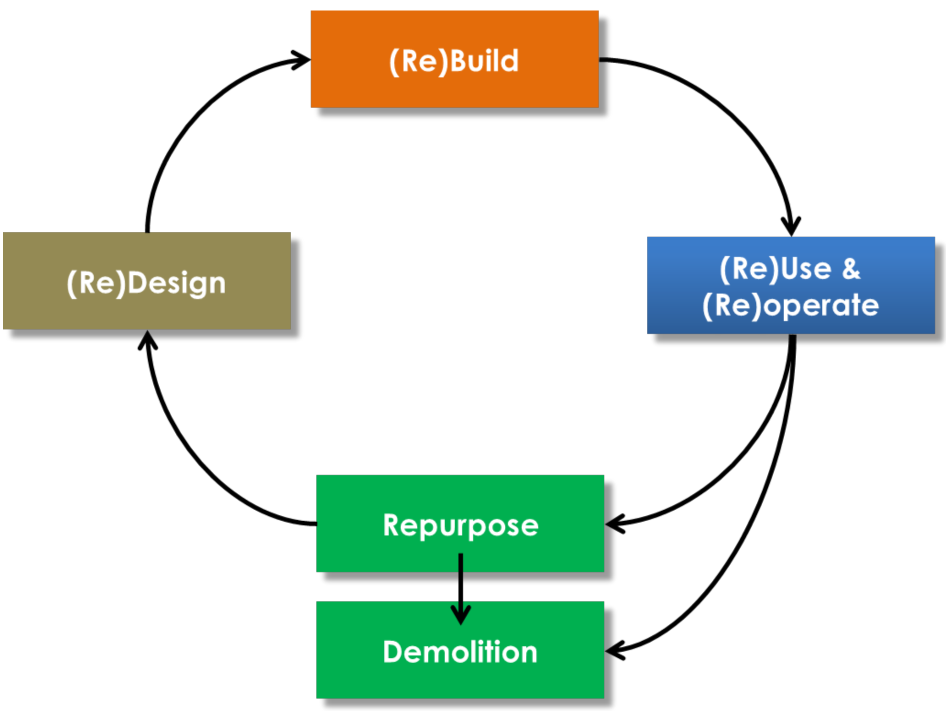

Figure 12: Building phases from a circular perspective, adapted from Peters et al., (2016)

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Although these 4 construction phases appear to have a linear dimension (Figure 11), the construction ecosystem is certainly not linear, as there are many iterative links and loops between the building phases and between the different network participants.

When looking at repurposing of buildings and components, the process can be considered to be circular or continuous, as the phases of (re)design, (re)build and (re)use will be revisited multiple times during the life-time or usage of a building (Figure 12).

4.3 Phase 1: Design

The design phase is a defining and critical initial stage in the lifecycle of a building. It captures and integrates the various requirements from use and operation of the building into a physical form. These requirements should reflect the key benefits for the various stakeholders, including maximizing the potential for repurposing and reusing the building and its content.

If done properly, the design phase will provide a sustainable direction for building exploitation embedding various services, with lasting positive impact throughout the whole lifecycle and lower total cost of usage – including the costs of repurposing, which goes further than the total cost of ownership).

Although the design phase is mostly associated with the construction of new buildings, it is also the starting point for renovation and rebuilding works when an existing building has been repurposed at end-of-use, or when parts of the building are adapted or extended in mid-use. Also, during the construction phase, elements might be reconsidered for redesign if necessary. Consequently, the design phase (and likewise all other building phases) should not be viewed only as a starting phase in a linear process, but rather as a phase that is revisited regularly during the lifetime of a building.

4.3.1 Process approach: sub stages, milestones and actors

The design phase can be split up into several sub stages:

1. **Identification of needs**: i.e. definition of requirements for various stakeholders, preparation of a feasibility study to identify financial, spatial and technical constraints and the development of a business and financial plan.
2. **Procurement**: i.e. the preparation of tendering documents, contracting of architects or design team, evaluation of proposals and selection of architect or design team. Participating architects need to prepare a conceptual design in order to apply. The degree of detail of this design varies considerably depending on the project type. For a typical private one-family house, this can be only a rough sketch. For a large public project, selection of the design team may be based on an architectural contest and the design is already more elaborated in this early stage (in some cases already a preliminary design). There is a distinction between architectural and engineering design requirements. For complex projects the engineering part will determine actual feasibility, supplier/ product selection, etc. So, there should be enough technical requirements specified to contract the appropriate/ best equipped engineering company.
3. **Preliminary design**: i.e. the development of the concept and overall plans for the building project. The level of technical detail is gradually increased during the process.

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The focus of the preliminary design lies on spatial typology, architectural appearance and general understanding of climate concepts and materials to be used.

4. **Definitive design**: i.e. the decision on the final design and elaboration of the functional plan of the building and integration between structure and services including major building connections and detailed material specification. The definitive design also includes documenting the building permit.

It is important to state that design activities partly overlap with the "build phase". Preparation of the technical plans is done by or in collaboration with the design team/architect, after the contractor(s) have been commissioned. Within this analysis, it has been chosen to add these activities within the "build phase" (see section 4.4)

The main outputs or milestones of the sub stages in the design phase are:

1. **Design brief:** describing the business case (cost, strategy, and timescale), requirements based on the feasibility studies (site information, geological survey, boundary conditions, sustainability, etc.). As a leading practice, this business case also includes a plan for the life-time/ usage of the building. Moving to total cost of use models will challenge the current business case concept.
2. **Selection of an architect(or design team)** to carry out the design
3. Building and (embedded) products designed in an **architectural plan**, **building permit** obtained based on definitive design and detailed specification of materials and construction costs, **financing**
4. **Detailed construction plan**, including material specifications.

There is quite some overlap between the final sub stage of the design phase and the first sub stages of the build phase, especially when complex buildings are concerned. The contracting of the builder (contractor), preparation for construction and elaboration of the technical plans takes place on this interface between the design and build phases. The degree of integration between the design and build phases and their actors may be higher or lower, depending on the building's complexity and existing regulations in individual countries. Also the exact stage where the building permit is delivered may vary among countries.

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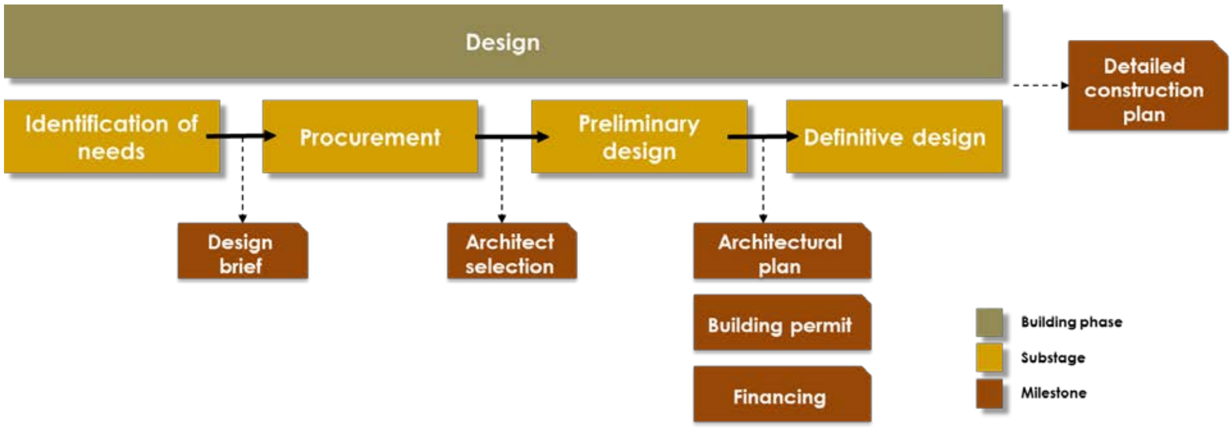

Figure 13: Sub stages during the design phase

The table below lists the relevant actors in the design phase, and their main role.

Table 2: Actors involved during the design phase

Actor	Related actors	Main role in the design phase	Comment
Property Owner/ Developer (Building Client)	Investor User Land owner	Definition of needs and requirements. Choice of architect/design team and approval of design concept.	
Property User(s) and visitors	Owner Tenant Visitor Employee	Definition of needs and requirements	
Land owner	Property owner Developer	Agreeing financial settlement on land lease/ land sale.	
Facility manager/ Maintenance provider	Operator	Definition of needs and requirements	In Business-as-Usual practices, there is no or limited interaction between (future) facility managers & maintenance providers and the design team.
Utility Providers	e.g. energy and water services, waste/ disposal services	Definition of needs and requirements, setting of technical boundaries (e.g. availability of sewage system etc.).	

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Emergency services	e.g. fire brigade, medical services, security	Building regulations related to safety Delivery of building permit Accessibility for all types of emergency services (different by emergency type)	
Architect/design team/engineers	Consultant Structural engineer Services engineer (ventilation, etc.) Specialist designers and engineers (acoustics, etc.) Cost consultants Environmental and safety consultants	Translating the requirements into a building concept, elaboration of architectural, structural and utility plans, choice of building materials, cost estimations, maintenance strategy, and sustainability strategy.	Depending on the complexity of the project (e.g. private family house or large multi-story building) the lead consultant can be a single architect, or a whole team of designers and engineers for the design of highly serviced specialist or surveyors for refurbishments.
Suppliers of building products, materials and technical services	Suppliers Manufacturers	providing technical, financial and logistic information on products, materials and technical services	At the moment the use of secondary products and materials is typically not addressed during the design phase
Main contractor	Builder Subcontractors	Providing technical information about installation of products/construction systems and construction in general, as well as a financial offer, or contract, to execute the construction/installation.	
Regulator, government, local councils	Planning agency Environmental agency City and regional council	High-level policy on urban planning, environmental constraints, waste compliance, etc. Local building regulations on building height, depth, type, materials, accessibility, cultural heritage, etc. Delivery of building permit Green Public Procurement Frameworks to assess the health and environmental impact of materials that will have an impact on the design of the building, the systems and components	
Financer	Bank Investor	Provision of loans, funding or investments (e.g. pension funds, etc.)	

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4.3.2 Value network approach: roles and interactions

Viewing the variety of profiles of the stakeholders and the capabilities of the enablers, the collection of the key relevant requirements and its matching with the right capabilities is not a trivial task. There is a key role and a focal point around the Architect/Design team to be the spider in the web in this crucial phase.

During the design phase we consider 4 major grouping of roles. The maturity of the links and the roles involved can differ by country and company involved.

1. **Definition of User & Building Requirements** through inventory of key information from various stakeholders.
2. **Planning & Development**: i.e. initiating the idea of the building project, defining the concept and plan for development, including funding.
3. **Assessing Products & Material Supply Potential**: i.e. investigating the possible supply of products, components and/ or material to realise the building
4. **(Re)Design**: i.e. taking into account information and direction from all connected partners in the ecosystem.

The interactions and information, material and financial flows between the different roles in the design phase are presented in the diagrams below. A distinction is made between the **business-as-usual situation**, representing the mainstream and well established interactions between the different roles (Figure 14) and the **state-of-the-art situation**, highlighting the interactions that are considered as leading practices in the construction sector, but are not yet regarded as mainstream and often lacking in current building projects (Figure 15). These leading practices and the type of interactions they embody are described in more detail in Table 3. The opportunities and advantages related to these state-of-the-art practices are described, but also the current barriers that explain the reason why these interactions are often lacking in mainstream building practices, are indicated.

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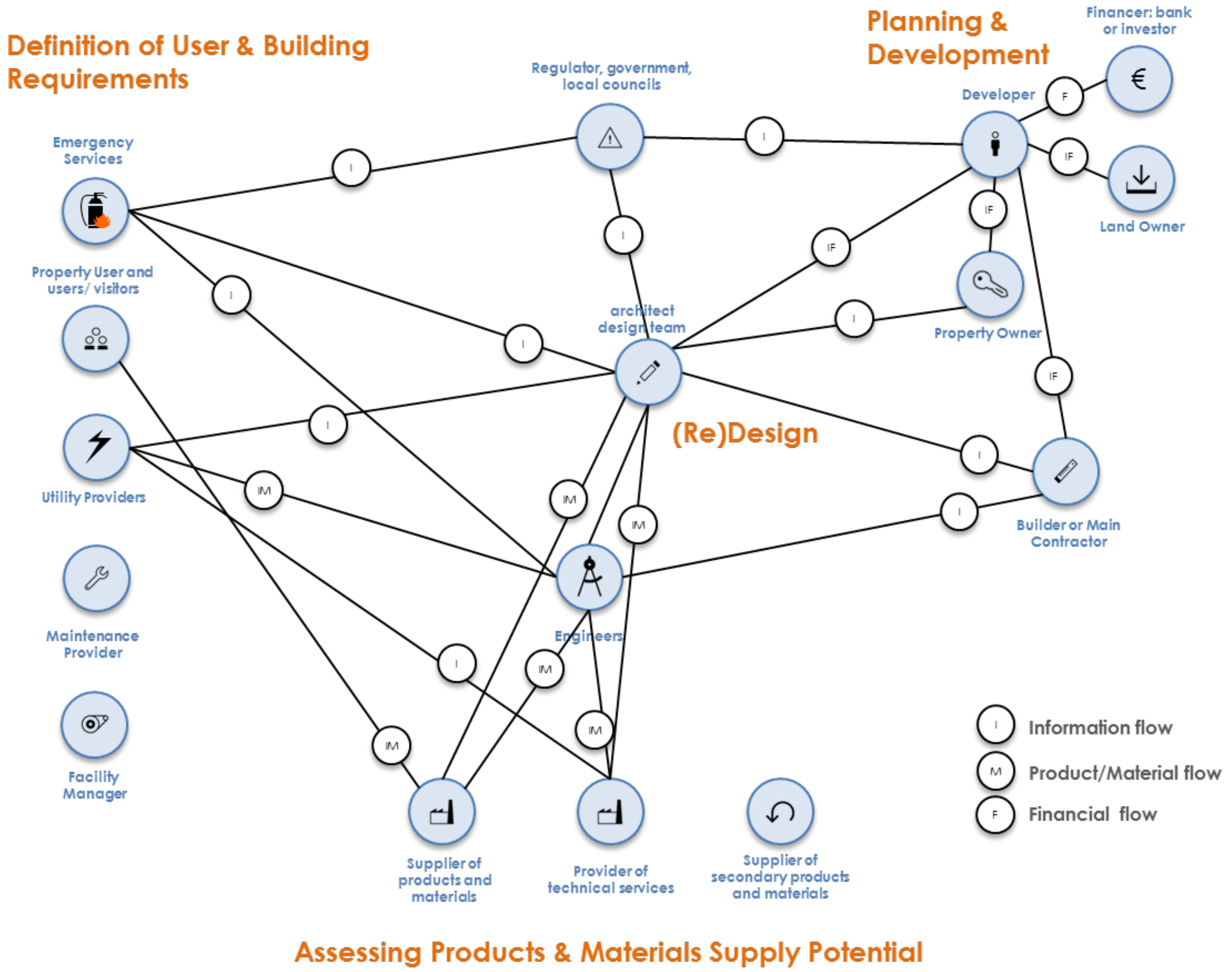

Figure 14: Roles and interactions during the design phase (business-as-usual)

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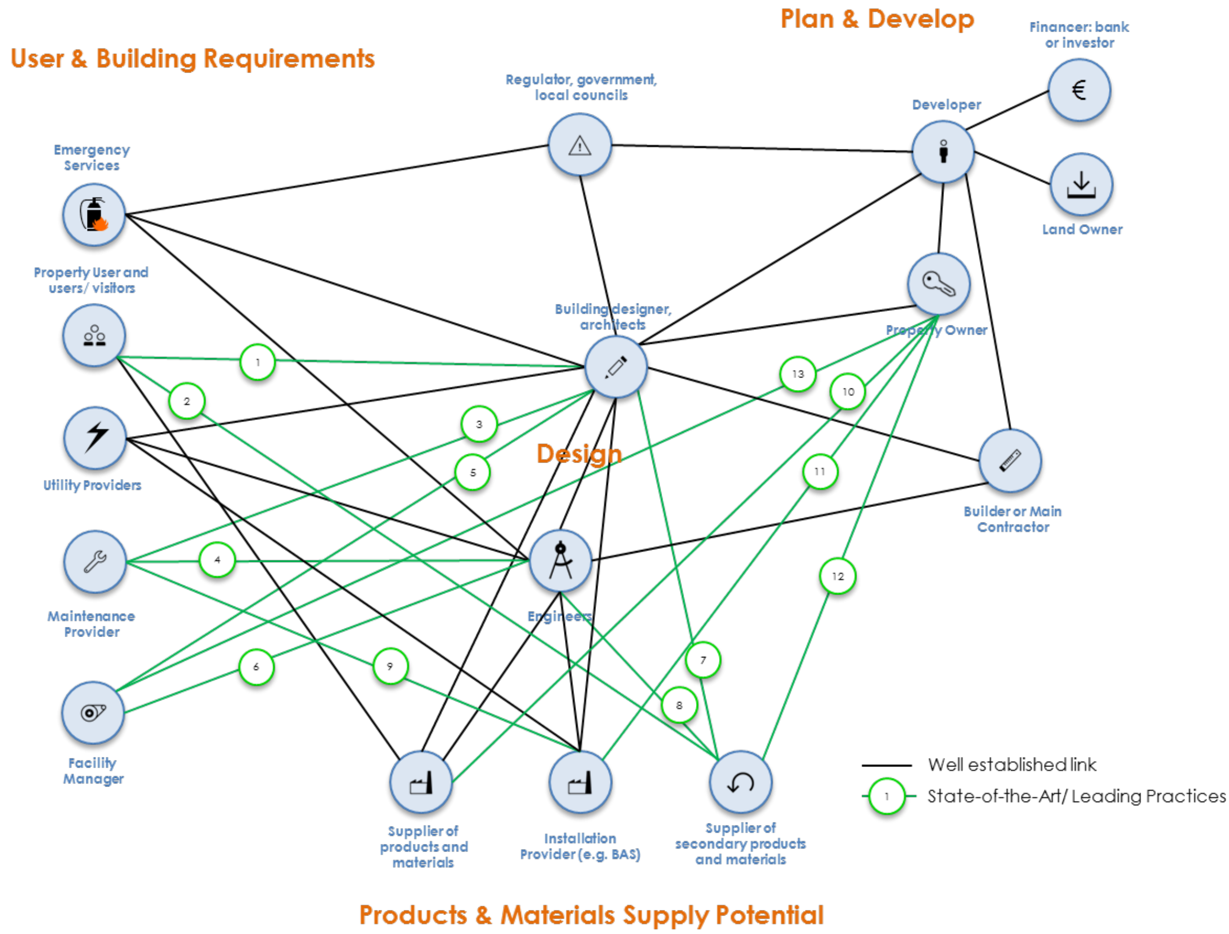

Figure 15: Leading practices during the design phase (state-of-the art)

Table 3: Leading practices during the design phase (state-of-the-art)

ID	Type of Exchange	Short Description	Development & Trends	(Current) Barriers	Opportunities
1	Information flow	Requirements from future users (incl. visitors) are communicated to the design team to understand preferences and imperatives on use of the building/ rooms/ equipment/ building products.	Defining the requirements with future users is not main practice and is considered leading in the industry.	Mostly limited access to future property users.	Understanding different perspectives of how users will use the building/ building products will need a more flexible design to accommodate these different preferences. As a result, a more relevant building now and for the future is achieved. This can leverage on current users who share frustrations and positive aspects.
2	Information-Product/ Material flow	Future users of the property getting information/ samples/ demos of reused/ refurbished building products planned to be used in the building.	Even though urban mining/ reuse of building products is starting to increase, volumes and examples are still very scarce.	Suppliers with proper mix between new and portfolio of reused products, components and materials.	Suppliers with a mixed new/ reused product portfolio can differentiate themselves in the market, serving different customer segments (customers open for using reused products) and increasing their margin by avoiding "new spend".

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3	Information flow	Requirements from maintenance providers will provide the design team a better understanding of accessibility to repair or replace building products. This will improve daily operations.	Many buildings are becoming more technological enabled to provide better/ customized services to the users. Technology also gets outdated, needing repair/ replacement, etc. with a need for maintenance providers to understand status and ease of access of those products concerned.	Due to many different product categories in a building it can differ by building which of those maintenance providers are most relevant to get requirements from.	Better, easier maintenance and easier repair.
4	Information flow	See description 3.	See description 3.	See description 3.	See description 3.
5	Information flow	Requirements from facility managers will provide the design team a better understanding on how they will operate the building product and its services (cleaning/ janitors, catering, other supply chain activities, reception. etc.)	Operating a building today is planning activities for many different building and operational processes (maintenance, catering, meeting room setup, etc.).	Many manual planning processes, using outdated data/ reports. To better plan best usage of building products, more data is required to plan relevant activities (e.g. condition based monitoring of products, usage of meeting rooms to provide most used setups, etc.)	More convenient building operations and management.
6	Information flow	See description 5, but more focused on technical capabilities/ requirements.	See description 5.	See description 5.	See description 5.
7	Information-Product/ Material flow	The design team getting information/ samples/ demos of reused/ refurbished building products planned to can be used in the building, and understand product properties like specifications, dimensions, status, materials, etc. What is important here is a transparent, reliable and easy visibility on the available supply of repurposed building modules and/or materials, as well as their specifications that are important for selection. That could include additional certifications such as C2C	Even though urban mining/ reuse of building products is starting to increase, volumes and examples are still very scarce/ limited to certain categories only.	Intellectual Property not shared by suppliers/ or available of (original) products. Limited information available on products in existing buildings. Suppliers lack business models to go-to market with a mixed new/ reuse products portfolio. Architects/ Design team do not design with reuse in mind! Liability requirements by country law is one to be tackled still as some repurpose projects are stopped when liability is not covered when e.g. using products for reuse that needs secure performance like steel beams for pedestrian bridges.	Detailed product data will benefit the design team of more options to consider when designing for new building/ renovation project.
8	Information-Product/ Material flow	See description 7, but more focused on technical capabilities/ requirements.	See description 7.	See description 7.	See description 7.
9	Information flow	If not performed by the same company, information exchange on how best to maintain the building installations.	Normally standard information exchange at handover (Build phase). When a maintenance provider is known and starting to work during the Design phase to optimize maintenance efforts is not commonly done, but a growing trend.	Maintenance providers are using more and more IoT/ Condition Based maintenance approaches, therefore requesting more data/ information from systems on actual performance to plan maintenance. Important data points are most times missing at start of maintenance cycles and added later.	Right data points will ensure right maintenance performed for longer life of the product and better product state at end of service. Correct product state at tend of service provides more accurate input on reuse options.
10	Information-Financial flow	The property owner can discuss innovative models for selling access to services and performance with suppliers (e.g. pay by use) or lease materials for example.	Some progressive investors and developers are appreciating the lower total cost of usage from different business models such as selling performance or leasing materials.	Currently the relation with suppliers of products and materials is a transactional product sale, focused on cost reduction, and where the general contractor tries to minimize purchasing cost.	Opportunity to innovate around the business model of engaging with suppliers, towards a value and performance driven purchase that will ultimately reduce the owner or the contractor total cost of usage.
11	Information – Financial flow	See description 10.	See description 10.	See description 10.	See description 10.
12	Information-Financial flow	See description 10.	See description 10.	See description 10.	See description 10.

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13	Information-Financial flow	Property Owner contracting a Facility Manager in the Design phase (like with product and services suppliers) will contribute to access/ functionality in the design from an optimal operations perspective.	In recent years the role of the Facility Manager is increasing with more tasks to coordinate during the Use & Operate phase of a building. Input in an early stage from the Facility Manager's experience and contracted scope will influence design related to operating a building.	A barrier is still the classical view of supplier/customer relationship from a Property Owner point-of-view.	Partnering/ contracting a Facility Manager in the Design phase (like with product and services suppliers) will contribute optimal operations during the Use & Operate phase of the building.

4.4 Phase 2: Build

The build phase aims for delivering the building/construction according to specifications, timely and in budget. It is the translation of the design requirements to the physical 'product'.

4.4.1 Process approach: sub stages, milestones and actors

The build phase can be split up into several sub stages:

1. **Pre-construction phase**: i.e. preparation of documents for tendering/bidding, contacting potential (main) contractors, evaluation of the offers and choice of (main) contractor.
2. **Mobilisation**: i.e. choice of building subcontractors and suppliers, assembly of the supplier and contractor network. The suppliers of building materials and components have their own design and production process, which are not included in this study. The contractor may also need to make adjustments to the technical building plans, e.g. related to the final choice of different materials based on user and technical requirements and cost (BaU), but also based on total cost of use and quality (leading practice).
3. **Construction**: i.e. logistics, actual construction works, monitoring and supervision of the construction works, final inspections

The main outputs or milestones of the sub stages in the build phase are:

1. **Contractual agreement** and appointing of main contractor(s)
2. **Establishment of the supplier & contractor network**
3. **Technical plans:** Adjustment of technical building plans where necessary.
4. **Commissioning of the building**: Contractor (and his network of subcontractors) managed to realise the building, final inspections and rectifications, as-built plan, operating and maintenance manuals.
5. **Functionality repurposed**, when (parts of) existing buildings are repurposed for other means than initial design

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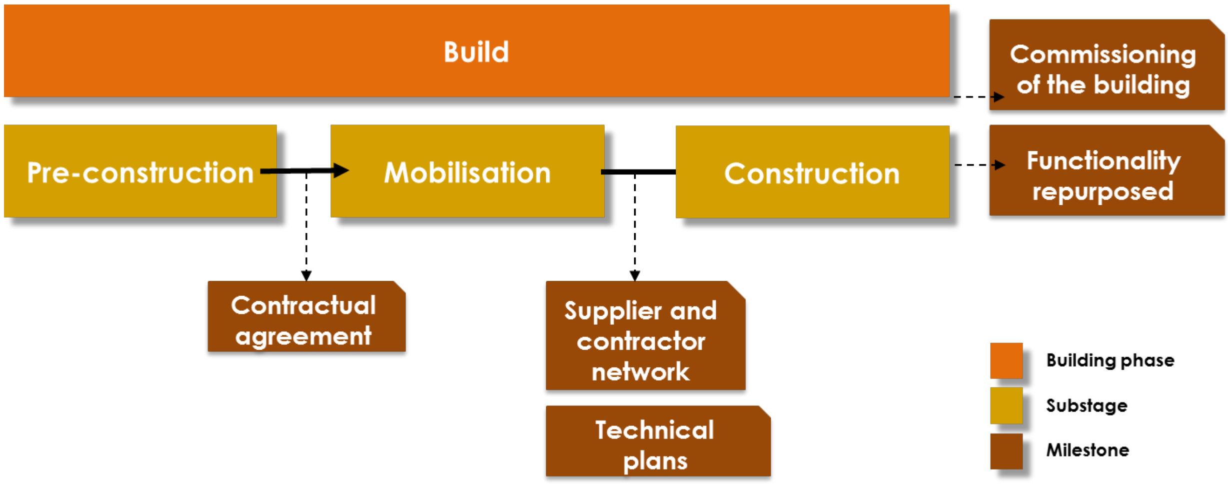

Figure 16: Sub stages during the build phase

The table below lists the relevant actors in the build phase, and their main role.

Table 4: Actors involved during the build phase

Actor	Related actors	Main role in the build phase	Comment
Property Owner/ developer	Investor	Choice or approval of contractor	
Insurer		Provision of insurance	
Lead consultant – Architect/design team/engineers	Architect Structural engineer Services engineer (ventilation, etc.) Specialist designers and engineers (acoustics, etc.) Cost consultants Environmental and safety consultants	Surveying of the building works, checking consistency of built with plans	Depending on the complexity of the project (e.g. private family house or large multi-story building) the lead consultant can be a single architect, or a whole team of designers and engineers for the design of highly serviced specialist or surveyors for refurbishments.
Main contractor	Site/construction manager Construction planning team	Planning and executing of the building works. Technical design of specialist infrastructures. Hiring of subcontractors and main suppliers.	

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Subcontractors		Executing of specialist building tasks.	
Material, product and service suppliers	Suppliers Manufacturers	Development, manufacture and delivery of building materials, products and technical services	In specific cases secondary products and materials are used in the building phase (e.g. bricks), however this is not common practice.
Regulator, government, local councils	City and regional council	Control of local building regulations Training of (sub) contractors on building regulations Quality requirements for granulates	
Quality control, building evaluator		final inspections against building standards and issuing certificates	

4.4.2 Value network approach: roles and interactions

In this phase, the central role shifts from the Design Team/Architect to the Contractor that will ensure that the building plans with all design requirements are correctly built and delivered.

During the build phase we consider 3 major grouping of roles:

1. **Realization of Building**: i.e. the main contractor, subcontractors, design team and engineers, and the different suppliers and providers are working together to realise the build.
2. **Products & Material Supply**: i.e. provision of products, building modules, components and/ or material. Suppliers of products have to adhere to their respective industry legislation and regulatory compliance rules, and basically have a value network of their own. This is not considered in the current report, as we focus on the value network for construction in which each (re)used product is assumed to comply with all available and/ or mandatory legislation and compliance rules. It cannot be denied that industry specific rules and legislation could either hinder or support the reuse of products, components and/ or material in the context of the construction industry.
3. **Handover at Completion**: i.e. after realization and quality control of the build, formal handover of ownership to the property owner.

The interactions and information, material and financial flows between the different roles in the build phase are presented in the diagrams below. A distinction is made between the **business-as-usual situation**, representing the mainstream and well established interactions between the different roles (Figure 17) and the **state-of-the-art situation**, highlighting the interactions that are considered as leading practices in the construction sector, but are not yet regarded as mainstream and often lacking in current building projects (Figure 18). These leading practices and the type of interactions they embody are described in more detail in Table 5. The opportunities and advantages related to these state-of-the-art practices are described, but also the current

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barriers that explain the reason why these interactions are often lacking in mainstream building practices, are indicated.

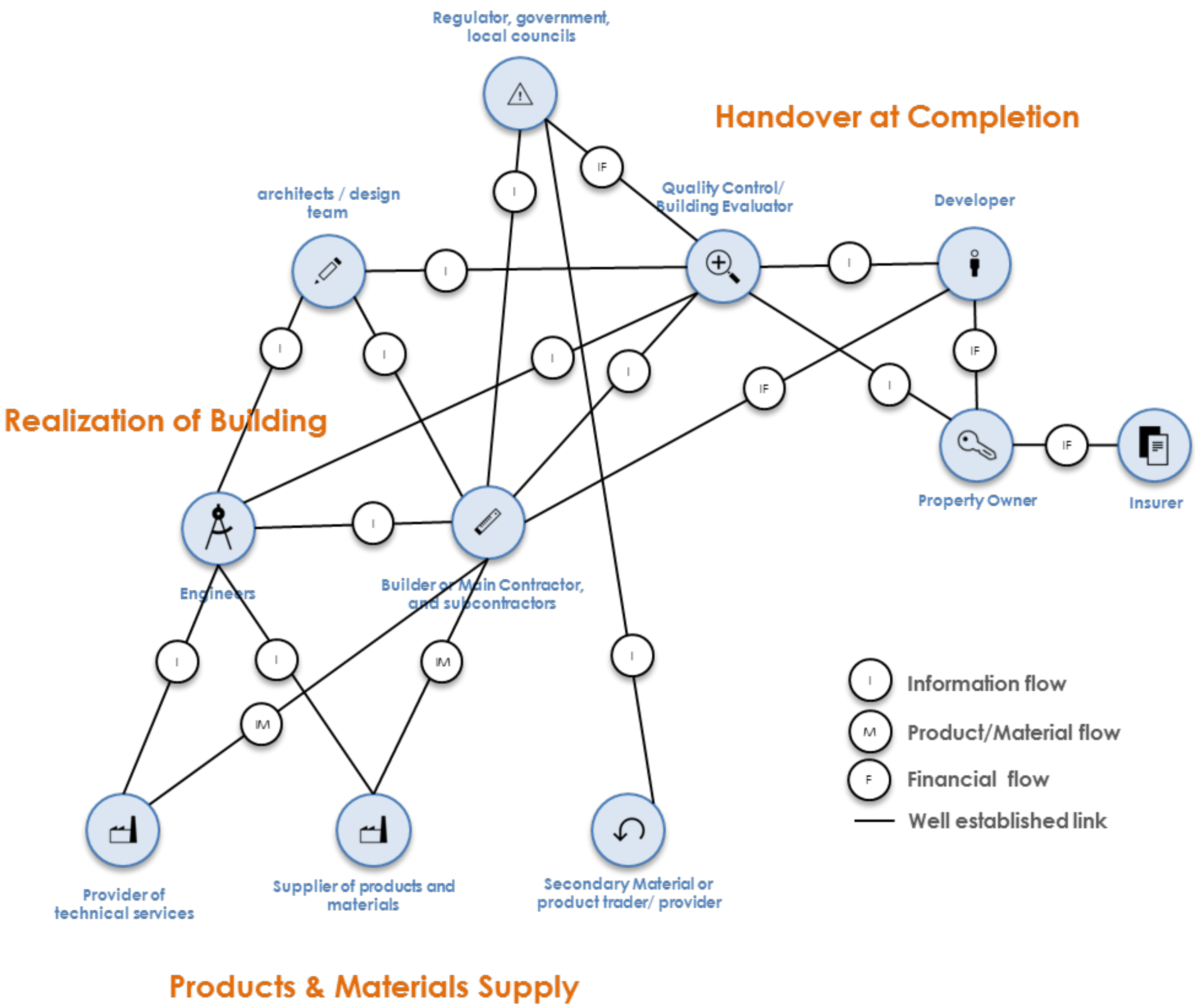

Figure 17: Roles and interactions during the design phase (business-as-usual)

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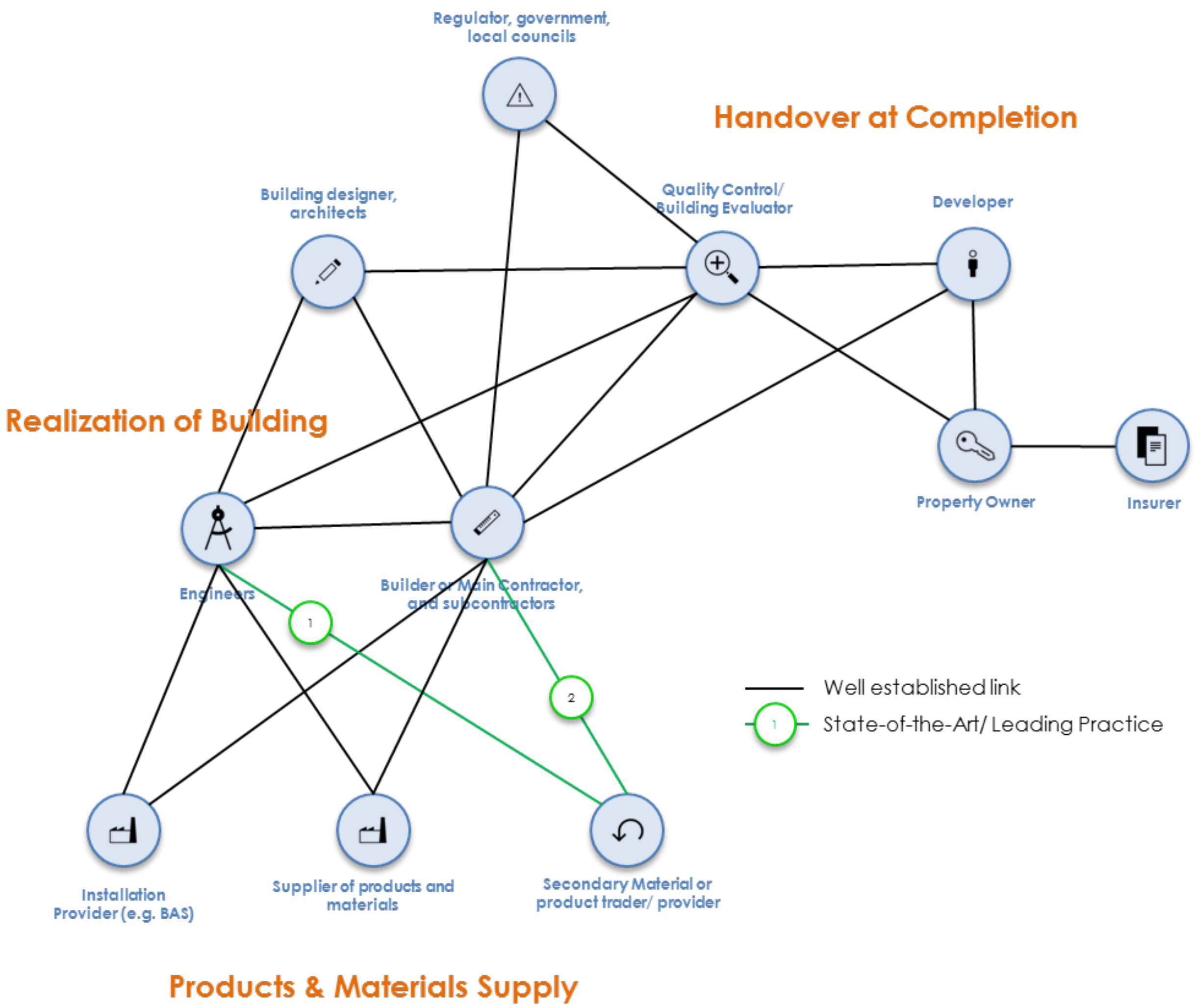

Figure 18: Leading practices during the build phase (state-of-the art)

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Table 5: Leading practices during the build phase (state-of-the art)

ID	Type of Exchange	Short Description	Development & Trends	(Current) Barriers	Opportunities
1	Information flow	The engineer is the key source of the requirements and specs of materials and mechanical/ electrical installations going into the building. This link relates to the exploration by the engineer to options in refurbished or remanufactured modules as well as recycled / retrieved materials from various sources (recyclers, other sites, market portals, etc.).	This link is still not solid and scaled up due mainly to the lack of certification as well as quality and volume guarantee of the secondary market. However, there are more waste management companies shifting their business models to become secondary raw materials producers, benefiting from improvements in recycling techniques and from improved modular design.	Key barriers are the lack of easy data access around the materials specs in buildings and products, as well as the lack of data around location, ease of retrieval and market demand. Information Technology and improved design for reuse as well as recycling technology should help scale up secondary materials and products market.	Reduce purchasing costs while maintaining same level of quality. Furthermore, new suppliers entering the construction supplier marketplace (e.g. recyclers, demolition companies).
2	Product/ Material flow	See description 1, since the engagement with materials suppliers will be depending on the context driven by the engineers or contractors (sometimes they are the same party).	See description 1.	See description 1.	See description 1.

4.5 Phase 3: Use & Operate

The Use & Operate phase has the longest duration within the lifespan of a building.

4.5.1 Process approach: sub stages, milestones and actors

The use and operate phase implies a dual perspective:

- User perspective, mainly involving occupation of the building, with minor maintenance and repair works performed or commissioned directly by the user
- Facility management perspective (for big buildings only), involving the management of operation activities of the building, such as renting out, major maintenance and servicing.

The use and operate phase has the following sub stages:

- **Ecosystem construction**: Completing the building with all necessary services and utilities in order to make it fully functional (e.g. cable distribution, grid connections, service contracts)
- **(Re)Use**: Occupation and/or operation of the building, maintenance and repair works
- **Ownership Transfer**: building transfer to new owner (when relevant)

The ‘use’ and ‘ownership transfer’ sub stages can be repeated several times within the same use-phase before the building proceeds to the repurposing phase.

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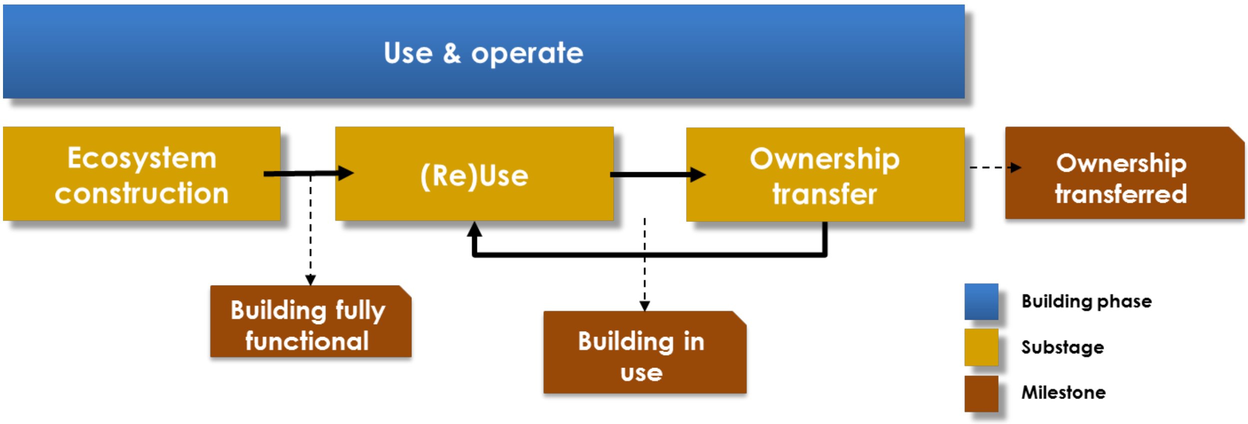

Figure 19: Sub stages during the use & operate phase

The main outputs of the use & operate phase are:

1. Infrastructure and ecosystem of the building are **fully functional**
2. **Building used** by all user types against (original and changed) use requirements; users like residents/ occupants, visitors, emergency services, facility managers
3. Building **ownership transferred** to new owner(s) (when relevant)

A building can have several consecutive use phases, separated from each other by the processes of repurposing, (re)designing and (re)building.

The table below lists the relevant actors in this use and operate phase, and their main role.

Table 6: Actors involved during the use & operate phase

Actor	Related actors	Main role in the use & operate phase	Comment
Property Owner and new property owner(s)	Investor Facility manager Property manager	Interact with the user on requirements. Responsible for large repair works or delegates this to the facility manager.	
Property User(s) and visitors and new tenants	Owner Tenant Visitor Employee	Use the building as residents, employees or visitors, including minor maintenance, repair and refurbishment works.	
Insurer		Fire insurance, mortgage insurance	
Facility manager	Operator	Facilities management, planned preventative maintenance and repair actions, renting out parts of the building	

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Providers of materials, products and technical services	Suppliers Manufacturers	development, manufactory and delivery of building materials, products and technical services related to major refurbishment or transformation works and big/small maintenance	At the moment the use of secondary products and materials is not mainstream during the use & operate phase
Maintenance services and utility providers	e.g. energy and water companies	Technical assistance and execution of refurbishment or transformation works, big/small maintenance and repair works	
Regulator, government, local councils		taxation on property ownership, establishing and control of local building regulations, also for refurbishment and renovation rules on what the building needs to comply with when you sell it or the actions that need to be undertaken e.g. energy performance (EPB Directive); electricity conformity attestation, etc.	
Suppliers of Consumables & service suppliers		Supply of moveable (consumable) products/goods and services in order to make the building liveable, usable.	
Emergency services	e.g. fire brigade, ambulance	Ensuring emergency assistance during the use of the building (safety regulations, exercises, emergency access)	

4.5.2 Value network approach: roles and interactions

During this phase we consider 3 major grouping of roles:

1. **Use-Operate-Maintain**: i.e. actual use and associated maintenance and operating activities related to the building
2. **Supply of Products, Consumables and Services**: all suppliers of different services and products needed to operate the building (e.g. consumables for catering/ printers, emergency services, maintenance providers and product suppliers when maintaining/ replacing products, etc.)
3. **Handover to New Owner or Tenant**: initiating a potential redesign and transformation of (parts of) the building

The interactions and information, material and financial flows between the different roles in the use & operate phase are presented in the diagrams below. A distinction is made between the **business-as-usual situation**, representing the mainstream and well established interactions between the different roles (Figure 20) and the **state-of-the-art situation**, highlighting the interactions that are considered as leading practices in the construction sector, but are not yet

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regarded as mainstream and often lacking in current building projects (Figure 21). These leading practices and the type of interactions they embody are described in more detail in Table 7. The opportunities and advantages related to these state-of-the-art practices are described, but also the current barriers that explain the reason why these interactions are often lacking in mainstream building practices, are indicated.

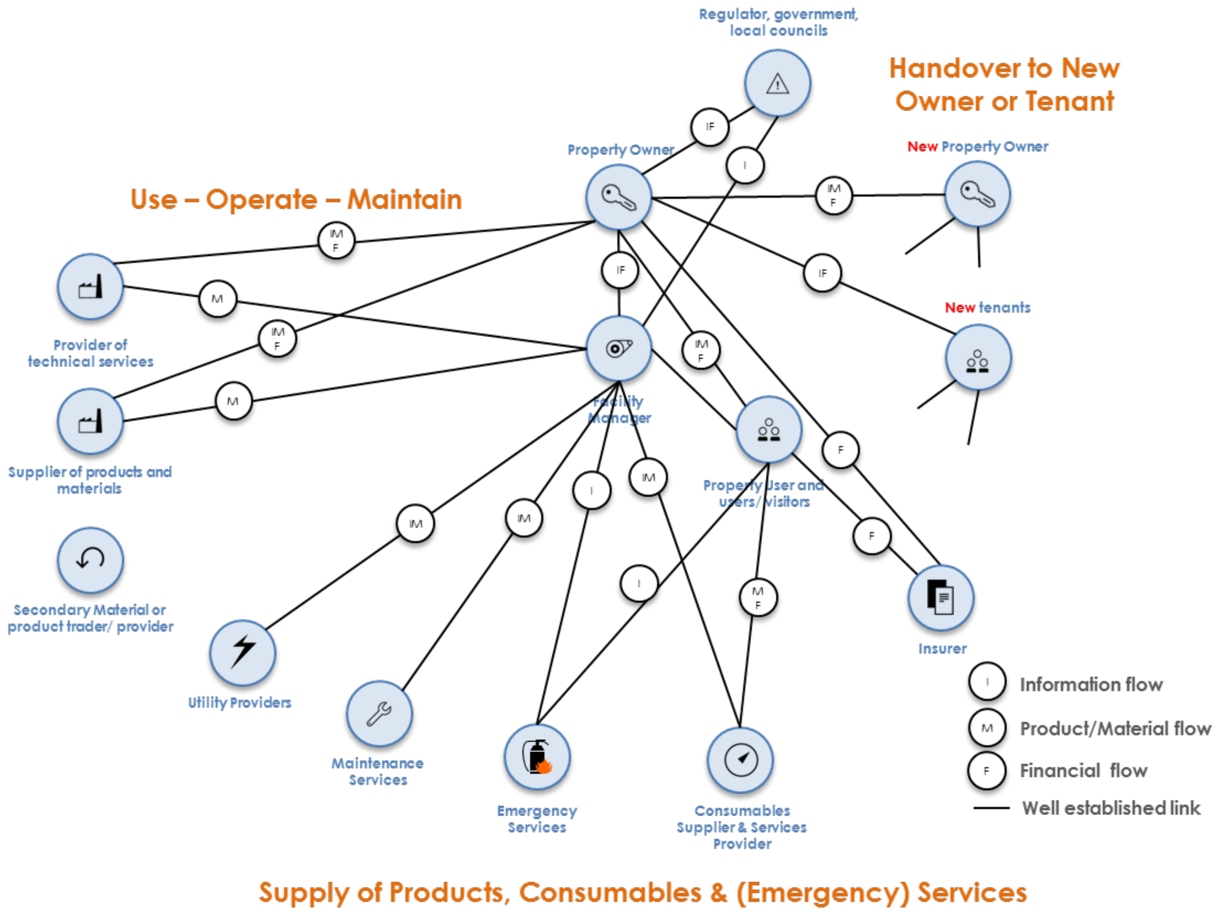

Figure 20: Roles and interactions during the use & operate phase (business-as-usual)

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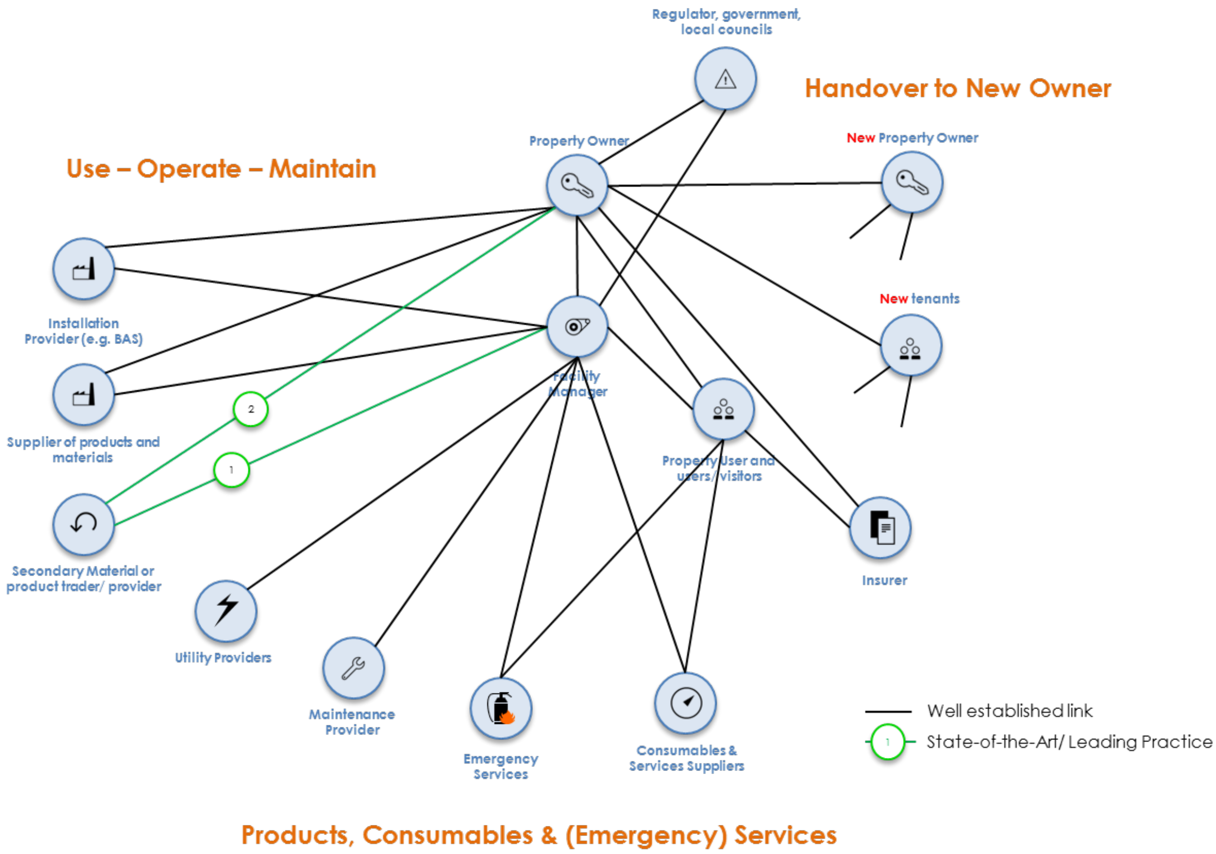

Figure 21: Leading practices during the use & operate phase (state-of-the art)

Table 7: Leading practices during the use & operate phase (state-of-the art)

ID	Type of Exchange	Short Description	Development & Trends	(Current) Barriers	Opportunities
1	Product/ Material flow	During use of the building products, components or materials are needed to maintain or replace used or end-of-service products. The facility manager coordinates this, as contracted by the property owner.	Reusing products, components and materials is not new to the industry but not widely practice yet, due to maturity of the industry and knowledge gaps in the disciplines of the design team.	Not many suppliers in construction have business models with mix of new and reused in their product and services portfolio. Suppliers of this industry have a major influence in the understanding of reuse potential by the design team (architects and engineers).	Facility managers are more and more stepping into full service models to manage all aspects of the building for the property owners. This includes managing/ coordinating all contracts and renovation/ maintenance/ replacement activities. Some facility managers are also the contract owners where they would need same data/ information as the property owners.
2	Information-Product/ Material - Financial flow	The property owner owns the contracts to the providers of products/ or services to the products, to maintain the building and its (embedded) products.	Some construction companies are re-using specific product categories (doors, interior walls, window frames) in their projects. However, many of these reuse initiatives are within the walls of the company in renovation/ building projects also managed by themselves.	Some Architect bureaus operate in a niche market where they first check what is already available before starting the actual design. Property owners do not have (direct) access to supply channels of reused products, components and materials.	A growing number of suppliers, with a portfolio of services or performance based contracts on their products (pay by use concept), will undergo an acceleration of adopting the principles of circular design and the inherent reuse of their own products and components for economic viability. Property owners that assess the supply market to understand all supply options and access to these reuse channels, can benefit directly by using the performance of the product and not worry about maintenance or replacement needs.

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4.6 Phase 4: Repurposing & demolition

In current construction practice the repurpose & demolition phase mostly results in the complete destruction of the building after use. Repurposing of buildings or components only occurs to a limited extent (e.g. repurposing of historic and factory buildings for commercial or residential usages, or reuse of durable components such as bricks, timber and steel joists, wooden doors and ceramic tiles).

4.6.1 Process approach: sub stages, milestones and actors

The repurpose & demolition phase can be divided into several sub stages:

1. **Preparatory study**: demolition study: asbestos survey, assessment of structural risks, information on hazardous materials and utilities, etc.);
2. **Demolition and dismantling**: Extraction of components for reuse and demolition of the building
3. **Repurposing**: Reusing the dismantled components and materials in new building projects.
4. **Waste treatment**: Sorting of the construction waste both on-site and off-site and treatment of building waste at waste treatment installation into materials for recycling, recovery or landfill.

The main outputs of this phase are:

- A **repurposing plan** for the building, part of the building or some components.
- A **demolition plan**
- Components **deconstructed** and materials/products **dismantled** for **reuse**
- **Demolition waste** that is sorted for **recycling** (e.g. steel, granulates, etc.), **energy recovery** (e.g. wood waste, biogas) or **landfill**.

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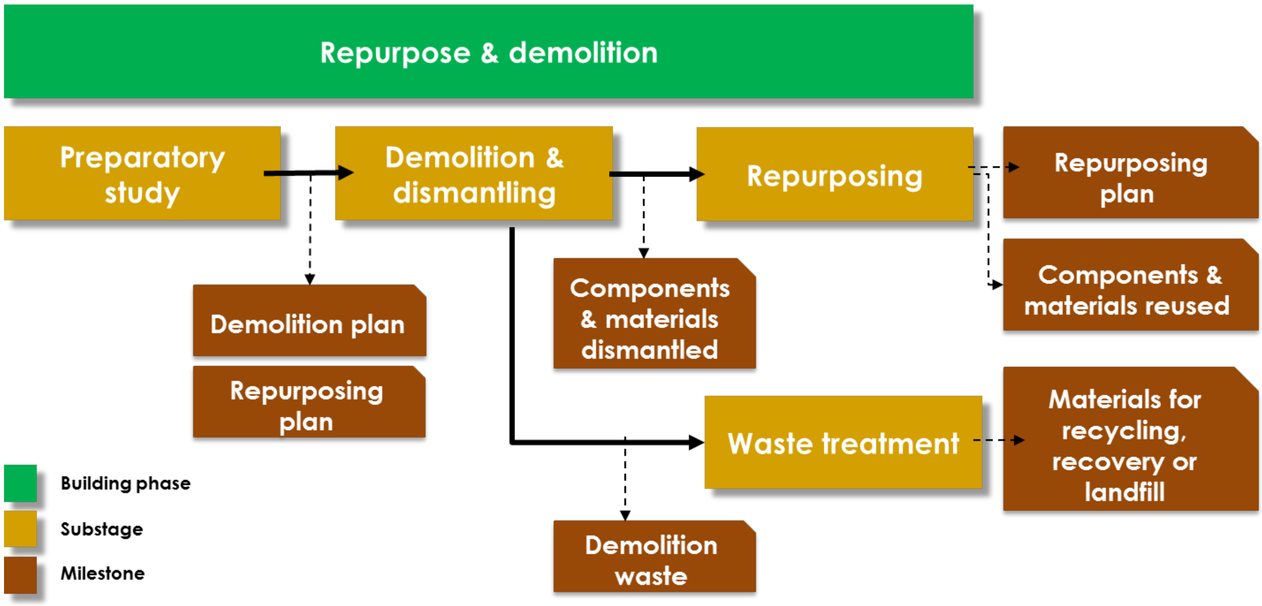

Figure 22: Sub stages during the repurposing & demolition phase

The table below lists the relevant actors in this Repurpose and Demolition phase, and their main role.

Table 8: Actors involved during the repurpose & demolition phase

Actor	Related actors	Main role in the repurpose & demolition phase	Comment
Property Owner	Investor	Deciding on the demolition or repurposing and contracting the demolition company.	
Facility manager	Operator	Managing the operation of the building in view of the repurposing plans or the demolition, e.g. dismantling of the activities, assuring a smooth handover.	
Demolition company	Waste treatment facilities	Demolishing of the building. On-site sorting of waste. Transfer of waste to treatment facilities.	
Transport / Logistics company		Transporting demolition waste and reclaimed materials and products to sorting and treatment facilities	
Products maintenance service		Cleaning, repairing reclaimed products in order to sell/lease them.	not mainstream, but for some materials streams, such as (reclaimed) bricks, a separate market is

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company			observed
Recycling company (incl. crushing and refinement)	Transport & logistics company Secondary material provider	Treatment and sorting of demolition waste into recycled materials, e.g. granulates. Feedstock and material recycling	current recycling activities are still characterised by secondary use of materials for lower (value) applications (cf. down-cycling)
Secondary material / reclaimed products provider		Supply of secondary materials and reclaimed products for other (building) applications	
landfill facility		Dumping of (inert and non-hazardous) demolition waste into designated land plots.	This should be avoided by principle as landfilling of waste means material value and reuse options are lost
incineration facility		incinerating (organic) demolition waste, with the possibility to recover heat and energy for other purposes	This should be avoided by principle as incineration of waste means material value and reuse options are lost
farming company		composting or extraction of biological components in order to provide nutrients for new biological (building) products	
Regulator, government, local councils		setting up demolition waste directives Permit for demolition or repurposing	

4.6.2 Value network approach: roles and interactions

During this phase we consider 3 major grouping of roles:

1. **Planning for Repurpose**: i.e. using all available information to understand product status and reuse options to plan for repurpose (as product, component or material)
2. **Demolition and Deconstruction of Building & Products**: i.e. actual extraction of products, components and materials out of the building, demolishing of the building, building waste transferred to recycler of waste manager.
3. **Assessing of Product & Materials Supply Potential**: i.e. channelling the (refurbished/ remanufactured) products, components and materials back into (re)designed buildings
4. **Waste treatment**: i.e. end-of-life treatment (and related logistics) of (sorted) construction and demolition waste, such as landfilling and incineration (with energy recovery).

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The interactions and information, material and financial flows between the different roles in the use & operate phase are presented in the diagrams below. A distinction is made between the **business-as-usual situation**, representing the mainstream and well established interactions between the different roles (Figure 23) and the **state-of-the-art situation**, highlighting the interactions that are considered as leading practices in the construction sector, but are not yet regarded as mainstream and often lacking in current building projects (Figure 24). These leading practices and the type of interactions they embody are described in more detail in Table 9. The opportunities and advantages related to these state-of-the-art practices are described, but also the current barriers that explain the reason why these interactions are often lacking in mainstream building practices, are indicated.

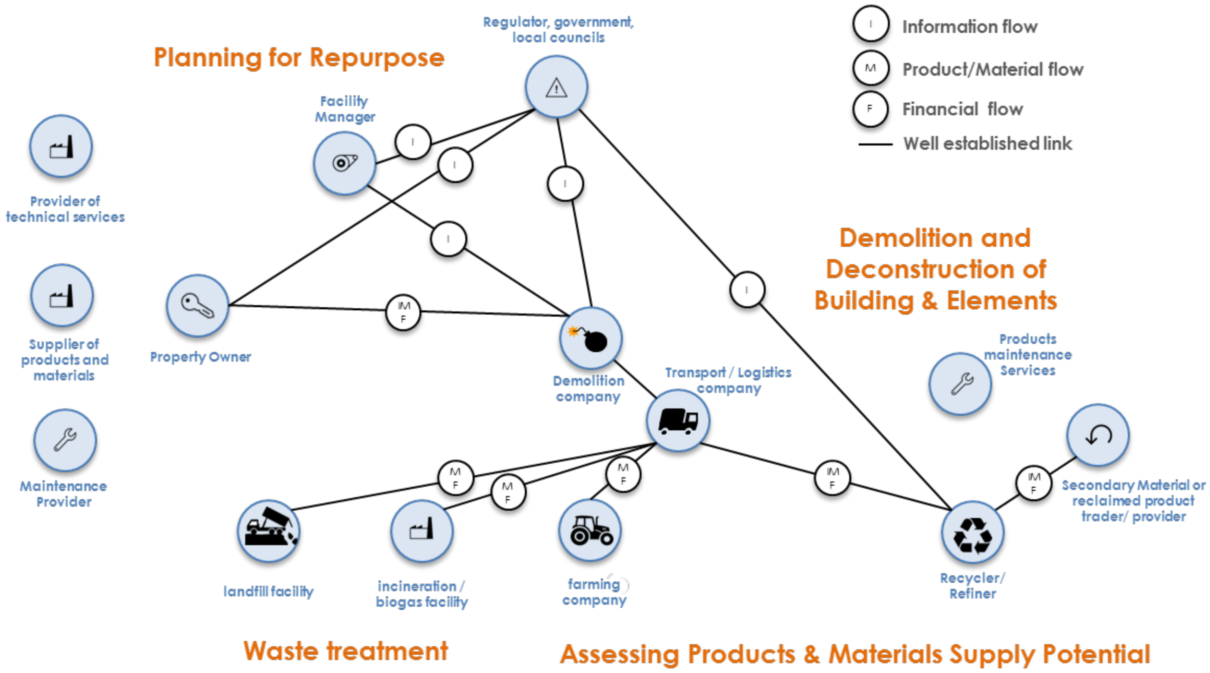

Figure 23: Roles and interactions during the repurpose & demolition phase (business-as-usual)

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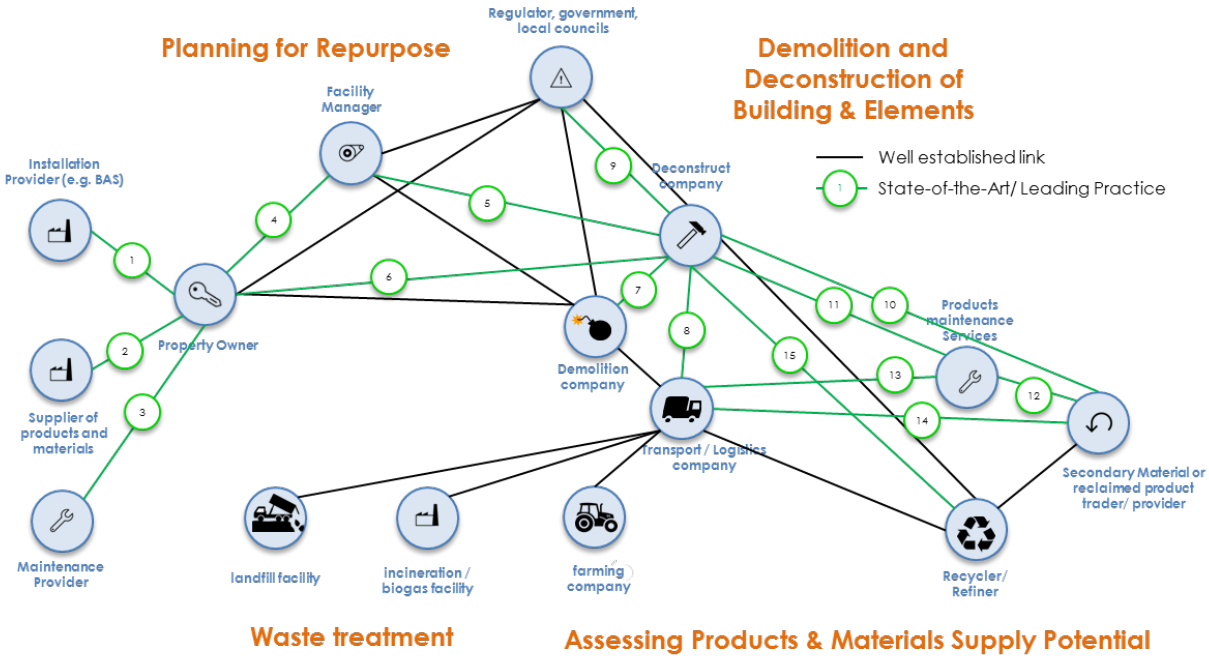

Figure 24: Leading practices during the repurpose & demolition phase (state-of-the-art)

Table 9: Leading practices during the repurpose & demolition phase (state-of-the-art)

ID	Type of Exchange	Short Description	Development & Trends	(Current) Barriers	Opportunities
1	Information-flow	Information transfer on products status to determine reuse options. This could include transfer of ownership with a performance based contract if the supplier decides so.	More data points on product or component use and state are collected. This data, when analysed and assessed against reuse options of the product or component, provides valuable information on actual repurposing potential.	Many suppliers of installation systems for buildings use propriety software and protocols, making it hard to collect data for other parties.	Access to use data of products and components (i.e. by contract) will provide the necessary data points to get more accurate information on actual repurposing options and choosing the right reuse loop.
2	Information flow	See description 1.	See description 1.	See description 1.	See description 1.
3	Information flow	Provide status data (usage, state) of products, as per maintenance data to increase quality of data and reuse decisions.	See description 1.	See description 1.	See description 1.
4	Information-Financial flow	Act as coordinator/ project manager of any deconstruction or demolition activity, on behalf of the property owner, at repurposing of (parts of) the building.	Property owners are leaning more on the expertise of facility managers, also as a result that facility managers have grown in the capability to coordinate and manage many different activities during the lifecycle of a building.	For facility managers to act on behalf of the property owners, they will need access to same datasets, and further develop analytics/ business planning capabilities. The big facility management companies are only recently offering this on the market.	Facility managers can play a more coordinating role across the industry as they combine expertise and experience of managing all these buildings through all of their lifecycles.
5	Information flow	Deconstruct company instructed/ managed by the facility manager to extract targeted products and components.	During deconstruction of (parts of) the building, facility managers are more and more being utilized to coordinate these activities with the contracted deconstruction	Deconstruction today is focusing on a limited set of product categories as full and optimized repurposing plans (for deconstruct and demolition) practically do not exist, thus limiting the need for facility managers to	Full and optimized repurposing plans will require companies, such as facility managers, to coordinate all related deconstruction activities.

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			companies.	resume such coordinating role.	
6	Information-Financial-Product/ Material flow	Instructing and/or contracting a company to deconstruct products and components as planned by the property owner.	Property owners have increasingly interest to monetize the actual value of building and (embedded) building products and materials, not limited to the value per current market criteria and accounting booking value.	Understanding of actual value of the building, its (embedded) products/ components and materials requires connecting many datasets.	Combination of different datasets to predict and optimize reuse loops of products, components and materials.
7	Information-Financial-Product/ Material flow	Deconstruct company working together with the Demolition company to repurpose any product, component and material.	Separation of deconstruct versus demolition capability is starting to take shape as companies with an Urban Mining profile, contracting demolition companies, are starting to emerge in the market.	Today there is no clear distinction between a deconstruction and demolition company as capability to plan for deconstruct is widely missing.	A separation of planning for deconstruct versus demolition of (parts of) the building and/ or its (embedded) products will increase quality of operations of both roles.
8	Information-Financial flow	Contracting (specialized) logistics service providers to collect, ship, store and deliver the products and components to the recipient/ buyer of the secondary products, components or material.	Suppliers of reuse products and components require more specialized or care in transportation of these products to avoid damage and additional repair/ refurbishing costs. By product category shipping instructions are required (similar to new products).	Logistics Service Providers missing overview of product status and shipping requirements. The deconstruction company needs to conduct proper packaging and provide shipping instructions to the contracted logistics service providers.	Cost of repair or refurbishment of reused products and components could be minimized when deconstruction and shipping activities are properly conducted, thus increasing the margins on resell.
9	Information flow	Deconstruct companies (i.e. Urban Mining) adhering to regulatory compliance rules and legislation when planning and executing deconstruction activities.	Urban Mining companies are entering the construction landscape, where focus on reuse is shifting from purely materials (demolition view) to product and component reuse (with higher residual value). This requires for public functions to learn and adapt to the changes of building circularity.	Legislation and compliance rules can hinder reuse of products and materials, and not limited to construction industry alone: E.g. as building are equipped with more technology, the impact of WEEE/ e-Waste is impacting reuse options for this product category.	Legislation and regulatory compliance rules on local, national and European level that is made fit for reuse of the different product categories that make up a building (spanning multiple connecting industries).
10	Information-Financial-Product/ Material flow	Providing reuse information and products to the buyer/ recipient of secondary products, components or material.		Upfront information on status of goods to be received hinders these suppliers to plan repair/ refurbishment activities and balance resources. Today they plan when actually receiving the products.	Components are often worth much more than their constituent materials. Stakeholders benefit earlier from component reuse than from recycling the materials.
11	Information-Financial-Product/ Material flow	Providing reuse and reclaiming information to the company that will clean and refurbish these materials into reusable materials ready for the market.		See description 10.	See description 10.
12	Information-Financial-Product/ Material flow	Providing reuse information and reclaimed (cleaned, repaired,…) products to the buyer/ recipient of secondary products, components or material.		See description 10.	See description 10.
13	Product/ Material flow	Transport of deconstructed materials to a company that cleans and refurbishes these materials into reusable materials ready for the market.		See description 10.	
14	Product/ Material flow	Transport of reclaimed, ready-for-reuse materials to the market.	New material salvaging techniques (like the cement powder not activated in high quality concrete) is being reused more every day.	Current cartel managed sectors (like cement) prohibit wide use of reclaimed materials, as this collide with normal mining or supply practices. Only a limited set of companies with a strong market profile are willing to incorporate	Supply of secondary material would reduce supply chain risks, while reducing the negative environmental consequences of new materials. Furthermore, quality can be as good or more pure than from new due to new applications of recovery techniques and

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				these materials in their products.	technology.
15	Financial-Product/ Material flow	Products and components that are not resalable anymore up-to or after extraction, is send to the recycler/ refiner to return these products to secondary raw material.	More Urban Mining companies are entering the market, with a need of strong business connections with recyclers/ refiners to maximize residual value for also products and components that are put in the material reuse loop.	Product properties and material composition information is not available for all products and components. Recyclers/ refiners focus on most valuable materials and discard the rest as their recovery processes do not have the required maturity and/ or do not know the material composition to plan for more material recovery.	Product properties and material composition information would help recyclers/ refiners to plan for full material recovery of all individual material composition.

4.7 Discussion

From the previous analysis it is obvious that the built environment consists of a sequence of building phases (and sub phases) and a broad variety of actors. **Only a few of these actors are involved in all phases (e.g. property owner), depending on the type of building project (e.g. public or private)**. Most actors, however, are only involved in one or two building phases and not throughout the entire value chain. It is observed that **the design and build phases have relatively well established connections** in terms of actors that are involved in both. However, as soon as the building is commissioned, these connections are cut off and actors that were involved in the design and building of the construction are rarely involved during use and repurposing/demolition phases. This means that a lot of valuable information about the construction, the operation, the materials and the reuse/recycling/recovery options is not available for the actors involved within repurposing and demolition/deconstruction activities. Seen from the demolition/deconstruction side, this also means that building design and construction actors do seldom take into account the end-of-use or end-of-life consequences when making design or construction choices, leading to waste streams that cannot be recycled or only down-cycled. Moreover, if **end-of-life issues would be taken into account during the design and construction phases**, this would also facilitate the reuse of components, that are often worth much more than their constituent materials.

In order to foster circularity in the building sector, **connections between all phases in the value chain are necessary in order to support communication and information transfer across the whole of the value chain/network**.

This is exactly what the BAMB project is aiming for! By supporting the development of Reversible Building Design Protocols, Materials Passports and related decision-making instruments during this innovation action project, "Design & Build" actors will have a better understanding on the potential consequences of their decisions made during these two crucial phases within the value chain. Moreover, the development of a Materials Passport IT Platform and a BIM prototype will serve as a proof-of-concept on exchanging information on building products and the building's operation to "Use and Repurpose" actors. The current development of the (integrated) BAMB output and the way it will (ideally) influence the value network is elaborated on in the next chapter.

Major opportunities and barriers identified during the value network analysis (see Table 3, Table 5, Table 7 and Table 9) are taken as input for Chapter 6.

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5 MATERIALS PASSPORTS AND REVERSIBLE DESIGN AS PART OF THE SOLUTION

5.1 Materials passports

5.1.1 Description

The term 'passport' in relation to buildings has been used for more than 35 years. However, there is no broadly accepted regulatory or industry definition. Within the BAMB project we use the following definition: "*Materials Passports are (digital) sets of data describing defined characteristics of materials and components in products and systems that give them value for present use, recovery and reuse*". (EPEA et al., 2016)[11]

Materials Passports gather materials data, maintaining confidentiality where needed, and offering information that users need. The data input isn't part of the Materials Passports. However, the output can be used for other purposes. Essential to materials passports success are solutions which play a key role in enabling the transition towards circular business models. This role is threefold: (1) gathering data about materials and tracing materials and products, (2) applications for organizing reverse logistics, and (3) accelerating innovation through information sharing.

Presently the information is dispersed or not available, which is a major cause of waste creation. Materials passports developed within the BAMB project will offer opportunities to recover value from recovery and reuse of materials, products and systems used in buildings for stakeholders across the value chain. They also work as a market instrument, to encourage product designs, material recovery systems, and chain of possession partnerships that improve the quality, value, and security of supply for materials so they can be reused in continuous loops or closed loops, or beneficially returned to biological systems. This is done by adding a new value dimension to materials quality. This new dimension is based on the suitability of materials for recovery and reuse as resources in other products and processes (Hansen et al., 2012; EPEA et al., 2016)

5.1.2 Observed niche activities

Identifying frontrunners depends on which type of passport you are looking for. There are product passports, passport for products in buildings, and building passports, as well as databases that are platform model examples to be considered by BAMB.

Mulhall et al. (2016) identified at least 13 product passport initiatives (see Table 10): five are in the private sector for building-related products; three are government agency driven – and among those the Declaration of Performance (DoP) and Material Safety Data Sheet (MSDS) – seem most established; three are offered by NGOs; one is for products and materials in ships; and two do not seem to be in the marketplace yet.

In relation to BAMB, many of those initiatives have relevance although they are not connected directly to buildings. The way they organize data, databases and access to information is relevant for BAMB (Mulhall et al., 2016):

[11] The definition of Materials Passports has been updated compared to (EPEA et al., 2016), based on state-of-the-art survey results.

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- *Data systems have high relevance.* Database initiatives ranging from BIM software to ISO and augmented reality were identified. These are rich sources of data and organization protocols for the Materials Passport IT platform to gain from as it develops.
- *Visualising data.* Augmented reality software has reached the point of tagging products in buildings and visualizing them with a tablet computer by pointing at the product while walking in the building, or from a desk where the person is location independent. It opens a substantial added value potential in BAMB to link passports with a 'point and see' capacity that provides instant information to users on site.

Table 10: identified existing Materials/Product/Recycling Passports, based on Mulhall et al. (2016)

Passport name	*Initiator's name*
C-passport	*Cirmar*
Circularity passports	*EPEA*
Cradle to Cradle Passport	*Sustainable Shipping Initiative*
Declaration of Performance (DoP)	*EC Product Directives*
Environmental Product Declaration (EPD)	*ISO*
Health Product Declaration (HPD)	*Health Product Declaration Consortium*
Material Safety Data Sheet (MSDS) & Safety Data Sheets (SDS)	*The Hazard Communication Standard, OSHA*
Product Passport *	*European Resource Platform*
Raw Materials Passport	*Turntoo & Double Effect*
Recycling Passport	*Agfa-Gevaert & Electrocycling GmbH*
Resource Identity Tag or Tool *	*Groene Zaak/Metabolic/Fairmeter.org*
Technical passport for equipment	*Kazakhstan & Russia*
Workwear Passport	*Dutch Awearness*

* = marketplace status uncertain

Table 10 gives an overview of identified existing product passports, all serving a specific or defined purpose. Multiple criteria analysis has been used to investigate the usefulness of the existing passports to address BAMB ambitions. It has to be noted, that this analysis is still ongoing, requiring further investigation. So far, the Circularity Passports, developed by EPEA, seem to be a good starting point for the development of the BAMB Materials Passports, and related IT platform. Table 11 gives an overview of the current situation of the multiple criteria analysis.

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Table 11: Assessing the relevance of existing Materials/Product/Recycling Passports for BAMB Materials Passports, based on Mulhall et al. (2016)
(in table indicates examples where criteria are specified but might not yet be put into practice.)*

Title ? = undetermined so far. Does not suggest missing, but rather requires further investigation.	Composition	Susainable resources use during production	Materials health	Designs for disassembly	Bio/technical cycle	Product /component re-use potential	Materials re-use potential	Noise reduction/safety/fire	Positive impacts	Certifications	Tax credits	Removal costs/residual value	Building Context	Automated entry of existing data	Updated during operations
BIMObject	✔	In some	in some	in some	no	?*	?	?	no	?	no	no	link to BIM	some	no
C-passport	✔	?	✔	?	✔	✔	✔	✔	?	✔	?	✔	?	?	?
Circularity passports	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	?	✔
Cradle to Cradle Passport for ships	✔		?	✔	?	?	?	?	?	?	?	?	?	?	?
Declaration of Performance (DoP)	?	✔	?	no	no	no	?	✔	no	✔	no	no	no	?	no
Environmental Product Declaration EPD*	✔	✔	Hazards	no	no	?	?	?	no	✔	no	no	no	no	no
Health Product Declaration (HPD)	✔	✔	✔	no	no	no	no	some	no	✔	no	no	no	no	no
Material Safety Data Sheet (MSDS) & Safety Data Sheets (SDS)	✔	?	?	no	no	no	no	✔	no	?	no	no	no	?	no
*Product Passport *European Resource Platform*	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
Raw Materials Passport	✔	?	?	?	?	?	✔	?	?	?	?	?	?	?	?
Recycling Passport *based on WEEE*	some	no	some	✔	no	some	some	some	no	?	no	no	no	?	no
*Resource Identity Tag or Tool	✔	?	✔	✔	?	✔	?	some	?	✔	?	?	✔	?	?
Technical passport for equipment	some	no	some	some	no	no	some	some	no	some	no	no	no	?	no
Workwear Passport	?	?	?	?	?	?	?	?	?	?	?	?	n/a	?	?

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5.2 Reversible building design tools

5.2.1 Description

In order to guide designers (i.e. architects, engineering firms as well as urban planners) and other stakeholders within the building value network, such as building clients, property developers and facility managers, to implement reversible design strategies and approaches, three tools will be developed within the BAMB project: i.e.

1. **Reuse potential tool**, to assess the technical reversibility of building designs and their constituting parts, in order to preserve the buildings, its components and materials residual value and foster high quality reuse.
2. **Transformation capacity tool**, to assess the spatial reversibility of building designs and their constituting parts, in order to enlarge (future) transformation possibilities on building, system as well as component level.
3. **Reversible Building Design protocols**, integrating the two tools above with the purpose to inform designers and decision makers about the technical and spatial reversibility of building design(s) and the impacts of design solutions during the conceptual design phase.

5.2.2 Observed niche activities

Although within Europe more and more projects emerge in which the building is designed and constructed to be easily transformed – in order to facilitate building reuse – or easily deconstructed – in order to facilitate component reuse – user-friendly (design) guidelines to do so and assessment tools are still scarce. Below a short overview of front-runner tools are listed into 4 groups: (1) geographical tools mapping the market availability of reclaimed building products, (2) scoring tools quantifying the potential for deconstruction and disassembly; (3) scoring tools quantifying the potential for adaptability; and (4) integrated life cycle approach.

1. Mapping the market availability of reclaimed building products

Within the Netherlands and Belgium some front-runner developers came up with different approaches to collect and map information on the availability of (potentially) reclaimed building products (Durmisevic et al., 2016):

- **Harvest Map** (www.oogstkaart.nl): a tool developed by Super use in Rotterdam to collect information about buildings in the Netherlands that will be demolished and putting the information on an open platform.
- **Resource Limburg database** (www.resourcelimburg.nl): a database of the materials that are coming out of the exhibiting buildings and are being put available for the market. Resource Limburg is developing methods to produce new building elements out of existing buildings that usually end up as a waste and has established a workplace for testing and upgrading of existing materials for new applications.
- **OPALIS web platform** (www.opalis.be): an on-line database of suppliers of reclaimed building products. Suppliers can be found based on location and type(s) of building material they specialise in. There is an info sheet with pictures for each reseller. The website also provides information and documentation on material and component reuse.

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2. Quantifying the potential for deconstruction and disassembly

Both DGNB and the BRE Trust have developed tools for quantifying Design for Deconstruction (or the 'technical reversibility' as described in section 5.2.1). The DGNB tool supports a new-build office scheme criteria and has scoring indicators relating to the ease of disassembly, scope of disassembly and viability of disassembly. The BRE Trust have recently developed an outline Design for Deconstruction methodology for new-build residential buildings [12].

Whilst a new **ISO standard 20887 Design for Disassembly and Adaptability of Buildings** is under development by TC 59/SC17, building on an existing standard from Canada, it is not clear at this stage whether this will result in a quantifiable design assessment tool.

The **BRE Design for Deconstruction methodology** focusses on the types of materials and components used, the way they are put together and their potential to be taken apart. The methodology has been applied to a number of case studies of residential buildings. A schematic of the methodology is provided in Figure 25. (Dodd et al., 2016; BRE Buzz, 2016)

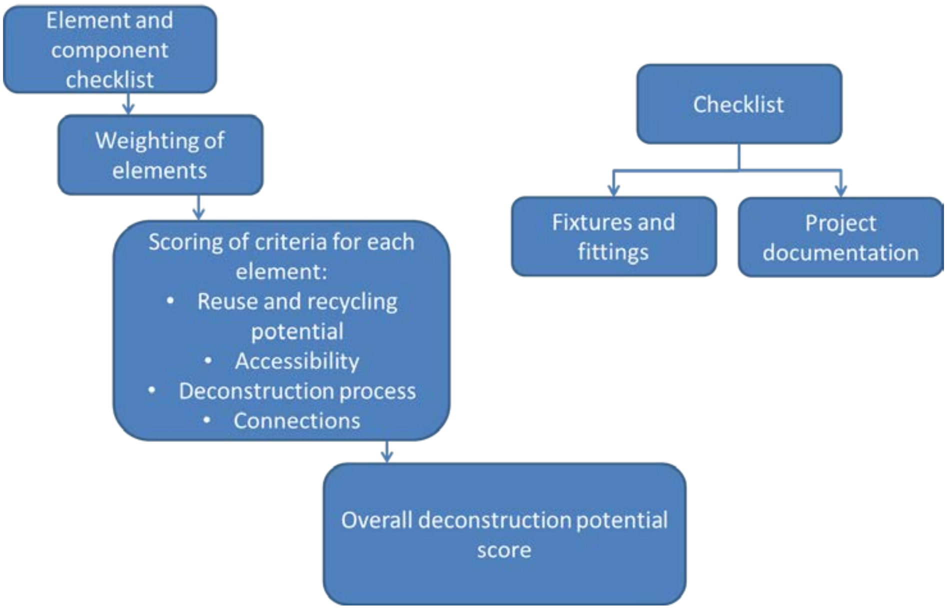

Figure 25: Schematic of BRE Design for Deconstruction methodology, from BRE (2015)

The methodology groups building elements into: foundations and ground floor, other floors, roof, external walls, other walls and finishes, floor finishes, building services and sanitary ware. Fixtures and fittings are also considered, if information is available. The building elements are then weighted according to their embodied CO_2 equivalents. The weighting is adjusted according to the form of house and building materials. (Dodd et al., 2016)

The German **DGNB scheme's category scoring for deconstruction and disassembly** considers four component categories: building services, non-structural building components,

[12] BRE Buzz, *Design for Deconstruction - helping construction unlock the benefits of the circular economy*, Accessed on May 2016, http://brebuzz.net/2015/12/04/design-for-deconstruction-helping-construction-unlock-the-benefits-of-the-circular-economy/

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non-load and load bearing components of the building shell. A brief overview of how the criteria scoring works is provided in Table 12. The two indicators are weighted equally and are intended to be complemented by a plan describing the 'means and financial responsibilities for controlled disassembly'. (Dodd et al., 2016)

Table 12: Scoring for DGNB TEC 1.6 Deconstruction and disassembly criteria, based on DGNB (2014)

Indicators	Category scoring	Category description
Difficulty of disassembly	Very high	*Disassembly requires very considerable effort*
	High	*Disassembly requires great effort (such as demolition of strong adhesive coatings)*
	Medium	*Demolition requires moderate effort (such as tearing up flooring)*
	Low	*Demolition requires little effort (such as removal of filler material)*
	Very low	*Very easily disassembled (such as clamped joints, loose supports, snapping or bolted joints)*
Scope for disassembly	Unfeasible	*Removal of material residues (e.g. screed, grout or sealants) on materials such as floor coverings or window frames. Separation procedures which cannot be carried out on-site.*
	Feasible	*Requires dedication of manpower and machines suitable for the sites: sanding, chipping, milling processes etc..*
	Easy	*Can be done manually by means of simple tools: lifting, pulling, and uncovering (floors, wall coverings etc..)*

3. Quantifying the potential for adaptability

BREEAM Netherlands and DGNB include tools enabling the quantification of the 'functional adaptability' (or 'spatial reversibility' as described in section 5.2.1) of building designs. Aspects such as placement of columns and bay windows, the ease by which interior walls can be moved, the extent to which the building is divided into one or more parts or wings, the load-bearing capacity of the floors and the plan depth and daylight penetration, are addressed by these tools. Both tools make reference to design criteria and specific recommendations. A comparison of the calculation methods developed by BREEAM Netherlands and DGNB is provided in Table 13. (Dodd et al., 2016)

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Table 13: Comparison of the BREEAM Netherlands and DGNB adaptability calculation methodologies, based on BREEAM Netherlands (2014) and DGNB (2014)

Aspect of methodology	DGNB	BREEAM Netherlands
Scope	*Changes in occupier requirements and change in use*	*Changes in occupier requirements and change in use*
Indicators	*Seven in total:* 1. *Space efficiency* 2. *Ceiling height* 3. *Depth of floor plan* 4. *Vertical access* 5. *Floor layout* 6. *Structure* 7. *Building services*	*Fifteen in total, split into three categories, each category with five indicators:* - *Allotment (partitioning)* - *Adaptability (unit level)* - *Multi-functionality (building level)*
Weightings	*Each can award a maximum of 10 points, with the exception of building services, which can award 40 points.*	*The three categories are weighted in a ratio of 5:11:15*
Distinct aspects	- *Space efficiency factor* - *Depth of floor plan* - *Vertical service access* - *Potential to reconfigure water system*	- *Column placement* - *Façade pattern* - *Daylight access as proxy for depth of floorplan* - *E-installation connections and independence to arrange them* - *Specification of unit size* - *Fire resistance of building structure*

4. Integrated life cycle approach

Through a couple of research projects (Paduart et al., 2013; Debacker et al., 2015) commissioned by the Flemish Public Waste Agency (OVAM), a widely applicable assessment framework has been developed. This assessment framework is based on an integrated life cycle approach and is comprised of a qualitative and a quantitative part.

The qualitative part of the assessment framework consists of a **set of practical Design for Change guidelines**. To assist in the application of these principles, each design principle was discussed and illustrated on a separate sheet. These sheets are available online and allow designers, developers and policymakers to get acquainted with existing solutions and at the same time provide them with an understanding of the importance of the Design for Change concept. Each principle also includes key questions in order to assess a design alternative. Within Figure 26 an overview of all Design for Change guidelines is provided. The synchronous treatment of three scales (building elements, buildings and neighbourhoods) ensures a holistic approach. To ensure the cohesion between these scales, all the guidelines are divided into three themes: the interfaces between components, the characteristics of those sub-components and their composition. (Debacker et al., 2015)

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	Interfaces	Sub-components	Composition
Element	Reversibility Simplicity Speed	Durability Reused Compatibility	Pace-layered Independence Prefabrication
Building	Accessibility	Demountability Reusability Extensibility	Versatlity
Neighbourhood	Clear Adaptable	Retrofitted Dimensioned Removable	Unified Multipurpose Diverse Densificable

Figure 26: Overview of the Design for Change guidelines developed within Debacker et al. (2015), based on Vandenbroucke et al. (2015)

The quantitative part of the assessment framework consists of executing a **life cycle assessment** (LCA) – to calculate the environmental impact – and **life cycle costing analysis** (LCC)– to calculate the financial costs – in parallel. LCA and LCC are used to investigate the effect of certain design decisions along diverging future use scenarios, in order to quantify the potential environmental and financial benefits from designing for Change. As it is the case for the qualitative part, the assessment can be performed on three scale levels (element, building and neighbourhood), depending of the scope of the project. It allows decision-makers to compare environmental external costs and financial costs – initial as well as life cycle costs – of conventional and Design for Change solutions and/or to narrow down design options. (Debacker et al., 2015)

5.3 The integrated BAMB output

5.3.1 Description

The integrated BAMB output aims to combine in an integrated way the outputs from the Materials Passports and the Materials Passport IT platform (Materials Passports) (providing the information on the resource productivity[13] of materials and products) with the outputs of the Reversible Building Design tools (providing information on the building design and assessing buildings and its constituting parts) within an information management tool (which might be BIM).

This could be an integrated tool or suit of tools or a broader output such as a platform that offers services integrating business models to different stakeholders of the building value chain.

[13] **Resource productivity** is defined as the process of using resources as effectively as possible when producing goods and services in order to reduce or avoid waste.

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5.3.2 Value Network based on integrated BAMB output

In the following sections an 'idealised' value network is analysed, imagining the integrated BAMB output is completely in place and enabling new relations between existing and new actors. The same main phases were used to group the output of the analysis, as it was done within the characterisation of the existing value network (see Chapter 4). New links are marked in red in the following diagrams. Major opportunities and barriers identified during the value network analysis (see Table 14, Table 15, Table 16 and Table 17) are taken as input for Chapter 6.

5.3.3 Phase 1: Design

The diagram below depicts the new links and interactions between different actors in the design phase that need to be created if the integrated BAMB output is completely in place. These links are described based solely on a theoretical definition and ideas, or if present, they are still in pilot phases and far from mainstream adoption. This will also require the definition of a new role, i.e. the '**Digital Architect**' that focuses on all technology aspects of a building or supporting the realization of the building. The Digital Architect brings together all relevant information for the design and build phases from all stakeholders and spans responsibility domains like (Peters et al., 2016):

- **IT infrastructure:** *physical IT infrastructure where sensors, systems, building installations, connectivity/ communication systems, etc. are easily "plugged-in"/ integrated.*
- **Data access/ security/ privacy:** *information and data exchange of sensors, building installations, etc. are crucial for monitoring performance, right maintenance profiles and product status at end of service.*
- **(Integration) protocols and standards:** *data exchange of IoT sensor or building installations need to follow standard protocols to ensure data can be used for more than 1 purpose, and next to monitoring or managing the device or system.*
- **Enabling technology:** *use and integration of correct use of enabling technologies like BIM/IFC, Asset Management systems, Facility Management systems, Material Passport, 3D-tooling, etc. to support the realisation and operations of the building*

Based on the structured database prepared by the Digital Architect, the actual building design or repurposing design can be elaborated. In many cases the role of Digital architect can probably be fulfilled by the Architect/Design team.

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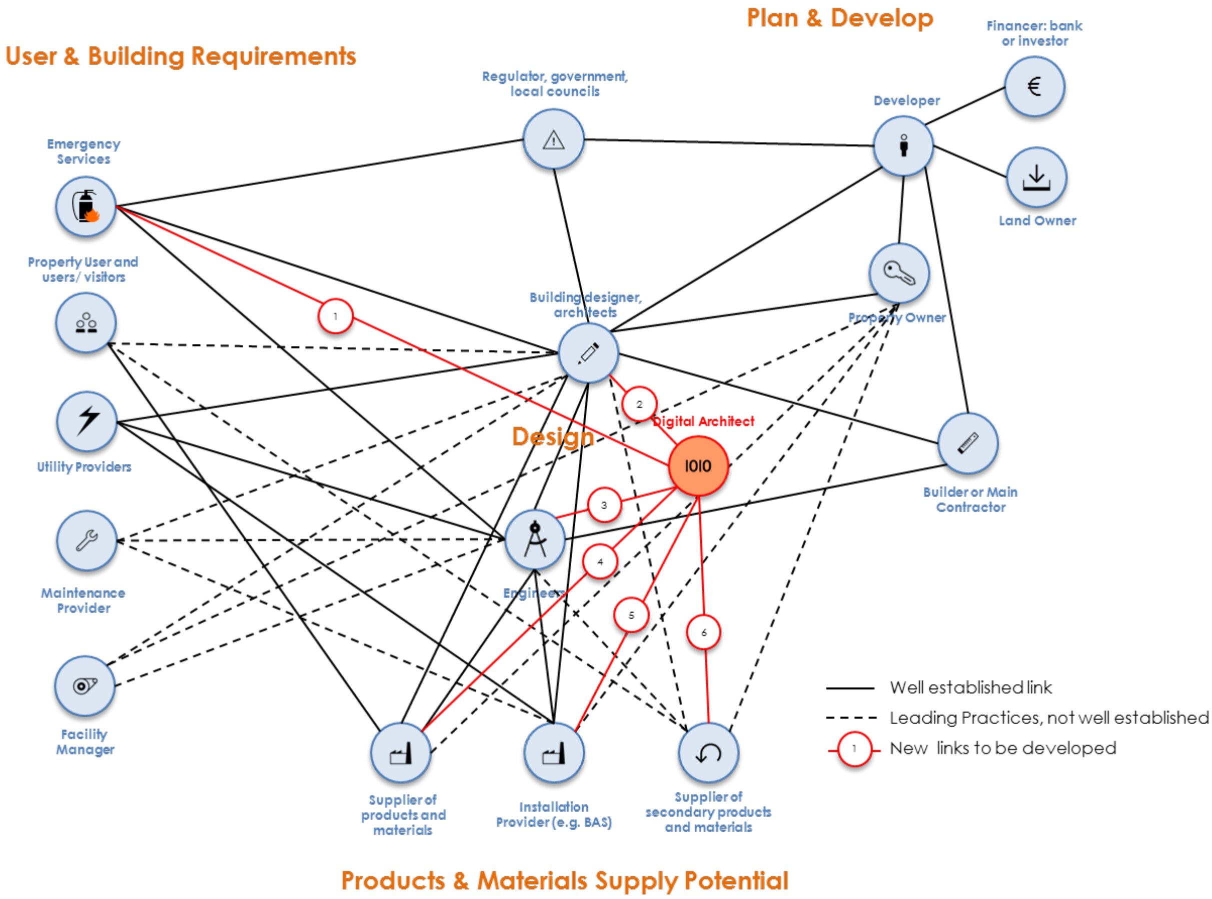

Figure 27: New value links to be developed during the design phase, based on the integrated BAMB output

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Table 14: New value links to be developed during the design phase, based on the integrated BAMB output, from Peters et al. (2016)

ID	Type of Exchange	Short Description	Development & Trends	(Current) Barriers	Opportunities
1	Information flow	Requirements from Emergency Services parties, like Police Dept., Fire Dept., and Medical Services that will need to have access to buildings in an emergency situation. This includes the way communication is conducted (e.g. sensors), access to building and availability of required products on site (fire extinguishers, axes, emergency stretchers/ carry chairs, emergency lighting, etc.).	Due to rise of IoT and enabling technologies, architects and engineers have a need to become more digitally savvy.	No integral view on enabling (and existing) technology to service multiple partners using a shared infrastructure. For public/ office buildings tighter cooperation is present as more people are involved in emergency situations than for homes/ residential buildings where more generic rules are used.	(IoT enabled) sensors provide opportunities to analyse (real-time) data to e.g. understand status of material, emergency equipment/ products on site, etc. and trigger maintenance/ replace activities.
2	Information flow	The role of the digital architect next to the building architect will be crucial and complementary in the future towards a more "intelligent" building that is connected and that generate valuable insights for the user, owner and operator. The value of the building will go beyond the physical construction towards more optimized user services and reuse insights. This necessitates a joint "physical digital" blueprint of the buildings of the future. BIM systems are one of the key information management tools in that context.	The practice of involving a digital architect early on in the design process is still far from practiced. However some innovative developers are starting to appreciate the value of digital capabilities to enable higher quality working environments that are also repurposable.	Currently the lifecycle of the building starting by design is often focused on the bare standard minimum requirements of delivering square meters of physical space, with the minimum budget. This short term view and conventional business assessment makes it harder to justify involving a digital architect in the design process.	There is a major opportunity for innovative value creation for developers and architect offices by "embedding" the digital capabilities from the start of the design process, to enable valuable services to the user (e.g. indoor air quality, optimal lighting, etc.) but also enable a credible and comprehensive digital representation of the building, valuable for optimal usage throughout the usage cycle. This would reflect in a higher value per square meter, compared to traditional buildings.
3	Information flow	Same as 2, to the extent that the engineers are closely working with the architects to refine the design. Furthermore mechanical and electrical engineering design should also align with the digital architect to reflect the relevant data generation and integration from mechanical and electrical installations.			
4	Information/ Product/ Material flow	The digital architect has to capture the relevant data around the specs analysed (incl. data security, data exchange protocols, IT infrastructure) of materials and products that are forming the building. This data ought to be captured and integrated in the appropriate data model that makes it ready to be. BIM systems are one of the key information management tools in that context.	The practice of integrating the relevant data around materials and products provided by suppliers is still not regular practice, making harder to quickly access and trace the nature of various items installed in the buildings years later.	Currently the lifecycle of the building starting by design is often focused on the bare standard minimum requirements of delivering square meters of physical space, with the minimum budget. This short term view and conventional business assessment makes it harder to justify involving a digital architect in the design process.	Opportunity to enrich further the "building passport" with the relevant data around the composition and anatomy of the building, which is important for a more effective materials mining of the building and a more effective repurposing at various layers of the building.
5	Information/ Product/ Material flow	Information and data exchange of building installations is crucial for monitoring performance, right maintenance profiles and product status at end of service. This data exchange needs to follow standard protocols to ensure data can be used for more than 1 purpose.	Architects, engineers, and developers understand that technology and data is crucial to better understand a buildings performance to match is to use requirements and providing input for repurpose options.	Maintenance providers are using more and more IoT/ Condition Based maintenance approaches, therefore requesting more data/ information from systems on actual performance to plan maintenance. Important data points are most times missing at start of maintenance cycles and added later.	When data points are shared as data sets according to set standards (rather than custom to that product), many datasets can be shared to get greater insights into (changed) usage patterns of the products and enhance possibilities of reuse.
6	Information/ Product/ Material flow	Same as 4 with the addition of capturing any additional testing certifications data for secondary materials.			

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5.3.4 Phase 2: Build

The diagram below depicts the new links and interactions between different actors in the build phase that need to be created if the integrated BAMB output is completely in place. These links are described based solely on theoretical definition and ideas, or if present, they are still in pilot phases and far from mainstream adoption. The new role introduced in the design phase, i.e. the '**Digital Architect**', should also be included in the build phase in order to assure the capturing of data on the as-built situation. Also, the **facility manager** (if present) should get a more prominent role in assuring continuity between the design, build, use and repurposing phases, in order to keep an overarching view on the whole of the value chain.

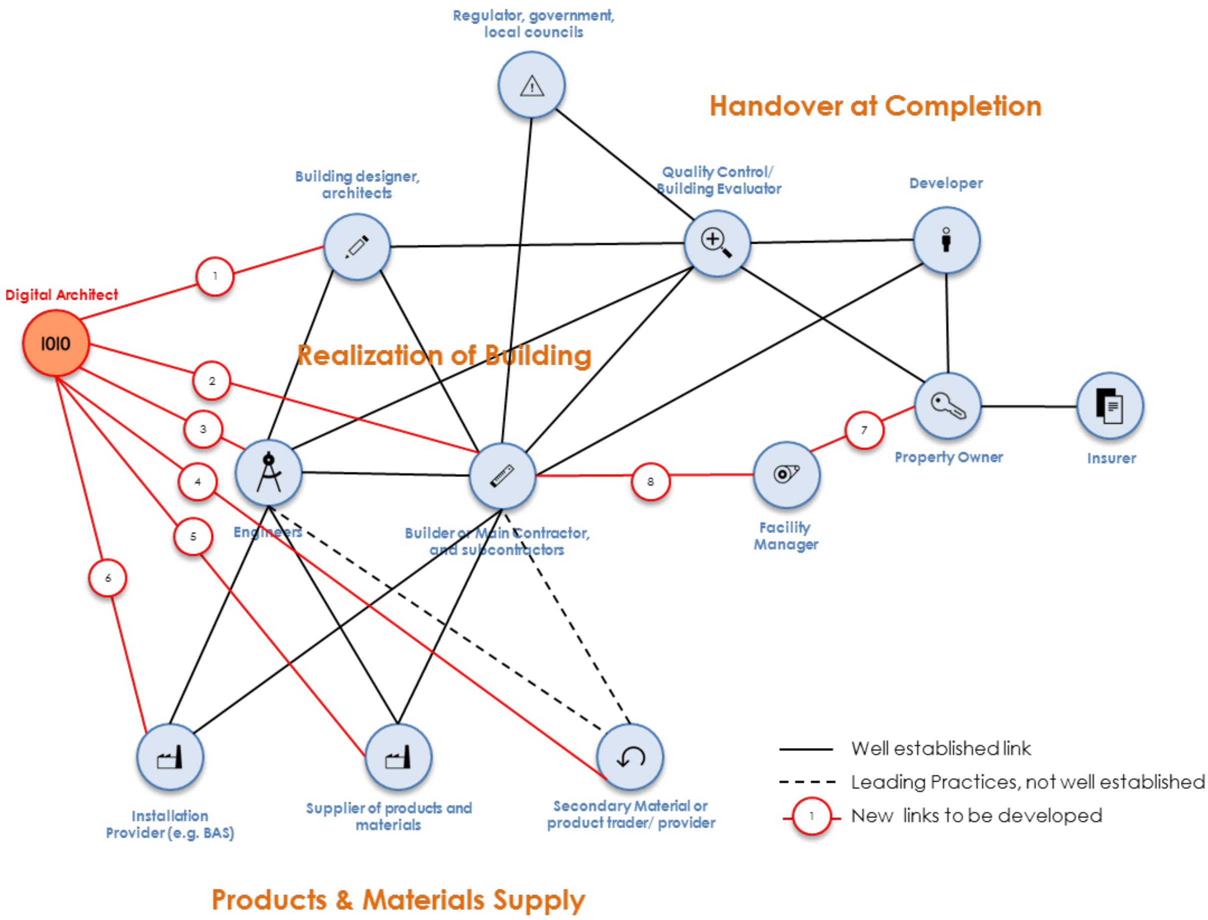

Figure 28: New value links to be developed during the build phase, based on the integrated BAMB output

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Table 15: New value links to be developed during the build phase, based on the integrated BAMB output, from Peters et al. (2016)

ID	Type of Exchange	Short Description	Development & Trends	(Current) Barriers	Opportunities
1-6	Information flow	All building and material information must be updated according to the as-built plan.			Opportunity to enrich and actualize the “building passport” with the relevant data around the real composition and anatomy of the building, which is important for a more effective materials mining of the building and a more effective repurposing at various layers of the building.
7-8	Information flow	The facility manager should keep an overarching view on the whole of the value chain			Optimal design and construction for the envisioned use and maintenance.

5.3.5 Phase 3: Use & Operate

The diagram below depicts the new links and interactions between different actors in the use & operate phase that need to be created if the integrated BAMB output is completely in place. An important challenge during the use phase is to keep track of (minor) changes in the building, such as repair works, refurbishment, minor renovations etc. The collection of this information and transfer to the new owner and users is an important task for the **facility manager**.

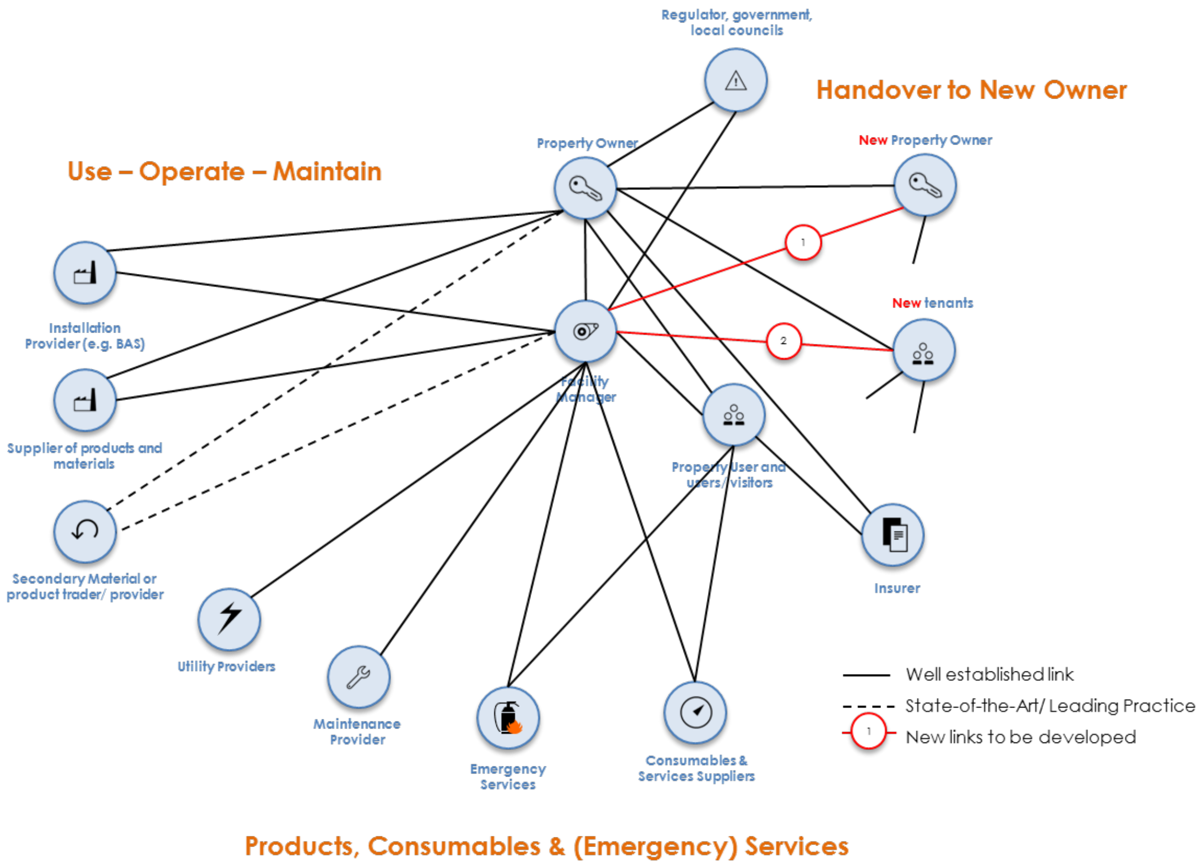

Figure 29: New value links to be developed during the use & operate phase, based on the integrated BAMB output

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Table 16: New value links to be developed during the use & operate phase, based on the integrated BAMB output, from Peters et al. (2016)

ID	Type of Exchange	Short Description	Development & Trends	(Current) Barriers	Opportunities
1-2	Information flow	Capture and transfer of information on changes in the building to new owners and users.		Information on current (installed) assets is needed but not always widely available on the right data level. Many different suppliers and product configuration means all individual installed product type needs long lead-times to digitize and link them to the building digital profile.	Availability of the product properties and status in a digital profile of the building opens up opportunities for product suppliers to assess if they want to buy-back their own products for reuse in their solutions/ product portfolio or maintenance cycles.

5.3.6 Phase 4: Repurposing, Demolition and Deconstruction

In the envisioned future of BAMB, the focus of this phase will be on repurposing buildings and materials instead of demolition.

The diagram below depicts the new links and interactions between different roles/actors in the Repurpose & Demolition/Deconstruction phase that need to be created if the integrated BAMB output is completely in place. These links are described based solely on theoretical definitions and ideas, or if present, they are still in pilot phases and far from mainstream adoption. This will also require the definition of a new role, i.e. the '**Building Digitizer**', that focuses on the use and integration of enabling technologies like BIM, Asset Management systems, Materials Passports, 3D-tooling, etc. for existing buildings (that did not have a BIM developed during their design and build phases. The Building BIM 3D Digitizer will produce a 'reversed BIM', by scanning tagging all building products/ elements with their characteristics (physical, chemical, but also use-related). Based on this information the options for building repurposing and component reuse can be evaluated and an informed repurposing plan can be prepared. Also, this 'reversed BIM' will serve as an important input for the Digital Architect and architect/design team to elaborate the repurposed design.

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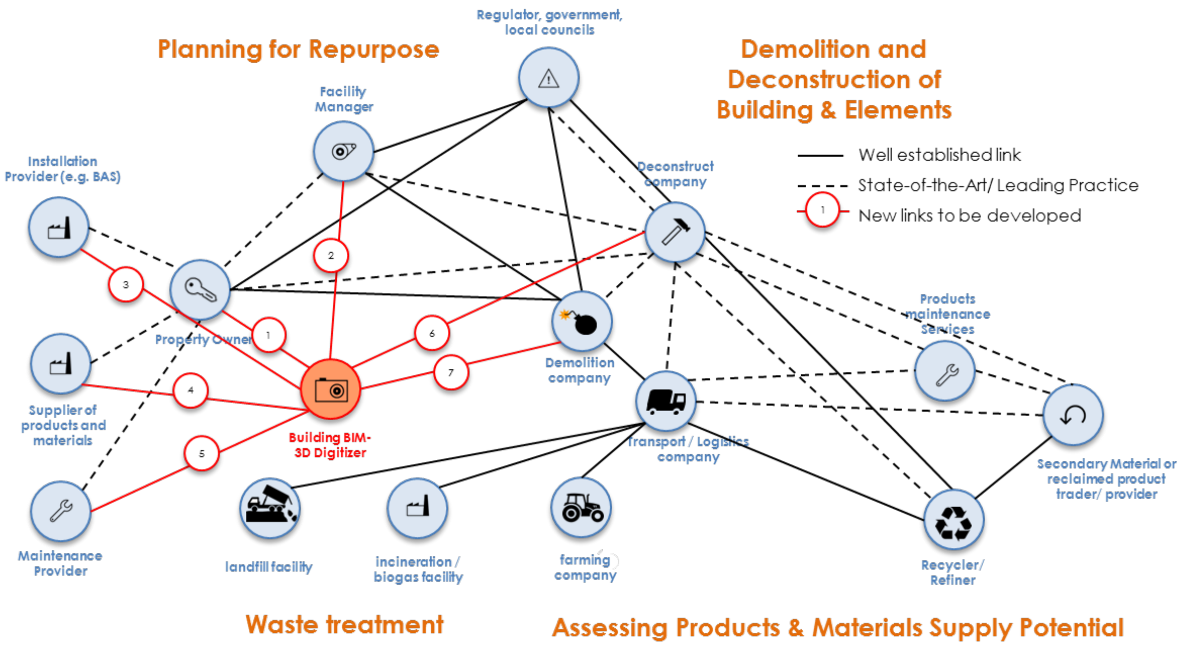

Figure 30: New value links to be developed during the repurpose & demolition phase, based on the integrated BAMB output

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Table 17: New value links to be developed during the repurpose & demolition phase, based on the integrated BAMB output, from Peters et al. (2016)

ID	Type of Exchange	Short Description	Development & Trends	(Current) Barriers	Opportunities
1	Information/ Financial flow	Many digital tools (e.g. 3D, CAD, BIM) are used today to design new (parts of) buildings. However, in the years to come the buildings that exist today without such a digital profile, require digitization of the building, its (embedded) products and materials (incl. chemical properties).	There are very few parties that provide these "reverse BIM" capability. This is not a mature practice yet due to the complexity of scanning and tagging all building products/ elements with correct properties and usage information. Most effort is done on a limited set of product categories already known for their reuse potential.	The combination of different skills and capabilities (i.e. 3D/ BIM tool designers, chemical expertise), limited demand in the markets for these types of services, and the long cycles to properly digitize an (existing) building hinders broad exploitation in the construction industry.	Some companies, using Urban Mining as their main slogan, develop this type of service using partner expertise to build building profiles. These companies will provide the necessary information that is lacking today on existing infrastructures to property owners to make the best reuse decision.
2	Information flow	Working together with facility managers to complete the building scanning/ reverse BIM, and provide information to the facility manager for overall deconstruct / demolition planning for coordination with deconstruct and demolition company.	Use the hands-on experience and knowledge of facility managers to complete a digital profile of the specific building profile is not common practice. This is also the case of facility managers using digital building profiles to coordinate any material extraction activities.	Reverse BIM is not a common capability today. See also description 1.	Embedding the specific building and product knowledge of the facility managers to complete a digital building profile will increase accuracy of an executable product and material extraction planning.
3	Information flow	Incorporating information of building installation systems to complete the building scanning, tagging of its (embedded) products and properties.	Properties of embedded products and installations to complete a digital profile of an existing building is increasing in importance as Urban Mining companies are entering the market and need this type of information.	Information on current (installed) assets is needed but not always widely available on the right data level. Many different suppliers and product configuration means all individual installed product type needs long lead-times to digitize and link them to the building digital profile.	Availability of the product properties and status in a digital profile of the building opens up opportunities for product suppliers to assess if they want to buy-back their own products for reuse in their solutions/ product portfolio or maintenance cycles.
4	Information flow	Incorporating information of products to complete the building scanning, tagging of its (embedded) products and properties.	See description 3.	See description 3.	See description 3.
5	Information flow	Incorporating information of products to complete tagging and status of its (embedded) products, as per maintenance data.	Maintenance and usage profiles of embedded products and installations to complete a digital profile of an existing building is increasing in importance as Urban Mining companies are entering the market and need this type of information.	Information on maintenance profile and product status of current (installed) assets are needed but not always widely available on the right data level or shared between these the different roles in the value network, incl. these (new) roles.	Availability of the maintenance profile and status in a digital profile of the building opens up opportunities for product suppliers to assess if they want to buy-back their own products for reuse in their solutions/ product portfolio or maintenance cycles.
6	Information flow	Deconstruct company using building profile and property information to plan for extraction (resources/ effort, equipment, time needed).	To properly plan efforts (resources, time, equipment) for deconstruct activities of existing buildings with no BIM/ digitized profile, deconstruct/ urban mining companies are now building limited capabilities in this space, focusing only on a limited set of building product categories.	Reverse BIM is not a common capability today. See also description 1.	See description 1.
7	Information flow	Demolition company using building profile and property information to plan for extraction of materials (resources/ effort, equipment, time needed).	See description 6.	See description 6.	See description 6.

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6 OPPORTUNITIES AND BARRIERS FOR MATERIALS PASSPORTS AND REVERSIBLE DESIGN

6.1 Analysis framework

For the analysis and discussion of drivers and barriers, the "institutional rectangle" concept will be used as a structural framework.

From a system perspective, the actual regime can be grouped into four key institutions of the modern society – i.e. market, state, civil society and science – and their mutual alignment in various arrangements, such as the market system, the governance system and the innovation system. Grin (2010, p.237-248) calls this the "institutional rectangle". All relationships between actors within the built environment described in the previous value networks (see Chapters 4 and 5) can be viewed from this institutional perspective. However, it is important to mention that some actors play multiple roles within the institutional rectangle, leading to a less rigid differentiation between market, state, civil society and science functionalities. For example, non-profit organisations and commercial firms work together to repurpose old building products and components into new applications.

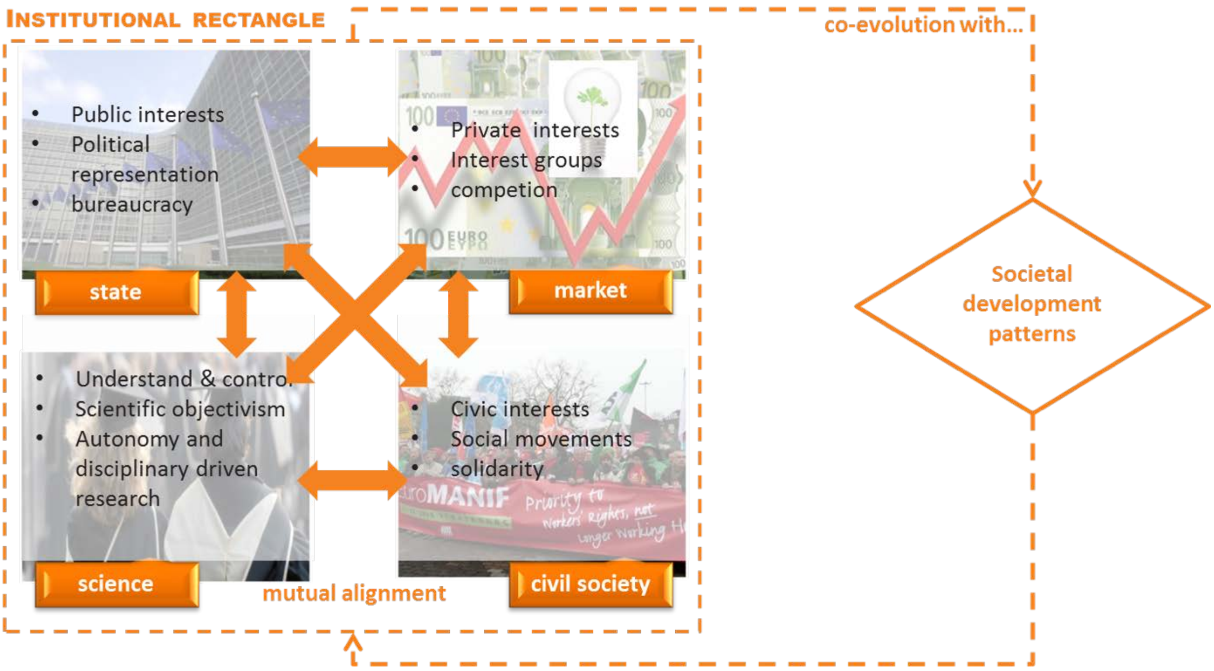

Figure 31: The institutional rectangle, adapted from Grin et al. (2010)

Within the built environment, the 4 institutional entities should be understood as:

- **State:** governance, authorities and local councils
- **Science:** knowledge institutions and research
- **Market:** industry, financing, insurer and consultants
- **Civil society:** building users and owners

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6.2 Opportunities for Materials Passports and Reversible Building Design

Table 18: alignment of identified opportunities over state, knowledge, market and civil society entities

Main identified opportunities	State	Knowledge	Market	Civil society
1. Anticipating demographic changes and changing user requirements	✓	✓	✓	✓
2. Eradicating C&D waste and down-cycling	✓	✓	✓	✓
3. Lowering environmental and health pressures of the built environment	✓	✓		✓
4. Development of applied socio-technical solutions	✓	✓	✓	
5. Development of guidelines and assessment instruments	✓	✓	✓	✓
6. Exchanging valuable (resource) information within the value network	✓	✓	✓	✓
7. Introduction of new commercial services and job creation			✓	✓
8. Introduction of innovative business models		✓	✓	✓
9. Increasing adaptability and versatile use of space	✓		✓	✓
10. Increasing life expectancy and real value of real estate	✓		✓	✓
11. Decreased renovation costs	✓		✓	✓
12. Decreased periodic maintenance and replacement costs.	✓		✓	✓

1. Anticipating demographic changes and changing building user requirements

Buildings designed and built to be easily transformed, will support to a certain extent changes in society – such as cultural diversity, domestic care of an ageing population, working at home, and a shift towards smaller families and one-parent families – but also changes related to new building users and new user requirements. At the end, the goal is to create a diversified building stock with the possibility to extend the functional lifespan, and resilient to unexpected change.

2. Eradicating C&D waste and down-cycling

Dedicated design for repurposing, reuse and remanufacturing will significantly lower the amount of C&D waste. Currently C&D waste is partly recycled, but often the quality of the recycled material is rather low due to a high waste heterogeneity, leading to down-cycling (e.g. granulates are used for road coverings and in building foundations). Reversible building design and Materials Passports would not only lower the amount of material that enters the waste stage at end-of-life, but also offer opportunities for 'design-for-recycling', so that building materials that cannot be reused can easily be deconstructed and sent to high-quality recycling.

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3. **Lowering environmental and health pressures of the built environment**

As discussed in section 3.1, the current built environment carries along a vast environmental footprint. The possibility to extend the useful functional lifespan of buildings and building components by reusing them for the same or other purposes, may lead to positive environmental impacts, giving nature more time to regenerate biological resources and opportunities for urban metabolism.

However, one has to be made aware of some potential pitfalls. The effective use of material resources may be at the expense of the entire building performance. A transformable building with poor energy performance may lead to bigger environmental impacts than a nearly or net energy zero building not designed for change. Furthermore, building (parts) designed for multiple uses, may lead to material intensive solutions, due to over-dimensioning.

Finally, more and more building owners are asking for healthy interiors. Health data related to building products should be key information over all building phases. Materials Passports support healthy interiors by providing user-friendly health information to building owners (and users), architects, engineering firms and facility managers to make a conscious selection of building materials and systems and identify their potential impact on building users.

4. **Development of applied socio-technical solutions for and with public and private stakeholders**

As the demand for reversible and circular solutions increases, new targeted socio-technological, solutions will need to be co-created with front-runners, leading to inter-disciplinary R&D opportunities; such as the creation of living labs, in which innovative reversible building concepts and circular building solutions are tested and evaluated in real life use cases, subjected to financial, juridical, legal and commercial influences.

5. **Development of guidelines and assessment instruments in order to facilitate decision-making along the building value network**

Due to the current lack of decision-supporting instruments for designers, facility managers, property developers and policy makers, R&D activities are needed to develop guidelines for reversible and circular building solutions within the design, build, operate and repurposing phases. In order to exchange valuable information between these decision-makers within the value network, it is strongly advised to integrate and analyse different data sources, among others BIM, Materials Passport, asset transformation plans and health (tracking) data.

6. **Exchanging valuable information within the value network**

In general the integrated BAMB output has an educational benefit, i.e. it gives feedback to current and future actors within the value network on enhanced systems thinking, by providing valuable information on reversible and circular building solutions.

The use of an information platform (including BIM objects and Materials Passports) should allow the sub-contractors to collaborate and communicate with each other and other actors on the project more efficiently. Better access to information will prevent costly mistakes during (de)construction and reduce (de)construction time. It will also allow actors in the

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repurposing/demolition phase to get a better view on the building elements and materials that are fit for reuse or remanufacturing, thus facilitating circularity.

Availability of the product properties, maintenance profile and status in a digital profile of the building opens up opportunities for product suppliers to assess if they want to buy-back their own products for reuse in their solutions/ product portfolio or maintenance cycles.

7. Introduction of new commercial services and job creation

Reversible building design offers opportunities for new and existing players, bringing new job opportunities in the construction industry. There will be an increase in demand for designers who can design for circularity and to develop innovative and functional design solutions that facilitate circularity. New consulting roles and services will emerge related to the reuse and recycling of building elements, the gathering and analysis of data on building status and reuse potential of materials, and the setup of new business models to accommodate these new circular practices. There could be a divergence in the demolition industry to create roles that are linked to a decommissioning and deconstruction service, reverse logistics providers and suppliers of secondary materials. This could include returning assets to suppliers who offer extended take-back or leasing services, and auctioning/finding homes for other assets, including opportunities for reuse, remanufacturing and recycling into new secondary materials for the manufacture of new products and materials.

8. Introduction of innovative business models for supply of performance-based or service solutions

New business models will allow service providers to embark into a different engagement model with the customers and thus enhance their value proposition. Supply of services (i.e. Performance Based Contracts or Pay-by-use models) while the ownership remains with the supplier will foster the setup of reverse logistics and take-back systems as suppliers (or third parties) will collect products at end of service or performance. This will also accelerate the reuse of products and components (e.g. components reuse of spare parts, embedding in new products) as suppliers can increase their margins by being able to use and reuse certain second-hand components and materials for a longer time without having to buy new raw resources.

9. Increasing adaptability and versatile use of space

Reversible building design has the advantage that a building can be adapted quickly and at minimal costs in response to changing needs (e.g. household size, number of employees, limited mobility, change of activities, etc.).

10. Increasing life expectancy and real value of real estate

The client of a reversible building owns a built asset that is adaptable in use. This means that the building can be used for a longer period, even when user requirements change. Reversible building design maximises the value of the building and its elements, also when considering resale value.

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Moreover, (IoT enabled) sensors would provide opportunities to analyse (real-time) data to e.g. understand status of material, emergency equipment/ products on site, etc. and trigger maintenance/ replace activities. By "embedding" the digital capabilities from the start of the design process, to enable valuable services to the user (e.g. indoor air quality, optimal lighting, etc.) but also enable a credible and comprehensive digital representation of the building, valuable for optimal usage throughout the usage cycle. This would reflect in a higher value per square meter, compared to traditional buildings.

11. Decreased renovation costs and added value of reusable building components

When renovation, refurbishment or rebuilding works are necessary, these can be accomplished with minimal costs. Upon repurposing or demolition, part of the building will stay in place or elements can be sold and reused, which implies there will be less waste going to waste treatment and landfill and so the costs associated with that (i.e. landfill tax) will be minimised. This could potentially reduce costs associated with demolition and deconstruction when the built asset has reached the end of its life. Furthermore, reusable building components have a higher (financial) value than their constituent materials, as long as they are fit for the same or another useful application.

12. Decreased periodic maintenance and replacement costs.

There is a major opportunity for optimal design and construction for the envisioned use and maintenance. Especially for building applications with high maintenance and (component) replacement rate – such as retail, schools, elderly care residences and offices – reversible building design has the potential to lower periodic in-use costs, compared with conventional static solutions.

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6.3 Barriers for Materials Passports and Reversible Design

Table 19: alignment of identified barriers over state, knowledge, market and civil society entities

Main identified opportunities	State	Knowledge	Market	Civil society
1. Fragmented policy framework: from the EU to municipalities	✓		✓	✓
2. Conflicting Energy and. Environment policy measures	✓		✓	✓
3. Lack of robust and standardised data/ information over the entire value chain of the product/building	✓	✓	✓	✓
4. Linear construction industry models			✓	✓
5. Intellectual property of material and product related data		✓	✓	✓
6. Higher complexity of disassembly compared to demolition		✓	✓	
7. General perception that reversible design solutions entail high financial costs			✓	✓
8. Lack of certification and quality assurance for reclaimed products and recycled materials	✓		✓	✓
9. Lack of a business model framework related to circular and reversible building		✓	✓	✓
10. Reversible building is largely unknown to the general public		✓	✓	✓

1. Fragmented policy framework: from the EU to municipalities

The fragmentation of regulating, stimulating and financing measures over the different policy levels and the current complexity of the legislative frameworks is responsible for a lack of integration of the different policies and could in some cases even lead to contradictions. For example, current urban regulations and building permits are based on a linear and static vision of buildings which may impede changes and transformations supported by reversible design and materials recovery. Similarly, some current financial incentives require complete ownership of buildings, which may be contradictory to new business plans and ownership models within a circular built environment.

2. Conflicting Energy and Environment policy measures

It could be argued that a key barrier comes through energy efficiency policies across Europe. The prioritisation of energy efficiency and high energy performance of buildings may unintentionally result in building design and materials which do not lend themselves to deconstruction and reuse. It is not the high performance, which could hamper the adoption of dynamic and circular

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building design but the choice of construction techniques and materials to achieve the required performance.

3. Lack of robust and standardised data over the entire value chain of the product/building

As data are lacking on product properties and specifications, product (health) status and where these products are located in the building (cf. digital profile, BIM), it is difficult to quickly identity the reuse potential of products and materials (availability, deconstruction method, health, quality criteria) and to select the reuse loop with the most value. Resistance to adoption of both BIM and the principles of reversible building design protocols in a traditionally conservative industry could make adoption difficult and slow for contractors. Any additional requirement for data inputs could also prove challenging in a time constrained system.

There is still a lot of uncertainty about what actually constitutes a Materials Passport, which information and tests are required, its benefits and its costs. A rich diversity of initiatives related to product passports and databases is already found on the market. However, they serve different users, have differing definitions and are not aligned. Databases like Health Product Declarations are transparent, but others are not, so it is unclear how many include e.g. product economic data and material health assessment. As well, passports using the same platform might contain different content, due to the lack of data availability or the lack of standardization within a platform and in the construction industry.

The benefits of going through the costs and processes needed to develop Materials Passports for products and materials by specific suppliers will need to be sufficiently evidenced and worthwhile to overcome this barrier.

4. Intellectual property of material and product related data

Trademark, copyright, open source, competitive considerations and contributed IP… each have substantial impacts on use and availability of data. Balancing IP on material and product related data with open source data remains a significant challenge, but is basic for success of Material Passports. Manufacturers and suppliers of (building) products, building systems and services are reluctant to provide information that could compromise their commercial status. However, technical (including safety) and financial feasibility studies, environmental hotspot analyses and health risk assessment studies often require detailed information on materials and products. Third party certification and labelling already offer user-friendly information to building professionals (B2B) and to end users (B2C) to a certain extent. However, the information provided by those instruments is still scattered and accordingly time-consuming to collect. Centralising all valuable information leads to legal issues on ownership and management of data, and protection of trade secrets.

5. Linear construction industry models

Traditionally, the construction industry model is linear as many parties work in silos, missing the opportunity of a system optimization and higher value creation. Currently the lifecycle of the building starting by design is often focused on the bare standard minimum requirements of

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delivering square meters of physical space, with the minimum budget. Also, the suppliers in this model are squeezed to minimize price, which in turn compromises quality and user and building owner value on the long term.

6. The complexity of disassembly is higher compared to demolition

A demolition company will require a whole new set of competences and engage in many new activities and partnerships in order to be able to take the role of a deconstruction company (e.g. deconstruction, material quality and sorting, repurposing opportunities, specialised transport, extensive partner network, increased storage). In addition to that, they will also need access to information on the building and on potential markets for deconstructed elements and materials. The costs and time associated with the need to adopt new tools/methods of working will act as a barrier to adoption.

7. There is a general perception that reversible design solutions entail high financial costs

While reversible design can in fact lower building and maintenance costs in the long run, it often entails higher investment costs. Additionally, it is hard to estimate the actual financial savings, as they occur in the future and are highly context-dependent. To cover this form of uncertainty, building contractors will increase their prices compared to conventional construction techniques. Speculative clients may not see any benefits to increased circularity since they are typically building to sell on and unless increased sales values are anticipated there would be little incentive. Shorter term value seems to be a priority for users, over raw materials value at end-of-building-use.

8. Lack of certification and quality assurance for reclaimed products and recycled materials

Only a limited number of suppliers provide reclaimed products and/or recycled materials with quality assurance at competitive prices. Liability issues, lack of certification instruments, warranties, and a guaranteed supply are major barriers perceived by design teams to use reclaimed products and recycled materials.

It is, however, important to emphasize that the obligation of a quality assurance and certification would probably hamper the existing market of second hand construction products. According to suppliers of second hand floor tiles and interior doors, it would make the price of these second hand products extremely expensive if they have to go through a certification or quality assurance process. It is thus important to find an equilibrium between the liability (and the need for it) and the (economic) feasibility.

9. Lack of a business model framework related to circular and reversible building

Resistance to adoption of a circular business model (e.g. supporting leasing and take-back guarantees) could potentially prevent suppliers from adopting reversible building design ideals. The market for such alternatives is uncertain, alongside the costs and benefits of developing new

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business models. It seems unlikely that many suppliers will go down this route unless there is much more evidence/certainty.

10. Reversible building is largely unknown to the general public – and there is little awareness about its advantages

There is a lack of decision-making protocols for building owners & users. User requirements and how they may change throughout its lifetime (i.e. from residential to commercial) must be better understood if reversible building design protocols are to be implemented.

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7 Synthesis

7.1 Conclusions

This synthesis report (D1) has to be considered as a living document. It provides a *snapshot* of the current system, as currently perceived from within the BAMB consortium. As forthcoming BAMB activities (especially linked to the pilots and the business modelling) and interactions with stakeholders outside the BAMB consortium will bring along new insights, as well as new opportunities and barriers, modelling of the current system will be refined on a regular basis during the BAMB project. The outcome of this learning process will be detailed in deliverable D3.

In this concluding part we will try to provide concise answers to the two main research questions presented in section 1.3.

Why are Design/Build for Change and Circular Economy not yet (fully) integrated in the current building practice and related policy?

To answer this question we had to **characterise the current system, from a process, a value network and a systemic perspective**. In Chapter 4 we concluded that the current building practice is made of a sequence of four main phases (i.e. design, build, use and repurpose) and related sub stages, involving a lot of actors, interacting with each other through material, information and/or monetary flows. We observed that **only a few of these actors are actually involved in all phases**, such as the property owner. **However, circularity in the building sector requires strong interactions between all main phases**, in order to support communication and information transfer across the whole value chain/network. When we co-created an idealised value network (see Chapter 5), based on the integrated BAMB output, we discerned **a lot of missing links between the current actors** – even when leading practices were taken into account. Furthermore some **new actor types** had to be introduced to allow a proper exchange of information, such as the 'digital architect' in the design and build phases and a 'building digitizer' in the repurpose and demolition/deconstruction phases. It is also suggested that **some existing actors**, such as the facility manager (if present), **should get a more prominent role in assuring a strong or seamless integration between the main phases**, e.g. to keep track of changes in the building (repair works, refurbishment and transformation actions) and to collect and provide this information to new owners and users, as well as to demolition/deconstruction companies.

Making such changes in the value network is all but easy in **a dominantly conservative building sector, with practises based on decades and centuries of traditions**. The majority of available business models and policy measures are still based on **linear construction industry models**, **providing end-of-pipe building (product) solutions for a slowly evolving building stock**. Current renewal and refurbishment of buildings usually end up into linear solutions, because (innovative) **circular and reversible building solutions are perceived as too expensive** compared to the conventional solutions, being optimised for decades. However, this is viewed from a **short-term perspective** (i.e. taking into account only the initial investment cost

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and not potential life cycle gains) and based on **traditional business and financing models**, in which ownership is being pushed forward instead of 'user-ship' (e.g. through leasing and take-back guarantee).

Nevertheless, based on the completed state-of-the-art analyses, **5 main landscape trends – announcing a systemic change** – have been discerned (see Chapter 3):

1. Increasing awareness of sustainability and circular economy
2. Down-cycling of C&D waste and landfilling practices are being recognized as end-of-pipe solutions
3. Building vacancy and premature demolition
4. A third digitalisation wave towards cognitive buildings
5. Increasing number of fragmented building regulation and building codes, making manufacturing, architectural and engineering industries reluctant to take on responsibilities

Beside landscape trends also niche activities related to the development of Materials Passports and Reversible Building Design tools have been identified (see sections 5.1.2 and 5.2.2). Regarding product passports 13 initiatives have been discerned; private as well as governmental ones, and directly related to the building industry or not. Front-runner tools related to Reversible Building Design are listed into 4 groups: (1) geographical tools mapping the market availability of reclaimed building products, (2) scoring tools quantifying the potential for deconstruction and disassembly; (3) scoring tools quantifying the potential for adaptability; and (4) tools fostering an integrated life cycle approach.

What are the main barriers and opportunities within the current system for implementing Materials Passports and Reversible Building Design Protocols?

To answer this question we again used a systemic concept, i.e. "the institutional rectangle", in which the actual regime is clustered into four key institutions of the modern society – i.e. market, state, civil society and science – and their mutual alignment in various arrangements, such as the market system, the governance system and the innovation system. Barriers and opportunities are not looked at from a single actor perspective, but are instead selected on the basis of their potential strengthening effect for the different modern institutions, in which multiple actors should benefit from the (to be) created possibilities or should undergo the (to be) caused drawbacks (see Table 18 and Table 19 in Chapter 6).

Twelve main opportunities have been identified when Materials Passports and Reversible Building Design Protocols – as part of the integrated BAMB output – should be fully implemented. These can be further grouped into

a. **Policy opportunities:** (1) anticipating demographic changes and changing user requirements, (2) eradicating C&D waste, (3) lowering environmental and health pressures of the built environment.
b. **R&D opportunities:** (4) development of applied socio-technical solutions, (5) development of guidelines and assessment instruments, (6) exchanging valuable (resource) information within the value network

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c. **Business opportunities:** (6) exchanging valuable (resource) information within the value network; (7) introduction of new commercial services on the market; (8) Introduction of innovative business models; (10) Increasing life expectancy and real value of real estate; (11) high(er) financial value of reusable building components
d. **Creation of building qualities for users and owners**: (9) increasing adaptability and versatile use of space; (10) Increasing life expectancy and real value of real estate; (11) decreased renovation costs and added value of reusable building components;(12) Decreased periodic maintenance and replacement costs.

Ten key barriers have been identified when Materials Passports and Reversible Building Design Protocols – as part of the integrated BAMB output – should be fully implemented. These can be further grouped into

a. **Policy barriers:** (1) fragmented policy framework: from the EU to municipalities, (2) conflicting Energy and. Environment policy measures; (3) lack of standardisation of qualitative data/ information over the entire value chain of the product/building
b. **Commercial barriers**: (3) lack of standardisation of qualitative data/ information over the entire value chain of the product/building; (4) intellectual property of material and product related data, (5) linear construction industry models; (6) higher complexity of disassembly compared to demolition; (8) lack of certification and quality assurance for reclaimed products and recycled materials; (9) lack of a business model framework related to circular and reversible building
c. **Communicative barriers**: (7) general perception that reversible design solutions entail high financial costs; (10) Reversible building is largely unknown to the general public.

7.2 Further and parallel actions

7.2.1 Development of a Blueprint for a future system configuration

Materials Passports and Reversible Building Design protocols are considered within this BAMB project as important instruments/means to enable the transition towards a circular and adaptive (built) environment. This long-term (macro) objective will require several systemic changes, going beyond technical innovation. In order to support this, a BAMB transition framework will be co-created. This framework is made of 3 pillars: (1) a set of leading principles for systemic change; (2) the identification of required system changes and (3) a blueprint (i.e. deliverable D2) of all short- and long-term activities related to these systemic changes. The framework – under construction – concentrates on key leverage points for the implementation of reversible and circular building (product) solutions and acts as a 'compass' to guide all involved actors, especially for (short-term) activities related to the pilot cases. (1) Through co-creative sessions the BAMB practitioners and involved frontrunners within the pilots are triggered to define common values and key principles for systemic change. (2) Based on their experiences and the outcome of the system analysis, several required systemic changes will be identified and characterised (e.g. based on their importance/potential impact and difficulty to realise them). This will lead to a 'blueprint' (3) for systemic change, separating early opportunities and easy barriers to be tackled (i.e. low hanging fruit) from disruptive interventions and slow evolutions. Back- and fore casting techniques are used to structure and group all identified activities/interventions on a time scale.

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7.2.2 Reflexive monitoring

Reflexive monitoring activities within the BAMB project have a dual function: (1) use the lessons learned from the system analysis and the BAMB transition framework to guide BAMB practitioners active within pilot cases towards a common goal, and hereby creating *new* opportunities for systemic change; (2) use the lessons learned within pilot cases to update the system analysis and refine the BAMB transition framework based on real life findings. Within each monitored pilot case a 'dynamic learning agenda' (DLA) will be used to systematically register (structural, content- and process-oriented) issues during the implementation of the project by formulating project specific reflective questions. On a regular basis all involved stakeholders come together to reflect on the decisions made (and still not resolved issues) and refine their objectives accordingly. Finally, also workshops are held between actors within all (monitored) pilot cases, in order to reflect on common issues and solutions. General findings will be used to refine the opportunities and barriers identified in D1 and D2, and identify best practices. The outcome will be shared with all BAMB partners.

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ANNEX A: EXECUTIVE SUMMARIES OF STATE-OF-THE-ART REPORTS

A.1. State-of-the-art Analysis of Materials Passports (+ value chain of building product)

Highlights

Materials Passports in BAMB have the potential to overcome barriers facing other passports, as well as consolidate strengths from other passports, by being a 'one stop shop' in a broadly accessible platform. In particular, the BAMB Steering Group might address how, when, and by whom to do the following;

- **Offer a broadly accessible platform as a 'one-stop-shop'**. The main elements missing from other passports are an input & output platform accessible to stakeholders across the building and product cycle, and a 'one-stop-shop' for information. A central tool for dissemination in BAMB.
- **Describe immediate and mid-term added value** in order to attract users to the passports platform. Residual value in 20 – 30 years is important, but today and the next 5 – 7 years are priorities for many users. For example;
    - **Holistic quality.** Most passports do not describe how a product or component supports building systems to generate holistic value. For example, products that contribute to healthy indoor environments and improve human productivity as a result provide the greatest added value in monetary returns, and an immediate benefit.
    - **Flexible use and reuse value of components** in products and systems is worth up to 50 times more than the materials that go into them.
    - **Back-casting residual value** of components & materials into present day cash flow is a new value proposition, and something that passports are positioned to support.
- **Implement quality assurance.** Due to the proliferation of passport types, quality assurance (QA) is a priority for credibility in the marketplace. Establish a QA mechanism for e.g. formatting and content in BAMB.
    - QA for different versions of the same passport, to reflect product version changes and building-specific context. Versioning is addressed by new BIM software, and by WP2 Platform designers.
    - Authorizations i.e. who fills in which parts of a passport is central to a credible passport and deserves special attention.
    - Validating data across multiple platforms.
- **Balance transparency with IP security.** Experience shows the advantages of balancing transparency with protecting suppliers' IP. Mechanisms like the Knowledge Trustee and

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distributed databases like block chain exist for that. It is suggested to implement those in the BAMB platform.

Those highlights are described further in the next part of this Executive Summary.

Content Major Contributions

A rich diversity of product & building passports and databases is in the markets for BAMB to benefit from.

However, they serve different users, have differing definitions, and are not aligned. Databases like Health Product Declarations are transparent, but others are not, so it is unclear how many include e.g. product economic data. As well, passports using the same platform might contain different content, due to the lack of data availability or the lack of standardization within a platform.

Shorter term value seems to be a priority for users, over raw materials value at end-of-building-use.

Diverse studies on passports identify scarcity as a driver for MPs e.g. secondary raw materials recoverable from a building at the end of its use. These seem based largely on the EC focus on strategic raw materials. By contrast, the marketplace is aimed at shorter-term or other value, which includes;

- Residual value in the short and mid-term

  - For private developments; residual value of interior products that are replaced in 5 – 10 years e.g. wall dividers, furniture, motors. Residual value includes value of components for reuse, and materials for recycling. For example, Delta developments made the priority clear in its presentations, explaining that commercial owners often recover their investment in 15 years. In Luxembourg, building owners on the Kirchberg, one of Europe's most expensive regional developments, are finding that buildings built only 7 years ago are changing tenants and have to be repurposed for their new requirements.

  - For institutional developments; integrated savings from combining residual value at end-of-use, with operational savings, and 'back-casting' those into present cash flow savings. The city of Venlo did this for its new City Hall, and started saving cash flow before the building was completed. Residual end-of-use value is important for institutional users, but more so if it translates into front-end savings. Back-casting residual value is a new financial innovation to be considered by BAMB.
  - **Healthy interiors that improve productivity.** Ronneby schools, Venlo City Hall, Park 2020, Alliander, and other buildings show that owners are increasingly looking for healthy buildings, also as a competitive advantage to attract personnel. However, 'healthy' does not just mean 'less toxic'. The great majority of databases today focus on keeping out toxic ingredients, but this is a losing enterprise as hundreds of thousands of new products come into the marketplace. A more

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manageable approach seems to be to develop lists of healthy ingredients, and this deserves special attention in the materials assessment segment of passports.

Systems Major Contributions & Barriers

One-stop-shop for information.

Users continuously ask that the information to achieve those values be in one place and easily accessible. For example, SundaHus has the experience that maintenance personnel perceive value in having maintenance data in one place. However, according to the state-of-art, most passport platforms do not contain the full range of datasets requested by users in the User Requirements Report.

Pilot with diverse users as a priority.

As SundaHus observed; 'Just because you can do something there is no guarantee that you actually will do it.' Passport platforms might have a capacity to include information, but in practice might not because for example the data is too time-consuming to obtain. For BAMB, this suggests that piloting with diverse users is a priority to see what they want.

Harmonize terminology & structural formatting.

Existing passport platforms do not share a standardized way of representing products or their contents, nor is the terminology aligned. Certain platforms do have standards in themselves. The potential for BAMB is to take the best examples and propagate those methods. Of special significance here might be the C4C commercial platform being developed with BAMB members BRE & IBM for BIM data protocols.

Convenience. How customizable, accessible, updatable & automated is it?

- Existing passport platforms do not seem to allow users to customize passport outputs, based on parameters preferred by the user.
- It appears many passports are not updated during the operations phase of a building, and as a result risk becoming outdated.
- Advanced software capacity to automatically import existing data from other platforms is missing, which suggest that time-consuming manual entries are required, leading to extra costs. There seems to be some manufacturer-updating capacity for some BIM objects.

The absence of each of those characteristics in the marketplace represents an opportunity for BAMB to fill the space in order to attract users.

Governance Major Contributions & Barriers

Intellectual property is a priority for governance and marketability.

Trademark, copyright, open source, competitive considerations and contributed IP; each have substantial impacts on use and availability of passports. Balancing IP with open source remains a significant challenge but is basic for success of passports.

- *Open Source* has diverse applications for passports including open source information, software and criteria. Often there is confusion between them. Clarification is warranted.

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A.2. State-of-the-art Analysis of Reversible Building Design: an overview of composition of C&D Waste per contributing country and dynamics around existing building stock

Major contributions form state-of-the-art

The biggest part of the building stock in the Netherlands, Belgium, Bosnia and Herzegovina and UK has been built in the 20th century.

The same reports point out that building stock constructed in the first quarter of the 20th century has a longer use life than the building stock constructed in the last quarter of the 20th century. In particular, research and data collected in the Netherlands indicate that ca 8.5 million m^2 of office space is vacant at the moment primarily built in the third and second quarter of the 20th century. Similar observations are made in the housing sector where out of 600.000 dwellings planned to be constructed 38 % will be a replacement of the existing housing.
According to previous research, key obstacles for successful transformation of buildings are often related to:

- Spatial inability to mutate from one use concept to another,
- inflexible load bearing structure,
- inflexible installation systems that cannot easily adapt to different spatial typologies,
- lack of accessibility to the old installations,
- lack of space for the new installations,
- fixed integration between load bearing and non-load bearing parts of the building.
- building volume in relation to the daylight, fire staircases and vertical communication.

These barriers for transformation are often related to the fact that building design did not take into consideration different time layers of the buildings

The waste composition and C&D waste presented in this report is structured around existing building stock which has predominantly used three types of materials such as: brick, concrete and wood.

State-of-the-art country reports from Belgium, Bosnia and Herzegovina and the Netherlands indicate that the C&D waste is ca 39-41 % of total waste production, in line with percentages on EU level.

An extensive study on the C&D waste of The Netherlands generated in 2012 shows small differences in the amounts of waste. A concise Material Flow Analysis (MFA) has been performed, identifying the different stages and different materials fractions undergoing on-site or off-site sorting and the waste treatment processes. The major part (93%) of the released stone waste material (concrete, bricks, tiles and ceramics, gypsum based material and rubble) in 2012 is used as base-material for roads, replacing gravel and sand.

Demolition in general can be defined as the process whereby the building is broken up, with little or no attempt to recover any of the constituent parts for reuse. Most buildings (built in particular after 1945) are designed for such end-of-life scenarios. They are designed for assembly but not for disassembly and recovery of elements and components. Different functions and materials comprising a building system are integrated in one closed and dependent structure that does not allow alterations and disassembly. The inability to remove and exchange building systems and

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their components results not only in significant energy and material consumption and increased waste production, but also in the lack of spatial adaptability and technical serviceability of the building.

Very often buildings are seen as finished and permanent structures. They are carefully designed around short-term predictions of building use. As a result those buildings have a long physical lifespan, but do not offer the flexibility to maximize their functional lifespan.

Some buildings are demolished because their technical characteristics have deteriorated. Most buildings, however, are demolished because they do not satisfy the needs of their users and their technical composition is represented by fixed physical layers so that building structures or whole buildings have to be broken down, in order to be changed, adapted, upgraded, or replaced.

Faster-cycling components such as space plan elements are in conflict with elements requiring less replacement and maintenance, such as the bearing structure, and the site because of the permanent physical integration between different time levels.

Such a static approach to building integration ignores the fact that building components and systems have different degrees of durability. While the structure of the building may have the service life of up to 75 years, the cladding of the building may only last 20 years. Similarly, services may only be adequate for 15 years, and the interior fit-out may be changed as frequently as every three years. The first step towards managing the temporal tension in building is through decoupling of slow and fast time levels

It has been argued that in the case of transformable building structures, it is not possible to fix a number of changing layers since they will depend on type of flexibility or transformation required. Different transformation scenario will require different number, arrangement and hierarchy of changing layers.

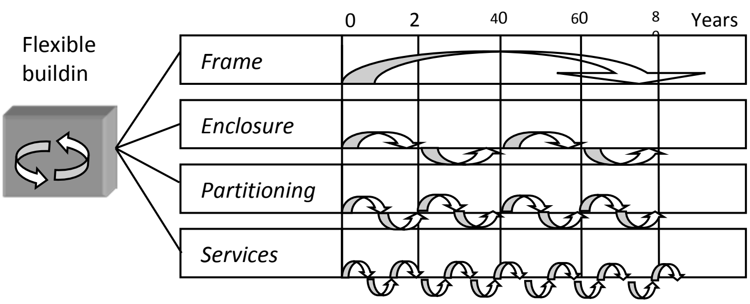

Figure 32: Different durability rates of building components (Durmisevic 2006)

Towards reversible buildings

When exploring the concept of circular buildings and circularity of material streams through all life cycle phases of the building, aiming to high quality reuse options of buildings and its constitutive parts, three types of reversibility can be identified: Spatial, Structural and Material. They have impact on all physical levels as building, system, and material level. Reversibility of these levels is accommodated by transformation actions as; the separation, elimination, addition, relocation, and substitution of parts and as such determine the level of space transformation, structural transformation and material transformation (see Figure 33). A key indicator of such

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three-dimensional transformation by high reuse potential that leads to reversible buildings is disassembly. Dominant agent of such three-dimensional transformable building is capacity of structure to transform and provide for high reuse potential of its parts.

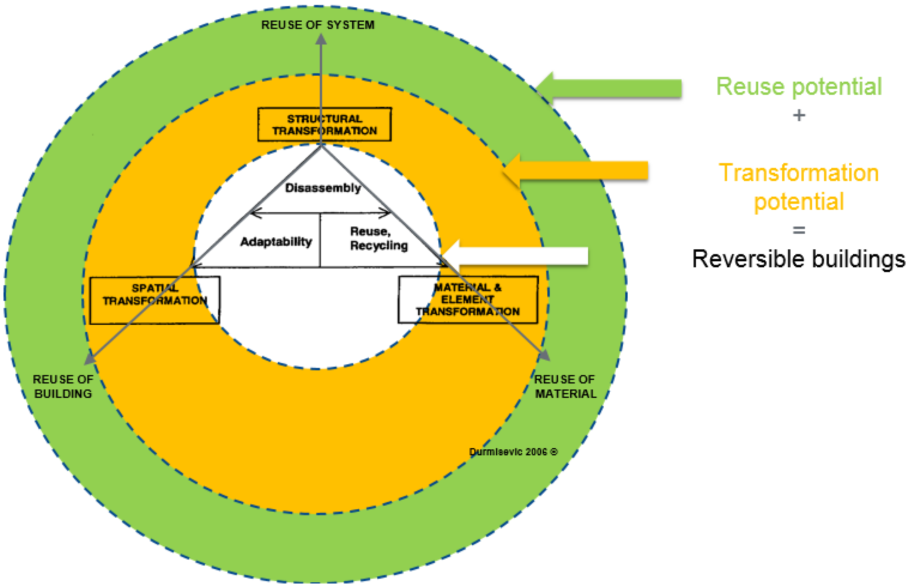

Figure 33: three dimensions of building transformation (Durmisevic 2006)

Opportunities and barriers to integrate circular and reversible building into practice

National Waste management Plans in Belgium, the Netherlands and UK as well as Dutch national program "The Netherlands circular in 2015" Encourage sustainable construction in various ways:

- encourage renovation over new construction
- encourage industries to develop circular processes and financial models
- encourage manufacturers to develop take back systems for their materials
- encourage the design of buildings that can adapt to changing functions and inhabitants
- encourage selection and use of materials that are more sustainable, use less resources, and are easier to reuse
- promote alternatives to building materials and products that contain hazardous materials.
- Support selective demolition, and stimulate the development of a social economy for selective dismantling

A report of Ministry of Environment and Infrastructure in 2015 proposes to "pre-finance the demolition of structures and the reuse of materials and construction elements (by disposal fee), as is already the case for cars".

Dutch government and government related stakeholders are investigating new procurement options that will encourage reuse and value disassembly and reuse upon demolition and recycling.

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However tools and protocols that can support transition towards circular and revisable buildings are scarce. As well as systematic evaluation tools that can inform all stakeholders about the technical composition of building structures and reuse potential of their elements.

Resent cases of buildings that were designed for disassembly and reuse but in the end demolished, show that these buildings are demolished not due to the lack of technical and functional performance but due to the lack of decision making protocols that will guide decision making procedures towards reuse.

Furthermore, many stakeholders agree that the lack of certification of components and elements coming from old buildings are a significant barrier to their broad application.

Lack of information about how buildings are constructed and which materials are used is also a bottleneck for their disassembly and reuse and is currently a dominant reason why many materials end up as waste.

Currently, there is no regulation requiring the building client or contractor(s) to consider deconstruction at the design stage. At the same time the lack of proper information regarding the advantages of reused elements might convince insurance companies to reduce their premiums. At the moment, premiums result to high prices discouraging the use of reclaimed material.

Finally, no protocols are in place for different building types that would speed up disassembly process.

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A.3. State-of-the-art report on Building Information Modelling.

Major highlights

The BIM State of the Art Report is a response to BAMB Work Package 5, Task 2. The aim of the report is to assess the current state of BIM within the UK, Europe and beyond, and within the context of BAMB, and to begin to investigate the role it has to play in materials passports and reversible design within a circular economy.

An extensive literary review was conducted, reviewing the definition and background of BIM and Circular Economy. The report also looks at current practices within the UK by investigating the key drivers of Level 2 BIM; comparing proprietary BIM tools used by industry; identifying the role BIM can play in a circular economy, and looking at the disruptive change management impact BIM may have on roles and responsibilities within the industry.

The current state of BIM has also been investigated by reviewing BIM adoption globally; working at EU level including standards and potential developments; looking at cross-country initiatives, and reviewing existing case studies.

Lastly, the future of BIM development was considered, with BIM Objects being identified as a key enabler for materials passports and reversible design.

This report is considered a live document which will be added to and updated when new research findings come to light as the BAMB project progresses. Already, future innovations such as Lexicon, a BRE and activePLAN initiative, which is being developed to standardize and align product data with BIM objects, is being looked at as a possible enabler. Although this report does not look into Lexicon, it will do so in the next release. BIM Object standards are another area of development that has been identified as important to the projects development.

Although the BIM State of the Art report is not exhaustive, it is an attempt to comprehensively cover BIM and the role it has to play within the context of the BAMB project.

Identified opportunities and Barriers

Key barriers and opportunities for BIM implementation have also been addressed. The perceived barriers identified in the report include upfront cost of implementation; risks of adoption linked to IP and copyright laws; licensing issues between collaborating parties and lack of technical skills and experience to drive implementation within organisations.

The following key opportunities were identified as having a push effect for economies adopting BIM within the AEC sector: reduction of cost, risk and time in the CAPEX and OPEX phases of an asset; potential for higher whole-life value of an asset from a comparable investments; expanded services for clients to raise the quality of their asset investment outcomes; enhanced international competiveness for economies adopting BIM; the potential for offsite construction for economy, speed and health & safety reasons; and the emergence of the ICT sector service as a key part of the construction sector.

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A.4. State-of-the-art on Policies and Standards

Major highlights

From the different policy instruments that are considered to have relevance in relation to promoting, or possibly hindering, the adoption of circular economy opportunities in the built environment, the binding legislations mainly focus on energy performance and construction & demolition waste management.

This results from the transposition by Member States of the requirements of the revised Waste Framework Directive (2008/98/EC) and the revised Energy Performance of Buildings Directive (2010/31/EU) into their legislation. The requirement level is depending of the Member State and the (sub-) national context. While the Scottish government has e.g. developed a Zero Waste Plan, the Flemish government has set up a Regulation on recycled aggregates and Sweden has developed the Swedish Waste Plan 2012-2017, in Portugal the waste management is not defined and implemented yet like in other countries in EU.

Even within sustainable building and circular economy policy instruments Energy remains an essential focus point. The Flagship Initiative 4: "Resource Efficient Europe" of the 10-year strategy Europe 2020 proposed by the European Commission e.g. supports the shift towards a low carbon economy, increase the use of renewable energy sources, modernize the EU's transport sector and promote energy efficiency.

Most policy instruments supporting sustainable building design and construction, comprising building materials (environmental) assessment, are voluntary instruments developed at national or sub-national level. Private certification schemes demonstrated to have a positive impact on sustainable building design.

The building sector is characterized by a complex and multi-disciplinary value chain, which is reflected by the wide range of policies impacting it. It is important to assess the impact of (future) policies on the different links of the value chain. The Construction Products Regulations (CPR) e.g. offers a common language and harmonised rules that could allow for reprocessed, recycled and reused materials to be widely exchanged by providing confidence in their performance and quality. However, obliging the CE marking for all reclaimed construction products could, depending on the type of construction product, have a contradictory effect and even distort existing second hand construction products networks, as a result of the complexity of the process and the resulting cost. It is therefore crucial to investigate the potential support and barriers for the different links of the value chain.

Identified Barriers

The fragmentation of the policies over the different policy levels and the current complexity of the legislative frameworks may lead to a lack of integration of the different policies and could in some cases even lead to contradictions.

It could be argued that a key barrier comes through energy efficiency policies across Europe. The prioritisation of energy efficiency and high energy performance of buildings may unintentionally result in building design and materials which do not lend themselves to deconstruction and reuse. It is not the high performance, which could hamper the adoption of dynamic and circular

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building design, but the choice of construction techniques and materials to achieve to required performance.

Furthermore the definitions provided by the EU Waste Framework, seems to lack clarity. As a result high recovery rates could correspond to down-cycling of stony fraction used for road foundation (and other low grade applications) which is far from the definition of 'recovery' as understood within the BAMB project.

An additional barrier can be seen in the fact that until recently many of the existing policies and instruments have been developed from a linear viewpoint, which does not take into consideration the potential reality of a circular built environment. For example, current urban regulations and building permits are based on a linear and static vision of buildings which may impede changes and transformations supported by reversible design and materials recovery. Similarly, some current financial incentives require complete ownership of buildings, which may be contradictory to new business plans and ownership models within a circular built environment.

The lack of knowledge and awareness of companies and technicians has also been identified as an important issue with regards to the implementation effective resource and waste management, as well as the implementation of Materials Passports and reversible design.

Identified opportunities

Although the lack of clear definitions is seen as a potential barrier, the EU Waste Directive also offers an opportunity to support the transition towards a circular building economy. The Directive introduces the "polluter pays principle" leading to Landfill Taxes in several countries. The increasing cost of landfill provides an economic driver for alternative solutions which avoid end-of-life waste, such as reversible building design. Further clarification of the current definitions could, in addition also, help to increase the quality level of the recovered, reused and recycled materials.

Existing hard laws on energy performance, waste management and construction product regulations offer the opportunity to address certain aspects supporting the implementation of dynamic and circular buildings. Extending these policy instruments by integrating Materials Passports and Reversible building design protocols would enable the development of an integrated approach meeting climate change, energy, environmental and economic issues.

This integrated approach is essential if we want to avoid that today's energy efficiency actions hampers tomorrow recovery of valuable materials. Energy Refurbishment of 3% required by the Energy Efficiency Directive (2012/27/EU) offer the incredible opportunity to do things better and to respond to a variety of challenges in a sustainable and effective manner.

More recently a new stage of policy development is underway. The Circular Economy Package (EU), Circular Economy Strategy (Scotland), Regional Program for Circular Economy (Brussels Capital Region), etc. have been adopted. All of these policy instruments recognise that the built environment is a key sector to introduce circularity.

This provides a significant opportunity to reframe sustainable building policies and instruments to allow for a circular approach. Existing voluntary programs, plans, strategies and tools are being investigated within the BAMB project and suggestions will be given to enable their adaptation to support the transition towards a circular and dynamic built environment.

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A.5. State-of-the-art report on the building value network

Shaping the background for a future where buildings are material banks.

The traditional value chains are decomposing and the different industries involved in the built environment are converging, forming new relationships - the nodes of the new networked ecosystem. In this new ecosystem players can and do take different roles in time, relationships become more complex and multidirectional in nature.

There are four main characteristics that will define the nature of the circular construction network(s) and that can help determine the extent to which the buildings will be considered as true material banks: *connectivity, interactivity, awareness and intelligence.*

In connectivity, we observe the transition from organization driven connectors (where information asymmetry restricts coordination) to an everyone-to-everyone system where connections are orchestrated and not mandated and information is shared seamlessly. *The Internet of Things (IoT)* will transform the way objects, machines, components and even materials communicate, opening up a number of significant new opportunities to implement models that accelerate the reuse potential of buildings. Concepts such as the *Materials Passport* can positively contribute to the strengthening of these connections.

At the same time interactions are moving from incidental (transactional) to symbiotic long standing (win-win) relationships. This is a relevant trend, as the reuse potential seems to be strongly correlated with the types of ownership models that are in place. Transactional relationships based on frequent and complete transfer of ownership are less aligned with reuse practices whereas *user-ship* models (decoupling ownership from use) seem to allow for better rates of product returns that in turn make possible higher percentages of reuse. It is expected that the interactivity between the different actors will be stronger and more constant over time.

In the specific case of the built environment, technological and methodological advances linked to improving awareness regarding the construction waste, are creating a breeding ground to mature concepts of green design, reversible design, design for disassembly amongst others.

The data explosion triggered by the above mentioned trends will define and additional key challenge, how will the network cope with such developments and how will it be able to create additional value from the new information collected?

The entire system will have to become more aware and intelligent, moving into contextual and cognitive constructs that are able to express and capture the different forms of value. This means that the entire system will have self-supported learning and predictive capabilities that adapt to each specific circumstance and that the system itself is able to make a large majority of decisions searching for a holistic optimum.

The emergence of such a circular network will most likely also lead to the development of new business and operating models that are more tightly aligned with the reuse principles.

Identified opportunities and barriers

The main challenges and opportunities in this construction value network overview is concentrated in 2 phases (and sub phases) where the integrated BAMB output provides the most

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contribution of information on product information and status to understand and plan to repurpose these products, components or material. These phases are (1) the design phase and (2) the repurpose phase.

Key challenges identified:

- The lack of data around product properties and specifications, product (health) status and where these products are located in the building (digital profile, BIM) as input to reuse intelligence in order to select the reuse loop with most value.
- Design teams not aware or open to explore reuse of existing building products and installations (no quick visibility and transparency on secondary products and materials that are available and meet the required quality criteria).
- Only limited number of suppliers providing the supply and quality assurance for reuse products at competitive prices that incentivise design teams to consider them as suppliers.
- In general, quality assurance (i.e. liability clauses, etc.), certification of products and materials, and supply reliability of secondary market for products and materials.
- The industry model is linear as many parties work in silos, missing the opportunity of a system optimization and higher value creation. The suppliers in this model are squeezed to minimize price, which in turn compromises quality and user and building owner value on the long term.

Key opportunities identified:

- Enable the concept of Urban Mining and Building as a Material Bank, whereby the appropriate design and digital profile availability of the building and its market context, will facilitate an optimal repurposing and/ or reuse of the building and its (embedded) products/ materials.
- New players (bringing new job opportunities) in the construction industry that are secondary products or materials suppliers. As an example: recycling companies to become Urban Miners, requiring other set of capabilities.
- Innovative business models for selling performance/ services/ solutions. This will enhance the value proposition through different engagement model with the customers. Buying of services (i.e. Performance Based Contracts or Pay-by-use models), with ownership residing with supplier, will accelerate the reuse of products and components where suppliers internalize their supply chain (e.g. components reuse of spare parts, embedding in new products) and therefore have a need to collect their products at end of service or performance.

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