D12 FEASIBILITY REPORT + FEEDBACK REPORT

Testing BAMB results through prototyping and Pilot Projects

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1 INTRODUCTION

Within the BAMB Project – Buildings As Material Banks – 15 partners from 7 European countries are working together with one mission – enabling a systemic shift in the building sector by creating circular solutions.

Today, building materials end up as waste when no longer needed, with effects like 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 economy.

Whether an industry goes circular or not depends on the value of the materials within it – worthless materials are waste, while valuable materials are recycled. Increased value equals less waste, and that is what BAMB is creating – ways to increase the values of building materials.

BAMB will enable a systemic shift where dynamically and flexibly designed buildings can be incorporated into a circular economy. Through design and circular value chains, materials in buildings sustain 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 – slowing down the usage of resources to a rate that meets the capacity of the planet.

The project is developing and integrating 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 which will be further detailed in this report.

1.1 Objectives of Work Package 4

- Investigate different aspects related to Materials Passports and Reversible Building Design.
- Investigate the waste reduction potential of Materials Passports and Reversible Building Design.
- Investigate certain aspects with regard to business models: suppliers' ownership and service delivery, reversible logistics etc.
- Investigate market readiness and the practical application of circular and dynamic building design with stakeholders.
- Raise awareness and demonstrate innovative approaches, investigated and implemented in the BAMB project, through practical application and physical construction.

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1.2 Description of the work and role of the Work Package 4 partners

In Work Package 4, new design, manufacturing, construction and maintenance approaches for dynamic and circular buildings are being investigated and demonstrated in 6 Pilot Projects. Reversible Building Design approaches, the implementation of Materials Passports, new business models for circular material value chains, organized supplier communities, etc. developed in other work packages are being investigated in 6 real construction or refurbishment projects.

In order to maximize the BAMB project's innovation potential, dissemination impact and stakeholder involvement, we have chosen to pilot and demonstrate project outputs in various operational and testing environments. The constructions are funded foremost by private partner investments. These private partners assign experts (designers, engineers, production houses, contractors…) for the design, manufacturing and construction of the pilots.

In doing so, 6 Pilot Projects that vary in function, typology, etc. (see § 2 Pilot Projects) are being implemented) and are spread geographically across Europe. BAMB results are being explored in feasibility studies, through prototyping and the construction of Pilot Projects. Input and results from Work Package 2 (Materials Passports) & Work Package 3 (Reversible Building Design) are being used to determine how the pilots are being developed in detail. The business model approaches and requirements developed within the Pilot Projects feed the reflection within Work Package 5 Action 2. The reflexive monitoring performed in Work Package 1 is being based on real life lessons learned through the Pilot Projects.

Finally, the pilots also play a decisive role in creating awareness for the BAMB concepts in the design, construction, management and disassembly of buildings. All pilots are locations demonstrating (aspects of) the project and can be visited.

1.3 D12: Description of the Work Plan

This feasibility report consists of a synthesis of the feasibility studies of the 6 Pilot Projects. The feasibility studies of the individual Pilot Projects are attached as annexes.

Pilot	Leading Partner	Action code	Deliverable code
			Feasibility study + Feedback report
Green Transformable Building Lab (GTBL)	ZUYD	A1	D12.1
Reversible Experience Modules (REM)	EPEA	A2	D12.2

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Green Design Centre Building	SGDF	A3	D12.3
Circular Retrofit Lab	VUB	A4	D12.4
Building Reversible in Conception (BRIC)	IBGE	A5	D12.5
New Office Architecture	D&S	A6	D12.6

Figure 1: overview of pilots

All pilots leaders have been asked to perform a feasibility study in which the objectives of the actions regarding Materials Passports and Reversible Building Design have been studied on a theoretical level. The different scenarios and choices have been described, as well as an analysis of all construction aspects needed to implement these objectives. These feasibility studies will be used as a basis for the prototyping and the construction of the pilots, since they will be developed and used as the construction dossiers of the pilots.

The functionality and ease of use of the developed concepts within the other work packages of BAMB will also be integrated and tested during the design stage: the developed framework for Reversible Building Design, Materials Passports, and the Building Level Integrated Decision Making Model. In addition, certain innovative financial and economic concepts will be implemented based on which input can be given to develop new business models. This will generate feedback to the other work packages, so they can improve their developments and research.

1.4 Outline of the feasibility report of the Pilot Projects

The feasibility report of each Pilot Project is structured around 5 chapters, in which the following topics are addressed:

- Processing and conclusions on the existing conditions:
    - The location
    - The local building industry
    - The stakeholders (design team, owner, industry partners) and their role in the pilot.
- Investigation of different transformation and/or relocation scenarios, for a minimum of 2 scenarios.
- Requirements concerning the technical, functional, and comfort aspects of the developed scenarios. Conclusions about the practical needs, technical engineering, architectural design…
- Design plans:

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  - Preliminary design plans
  - Implementation plan
  - Technical detailing and/or technical specifications of (part of) the construction.
- Feedback report on the tools/concepts/frameworks developed in Work Package 1, Work Package 2, Work Package 3 and/or Work Package 5, tested or investigated within the pilot. This feedback will contain the ease of use, the strengths and the weaknesses of the assessed tools/concepts/frameworks. Recommendations for improvements will be given.

1.5 D12: Synthesis of the feasibility reports of all Pilot Projects

All 6 Pilot Projects made their own feasibility study and feedback report (see §1.4). This report is a synthesis of the reports drafted for each Pilot Project. It provides an overview of the main features of the different Pilot Projects and highlights the findings of the separate feasibility studies through the following chapters:

1. Introduction: the objectives of Work Package 4 and deliverable D12
2. Pilot Projects: a brief overview of all 6 Pilot Projects with a description, design scenarios and plans.
3. Dynamic and circular building concepts: an overview of the Reversible Building Design, Material Passports and Circular Business Models aspects investigated within the BAMB project.
4. Technical Aspects: an overview of the different technical choices and solutions implemented on a building level, as well as on an element level
5. Impact assessment: a qualitative assessment of the actions taken within the different Pilot Projects to reduce the production of construction and demolition waste, as well as the use of virgin resources.
6. Interaction with the Value Network: an overview of the involvement and interactions with different types of stakeholders, addressing some barriers and opportunities.
7. Feedback on the BAMB outputs: lessons learned in regards to circular economy in the built environment, the use of Materials Passports, Reversible Building Design tools and circular business models
8. Conclusion: a brief final conclusion

Within this synthesis report, we answer amongst other things, the following questions:

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- How can Reversible Building Design be implemented and what are the challenges to tackle?
- How can we profit from Material Passports?
- How can new business models be introduced and what barriers have to be tackled?
- What methods are used to reduce the amount of waste?
- How can we involve the stakeholders?

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2 PILOT PROJECTS

Within this chapter, a brief overview is given on all 6 Pilot Projects, describing the most important aspects and objectives of the pilot and illustrating the design and scenarios.

2.1 Green Transformable Building Lab (GTB Lab)

Focus: 1) Reversible Building Design supporting the transformation in size, shape and function of the Pilot Project at least 1 time during the BAMB project;
2) Investigation of business model needs and requirements of the local stakeholders participating in the project

Type of construction: New Construction

Size: minimum size: 150 m²; maximum size: 1200 m²

Function: Initial: multifunctional space that can adjust to changing daily activities from work lounge to meeting space and lecture hall, and 1 housing unit
After the 1st transformation: Offices and housing

Country: The Netherlands

2.1.1 Description

The Green Transformable Building Lab is a new building of 150 m² that has the potential to be extended up to 1200 m^2. It is part of the international expo on the Dutch/ German border: IBA2020 at Heerlen, The Netherlands. GTB Lab will act as a showcase of Reversible Building Design and how a building can be developed as a Material Bank for the international Expo IBA2020[1].

The Lab will be the place for testing and the demonstration of design tools, building products and elements in an operational environment. In order to provide independence and exchangeability of building elements (a key to reuse), experiments will especially focus on the standardization of the connections between different building systems and the use of transformable and upgradable components.

The design enables the transformation from one functional program to another. By introducing building components that are standardized and have exchangeable interfaces, the structure will be able to adjust its configuration to the required change in performance without a substantial loss of value of the materials. By doing so, optimal comfort, a healthy climate and local energy production will be provided for each functional program.

[1] http://www.iba-parkstad.nl/

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After the construction of the first configuration (the core of the GTB Lab), at least 1 transformation of the building will be performed. Transformation will involve the modification of a reversible module, without creating any construction and demolition waste.

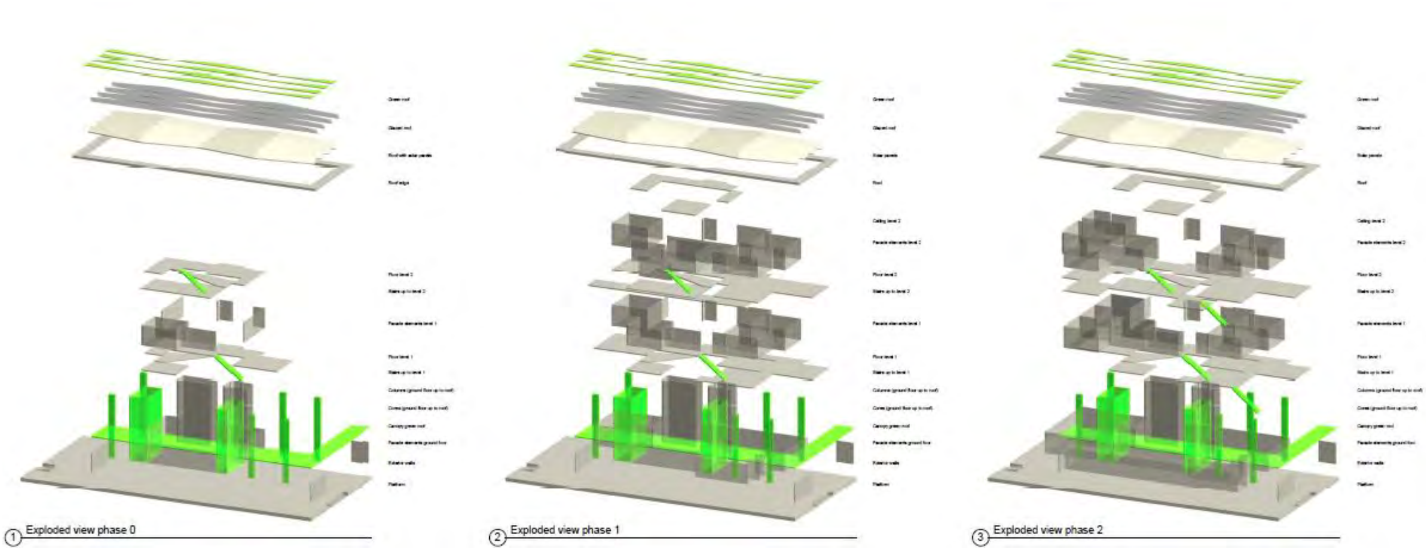

Figure 2: Schematic overview of the Green Transformable Building Lab structure.

2.1.2 Design scenarios and plans

In order to develop the scenarios and the concept of the GTB Lab, expert groups[2] had joint meetings. Various solutions and possibilities were tested through workshops and design studios. The building will be transformed by changing its function and shape every 10 months and there will be at least 1 transformation during the BAMB project. Multiple transformation scenarios have been investigated (*Figure 3: Multiple use scenarios investigated.*).

[2] Divided into two main clusters: industry cluster and knowledge cluster.

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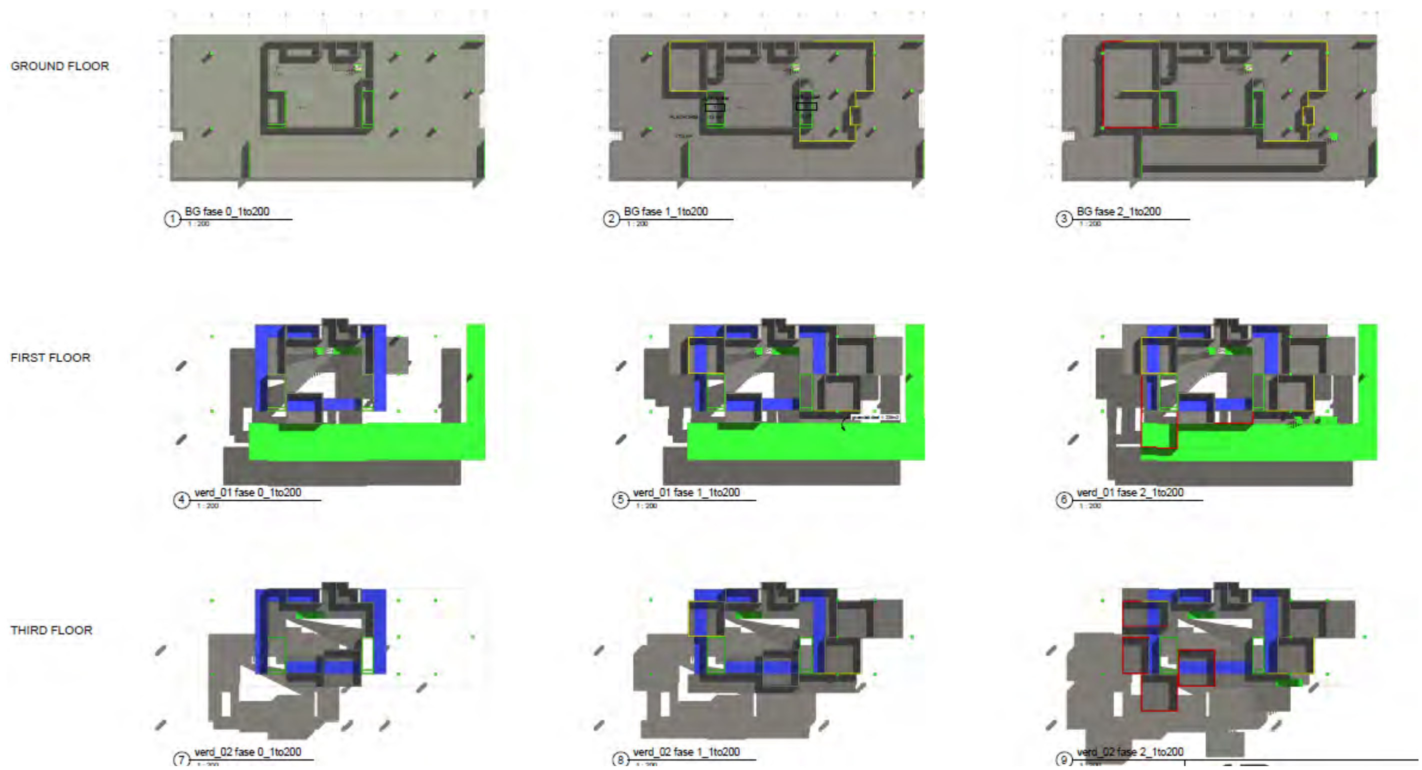

Figure 3: Multiple use scenarios investigated.

The scenarios that have been selected by the expert team are:

- The start phase will be the core of the GTB Lab with one meeting space. The core will accommodate all future predefined use scenarios.
- The first use scenario will be a multifunctional space that can adjust to changing daily activities from work lounge to meeting space and lecture hall. It will also include one housing unit of 35 m^2, added to the core.
- The second scenario includes the transformation of the housing unit from a studio to three senior apartments of 70m^2, 115m^2 and 120m^2 and the addition of an office space and a terrace on the first and second floors.
- The third scenario includes the transformation of an apartment into an office space of 160 m^2. Two senior apartments of 70m^2 and 120m^2 remain.

The technical requirements for these three scenarios include the design of the core of the GTB Lab that can support internal flexibility and extendibility, as well as the integration of a service network into the core to support natural ventilation for all units of the lab, water supply/discharge, electricity and adjustments to the natural light.

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The first use scenario forms the multifunctional core of the GTB Lab with the service core, and a space to be used as an expo space, a work lounge and a lecture hall. Three main spatial requirements are defined as: internal flexibility (i.e. space adjustment to daily needs), multi-functionality (i.e. transformation of an office into an apartment) and extendibility (i.e. enlargement of space). The main technical requirements deal with the structural flexibility that will support three spatial scenarios. Besides structural transformation, another technical requirement is related to the provision of optimal comfort for each transformation, including the provision of natural ventilation and daylight for all of the units of the lab, as well as resource effective electricity, space heating and domestic hot water supply.

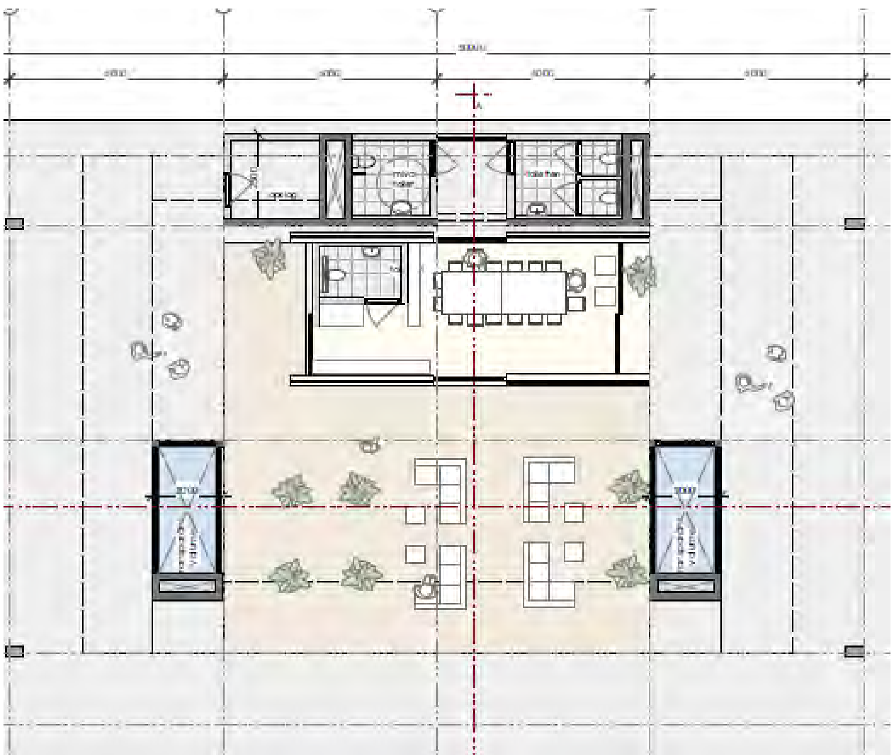

Figure 4: Ground floor- start phase (core+ meeitngplace).

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Figure 5: ground floor - scenario 2 (core + multifunctional space)

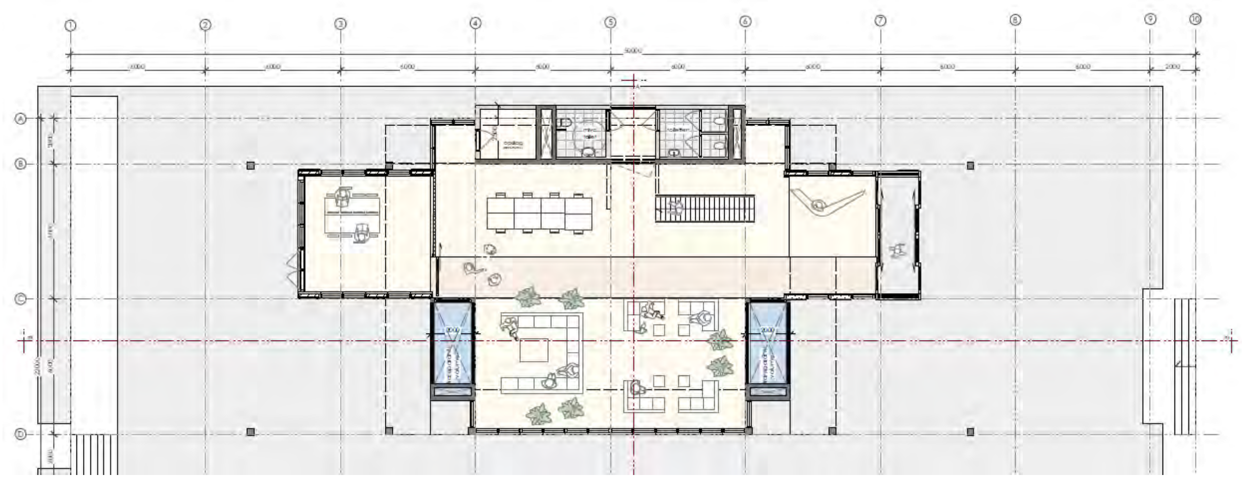

Figure 6: ground floor - scenario 3 (core + units)

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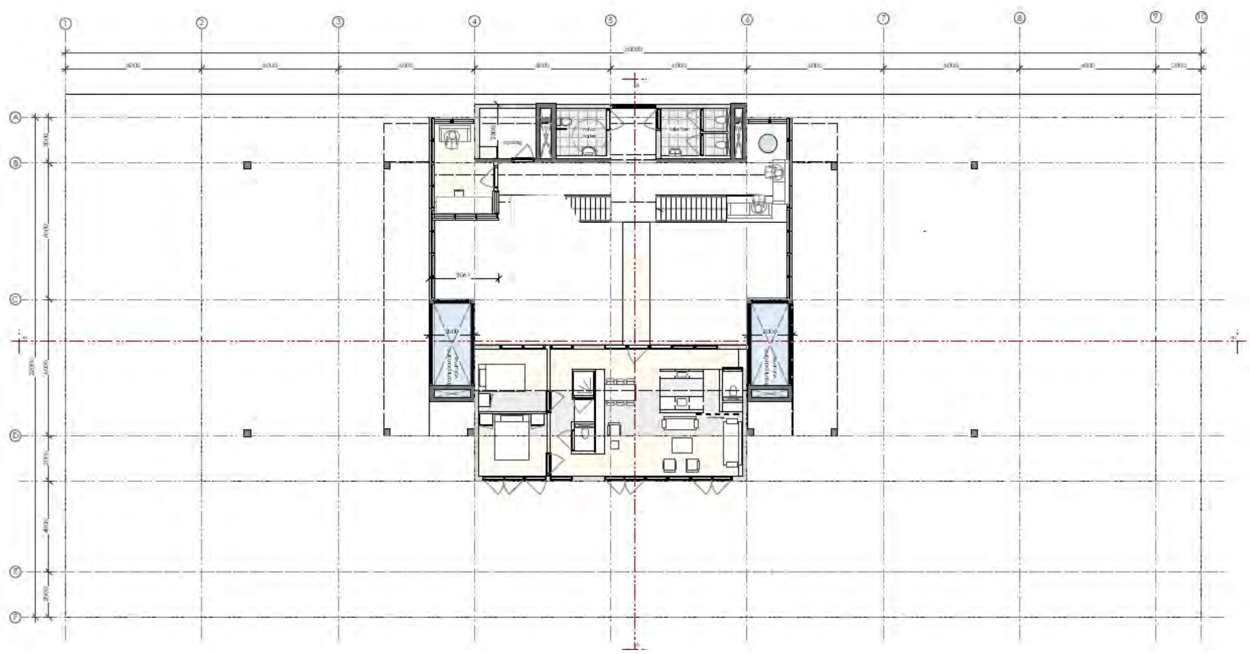

Figure 7: first floor - scenario 2 (core)

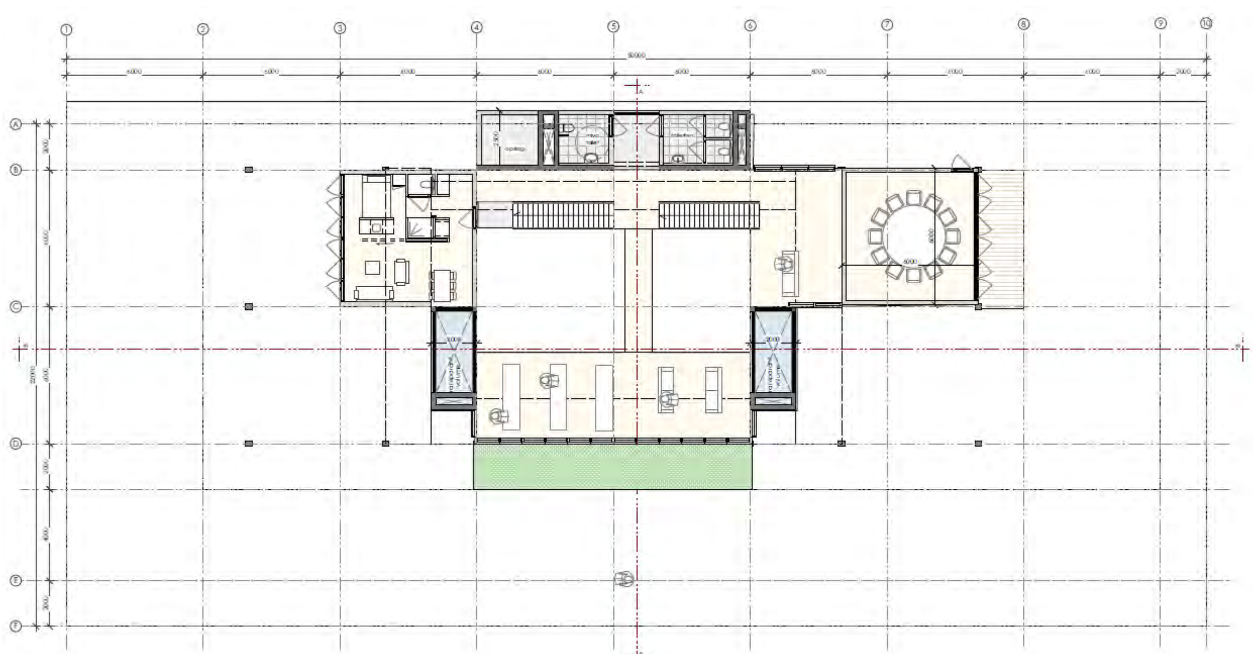

Figure 8: first floor - scenario 3 (core + units)

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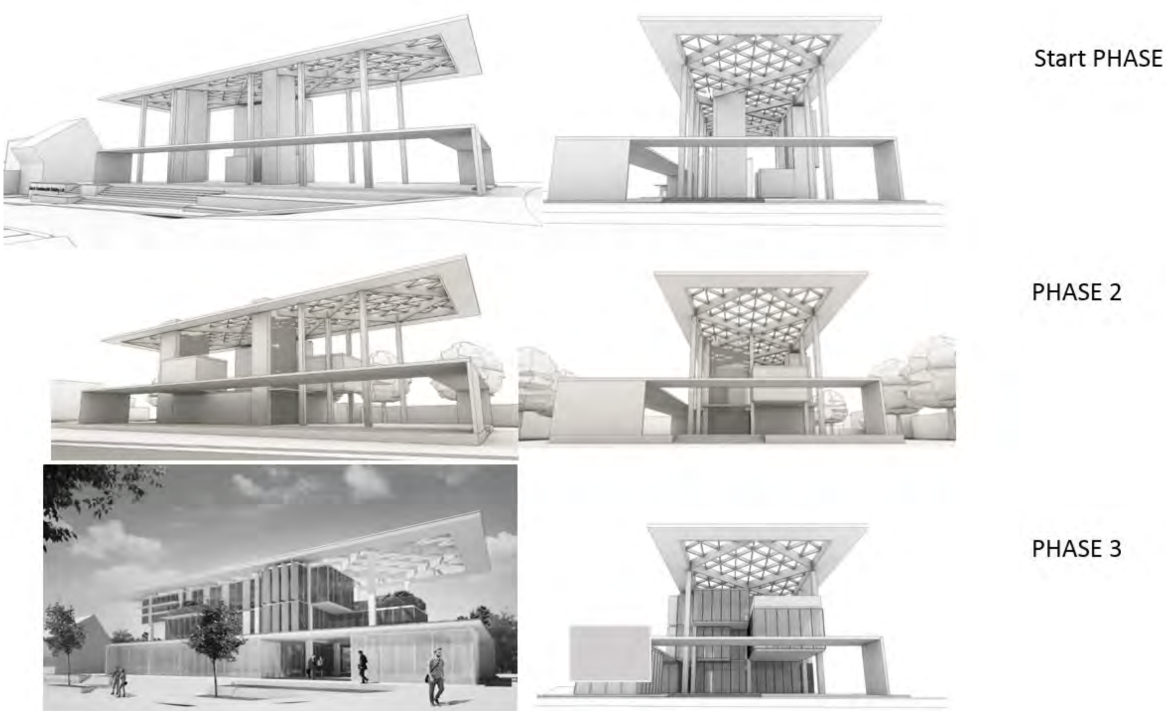

Figure 9: 3D models GTB Lab

2.2 Reversible Experience Modules (REM)

Focus: 1) Materials Passports: The Pilot Project will enable experiencing the use of Materials Passports by providing access to the Materials Passports Platform and the Materials Passports of the different construction products used in the project. It will also invite visitors to physically reconstruct and rearrange the exhibition area, guided by the Materials Passports.
2) Reversible Building Design: The Pilot Project can be disassembled and reassembled in different locations and according to different floorplan configurations.

Type of intervention: New Construction

Size: minimum size: 2m²; maximum size: to 89m²

Function: Exhibition

Country: The Pilot Project will be travelling to different locations in different countries throughout Western Europe

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2.2.1 Description

The Reversible Experience Modules Exhibition (REM exhibition) is a travelling exhibition that will provide a user experience of the new possibilities created for the built environment by combining Materials Passports with Reversible Building Design.

A “Reversible Experience Module” is a physical demonstration object, based on a product (e.g. a door) or system (e.g. a ceiling system) from the built environment, focused on interactively displaying the possibilities and advantages of Reversible Building Design and Materials Passports.

A Reversible Experience Module (REM) consists of two parts:

1. a product for the built environment from a specific industry partner
2. its corresponding Materials Passport.

When put together, groups of REMs form an exhibition about the advantages of Materials Passports for flexible and reusable building products. They invite visitors to physically reconstruct and rearrange the exhibition area, guided by the Materials Passports. This interactive learning environment shows professionals within the built environment how to improve resource productivity, value and design for positive impacts and the Circular Economy. The REMs will also enable testing the passports through the Materials Passport Software platform by retrieving information related to the REMs and comparing the information with the actual product or the description and visualisations of the product.

The REM exhibition will be made out of at least 30 physical REMs, and 40 visual REMs (posters, videos or other visualizations). Each REM follows the principles of circularity, and therefore the total REM exhibition as well. The REM exhibition explains the added value to the daily professional practice, and aims for an international demonstration in Reversible Building Design and Materials Passports. The exhibition will give visitors the impression of being in an actual building. However, several constructions will be simplified compared to actual buildings to facilitate visitors’ reassembly and to provide instructions on reversibility as clearly as possible.

The travelling exhibition will visit 6 locations in Western Europe. The design for the REMs will be 100% reusable in the different locations, leading to a 100% prevention of waste.

2.2.2 Design scenarios and plans

The discussion on concept design led to the conclusion to adopt a unit-based build-up of the exhibition. The choice of units was limited to office, home, and sanitary units.

The indoor exhibition demonstrates the advantages in two archetypical building types that everybody recognizes: the home, and the office. You will see the transformations possible from home to office and back.

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The unit spaces are a broad representation of the different types of constructions and materials used in buildings, and are at the same time recognizable for a large group of diverse visitors. Visitors will enter in the corridor, which is connected to the various units.

Units are (re-)attachable to the central corridor. The units and corridor can be shortened or elongated by adding modules.

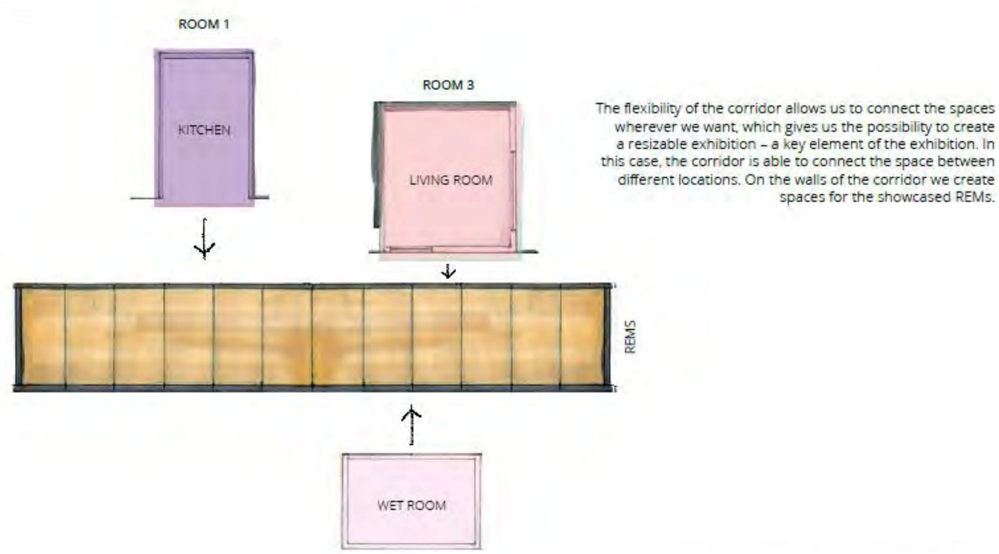

Figure 10: modular element of 2m² used for units and corridor

The entire exhibition is built from products that are fit for circular buildings. The exhibition can have a total floor surface ranging from 2m² to 89m², with intermediate floorplans measuring approximately 25 m² – 50 m².

The units are reconfigurable, taking into account different floor plan patterns. At each location, the floor plan will be unique, yet recognizable.

A basic building unit is repeated 15 times in the largest floorplan to hold the 30+ REMs. The floorplan can be adjusted, however, in various configurations as is shown in "Scenarios". The entire exhibition can be dismantled to be transported. Due to the necessity of transportation, the basic building unit is adjusted to limitations such as a maximum volume and weight and protection against damage.

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Figure 11: maximum floorplan

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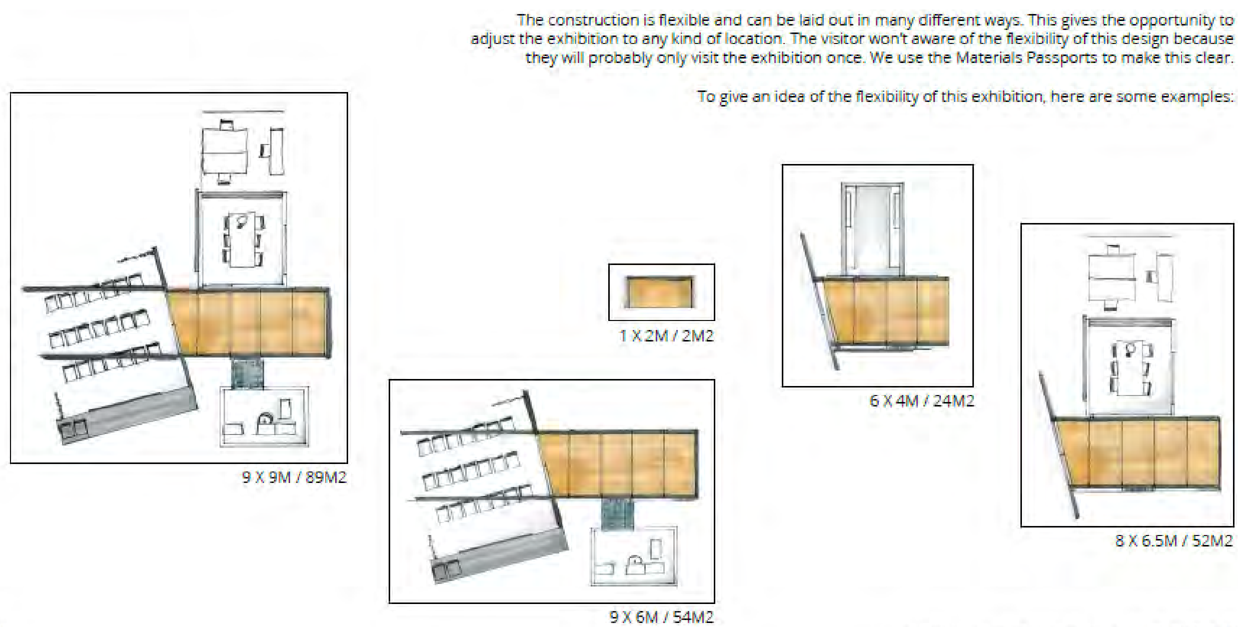

Figure 12: possible floorplans

As examples, three possible floorplans are shown: Small, Medium and Large. However, more configurations are possible. The small floorplan consists of one single basic building unit of 2 m² total. The medium floorplan with the corridor and a reduced office unit measures 9 basic building units of 38,5 m² total.

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Figure 13: minimum - medium - maximum floorplan

The large floorplan measures 13 basic building units and 63 m², and includes the corridor, a home unit and a reduced office unit.

Furthermore, the elements (e.g. wall panels) can be interchanged from one functional basic building unit to the other and the functional units can also be relocated to create an alternative floor plan configuration.

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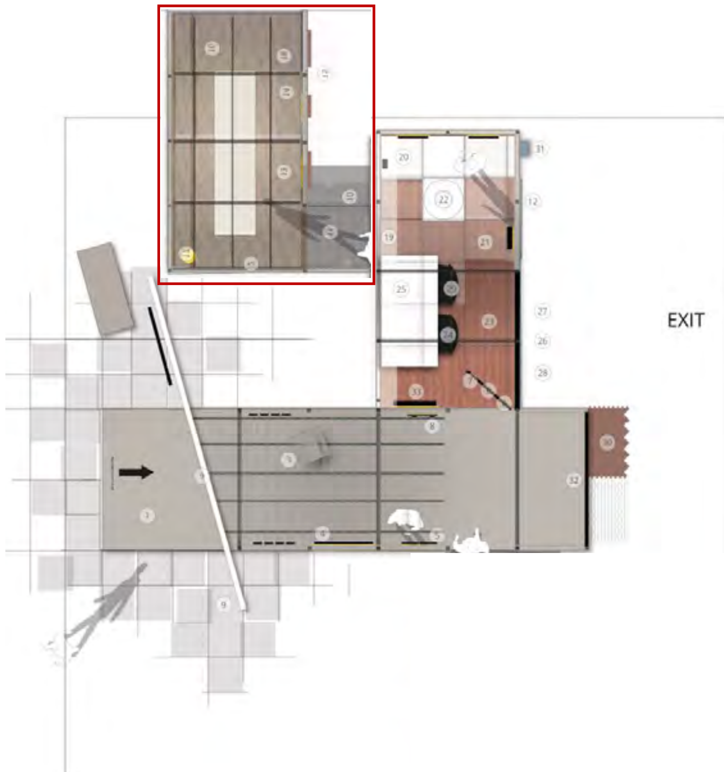

Figure 14: possible reconfiguration of unit

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2.3 Green Design Centre (GDC)

Focus: 1) Reversible Building Design supporting the transformation in size and internal floor plan
2) Investigation of business model needs and requirements of the local stakeholders participating in the project

Type of intervention: Refurbishment

Size: minimum size: 180 m²; maximum size: to 250m²

Function: Exhibition and office space

Country: Bosnia and Herzegovina

2.3.1 Description

The Green Design Centre (GDC) consists of a refurbishment project of a military storage unit built by the Austro-Hungarian government at the end of the 20th century, located in the city of Mostar, Bosnia and Herzegovina. The GDC Pilot Project will be a creative hub bringing design and production industries together and will be used for educational purposes and as a construction innovation platform. GDC will be owned by the city of Mostar and will function as a Green Design Innovation Park.

The centre is designed with the capacity to illustrate functional change from/to an exhibition space, a workshop space and an office space. The experiments will showcase the Reversible Building Design approach and its materialization through the development of integrated architectural and technical solutions that support the reversibility of the building function, and accordingly its structural configuration, without waste generation. It will consist of a multi-purpose and demountable/replaceable structure.

GDC will have 180 m² of exhibition/office space on the first floor and will be extended to 250 m² of exhibition/office/meeting/lecture /workshop space.

2.3.2 Design scenarios and plans

The **Green Design Center** is built up as a reconstruction and transformation of the existing building structure which is to be reused at a rate of 80%. The existing structure functions as a core. The core has been upgraded by the creation of a steel grid raised floor, which is hosting installation services and which allows the flexible rearrangement of space. The extension of the steel grid allows the addition of extra space by placing additional independent units which can again be replaced. The aim of the design is for the structure and the units to be built from prefabricated components and units.

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Figure 15: Representation of the existing building structure and the image of the building after removing all infill elements (non-structural elements).

As a result of an analysis of the existing structure, it has been decided that during the first refurbishment/construction phase, the existing structure will be stripped and all infill elements, including facade blocks between columns, will be removed. Furthermore, a new structure will be placed on the first floor, forming the public space of the GDC where exhibitions, workshops and lectures will take place.

GDC will be a flexible building that explores strategies for reversible interventions in a way that can extend the use of existing structural elements and create new space by reusing its capacity. The building will be developed with the potential to be extended and upgraded. The main spatial flexibility deals with internal flexibility and space enlargement. Technical requirements are related to technical services that will support spatial flexibility while eliminating waste and supporting material circularity. The new innovation park around the building has been designed with the same grid (3,1 m) in order to enable circularity of materials used in the building and in the park. Parts of the modules from the building can be replaced in the park and form a pavilion and the other way around. Comfort, especially in summer, is an important requirement, as well as the use of green services to improve the micro climate during hot summer days. The use of movable sun and wind protection panels will also increase comfort.

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Scenario 1

The design of the 1st scenario will consist of 180 m² of exhibition/office space on the ground floor and a terrace/garden on the first floor. All structural elements in the middle of the ground floor will be removed as well as facade filling between the columns. A raised floor will be placed on the ground floor, made of steel beams, to provide space for the distribution of technical services, space for green gardens on the first floor and connection points for the transformation of the first floor during the second scenario by adding units.

Scenario 2

In the second scenario, the modules forming the GDC will be extended including angled south modules that will be covered by PV panes and modules facing north will be covered by green plants. Primarily exhibition space on the first floor will be rearranged into meeting/office spaces. The ground floor will be organized as a workshop space, connected with an outside terrace for working outside in summer.

The floor plan below illustrates the extension of the first phase into the second by the addition of the modules to the existing structure.

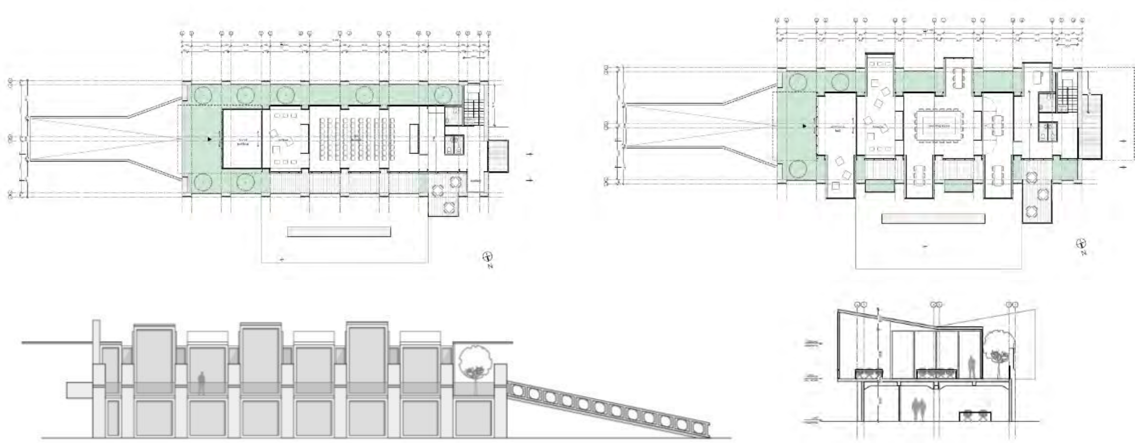

Figure 16: Left: first construction phase. Right: second construction phase extending the volume.

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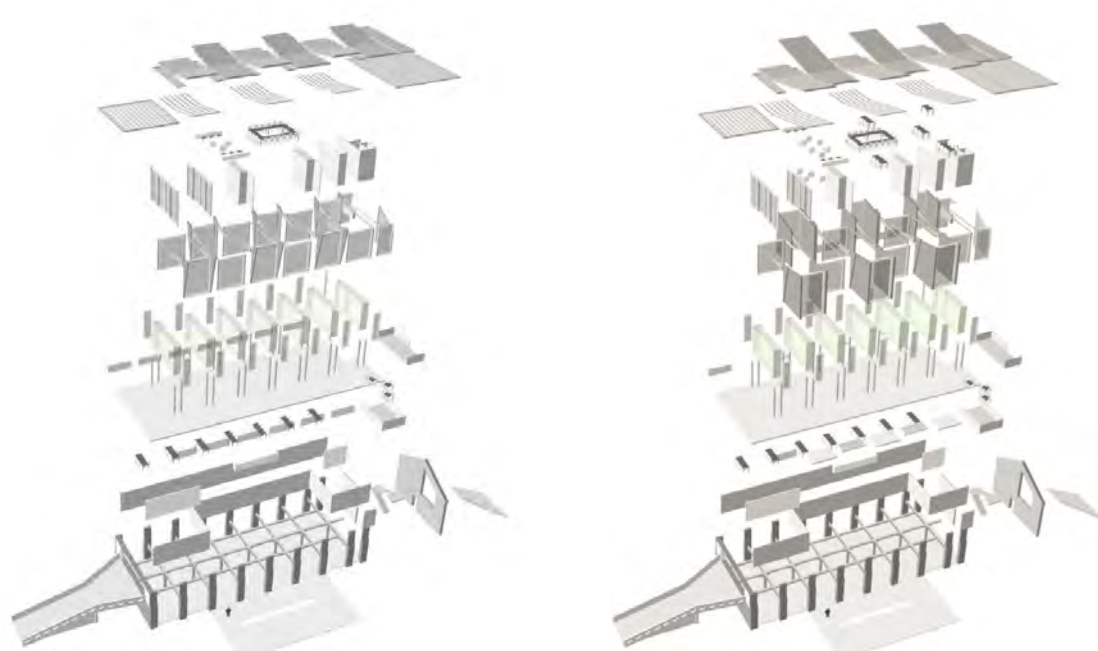

Figure 17: minimum (scenario 1) and maximum (scenario 2) scenario.

Third scenario

A third transformation is planned to present the transformation of one office unit into a housing studio and to demonstrate the reversible construction method for housing.

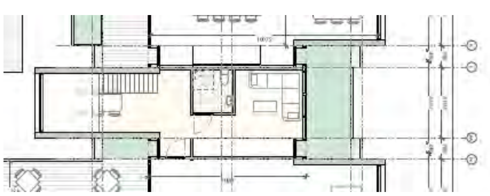

Figure 18: Transformation of one unit within GDC

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2.4 Circular Retrofit Lab

Focus: 1) Reversible Building Design supporting the transformation of the internal floorplan and facade
2) Investigation of business model needs and requirements of the local stakeholders participating in the project

Type of construction: Refurbishment

Size: 200 m²

Function: Ground floor: Exhibition and dissemination space

First floor: Housing (1nd Scenario)

Office space (2nd Scenario)

Country: Belgium

2.4.1 Description

The 'Circular Retrofit Lab' concerns the transformation of 8 existing student housing modules on the university campus of the Vrije Universiteit Brussel in Etterbeek. The Circular Retrofit Lab is located in the heart of the university campus. In this central zone, about 350 student rooms were designed and built by Belgian architect Willy Van Der Meeren as a temporary solution for student accommodation in the 1970s. The construction process of the student housing units was rationalised by using prefabricated concrete support modules (aka Variel system) and infill components for exterior and interior walls. Arranging these standard modules in different spatial ways resulted in a variety of urban cluster configurations on the campus.

Three general renovation strategies are being examined for the existing student modules: 1) internal transformation of the modules, 2) external transformation of the modules, and 3) spatial transformation of the modules based on reconfiguration of the existing concrete structural modules.

Within the BAMB project, the focus of the living lab is on how Reversible Building solutions can be developed for the interior fitting-out of existing buildings (partition walls, technical services, interior insulation and sanitary cells). Therefore, solutions will be prototyped and tested.

In the Circular Retrofit Lab, two floors - consisting of 4 student modules each - will be reconverted into a dissemination space on the ground floor, and a changing function on the first floor. The total surface of the living lab is +/- 200m², with +/- 100m² on each building level. The changing function on the first floor will demonstrate the ease to transform the lab from eco-guestrooms to a work space. The transformation will enable testing the transformation capacity and reuse potential of the

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implemented Reversible Building solutions. Also, the pilot will be used to check how Materials Passports can be integrated, how a BIM model can be used to overview the reversible properties of the pilot, and how industrial players can be involved in the development of innovative reversible solutions.

Figure 19: Existing student housing modules on the VUB campus finished in different colours (Etterbeek, Belgium)

The general goals of the Circular Retrofit Lab are twofold. First, when looking at all student modules on the VUB university campus, the Circular Retrofit Lab aims to act as a good example and catalyst for the future reconversion of all modules that is planned in the coming years. The living lab can serve as an alternative for the current renovation solutions in which the future use of buildings and their change is neglected. The living lab acts as a demonstrator of how the existing modules' transformation potential can be enhanced during their renovation so that they can be more efficiently maintained and more quickly reconverted from one function to another in the coming years. Renovation today needs to support the necessity for change and maintenance from a life cycle point of view. Hence, the Circular Retrofit Lab will offer an efficient answer when the university needs buildings with e.g. new functional requirements, evolved comfort needs or an alternative use of the modules.

2.4.2 Design scenarios and plans

In order to choose several functions for the Circular Retrofit Lab, a research-by-design method was applied for the internal configuration of the existing building.

The structural facade and large span of the concrete floor elements of the Variel system result in an open plan layout. By removing the internal partition walls that are non-structural and the prefab sanitary units, this open plan can support a wide variety of alternative functions. Functions, supporting the (student) life of the university campus, have been investigated. Some examples of new functions in the square configuration of 4 modules are: a dissemination space,

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an eco-guest house, a bicycle repair shop, a student information point, a plugin office, a coffee shop, etc.

From an architectural point of view, all of the original plans have been designed with a certain logic towards its structure and services. Zones with maximum natural daylight are filled with living spaces; all sanitary and technical services are clustered into darker zones, where the building connects to an adjacent building.

In the context of the Circular Retrofit Lab, three representative functions were selected that have other characteristic functional requirements in terms of space, ventilation, plan lay-out, finishing, services, etc. Hence, a transformation of one function to another will test the reversible concepts and transformation capacity at building level. By selecting very diverging functions, the benefits of the reversible solutions can be demonstrated. At ground level, it was chosen to design a dissemination space so that the BAMB pilot results can be shown and disseminated during the BAMB project.

On the first floor, an eco-guesthouse will be built, which will later on be transformed into a plugin office to test the transformation capacity of the implemented building systems. The selected functions all need different internal organisation, natural daylight and technical services.

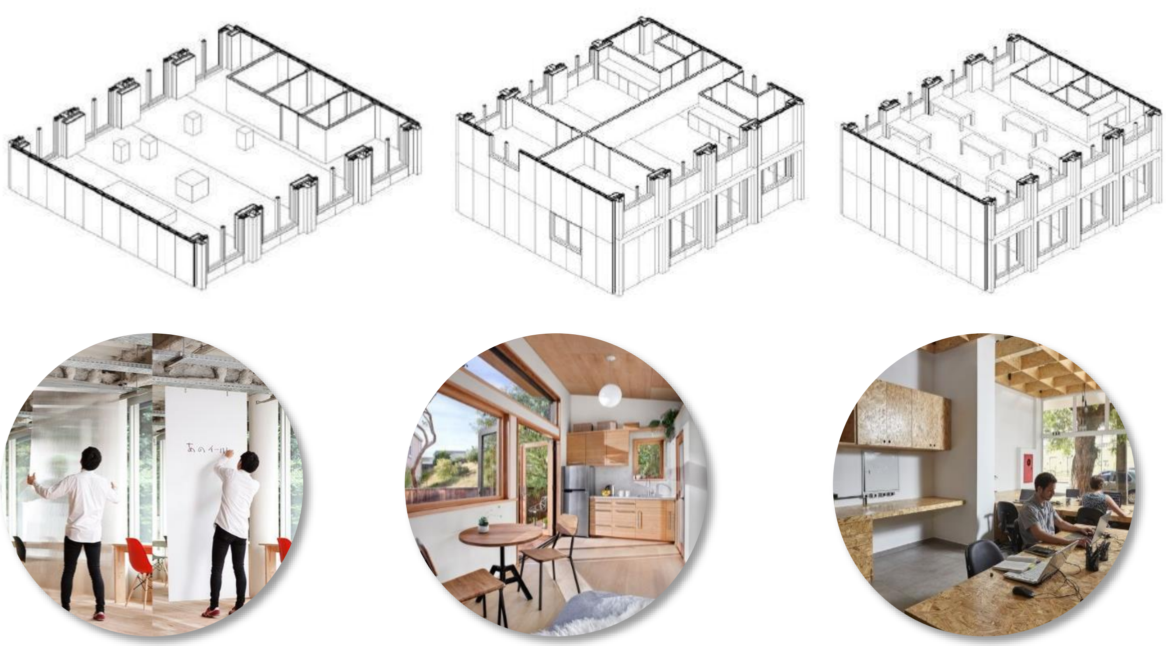

Figure 20: Selected representative functions (left-to-right: dissemination space, eco-guesthouse, plug-in office space).

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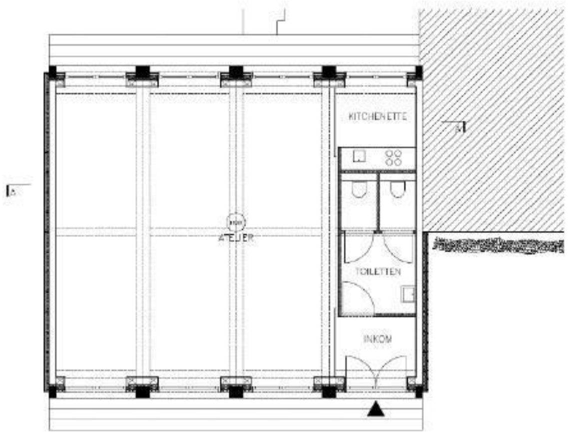

Figure 21: ground floor - dissemination space

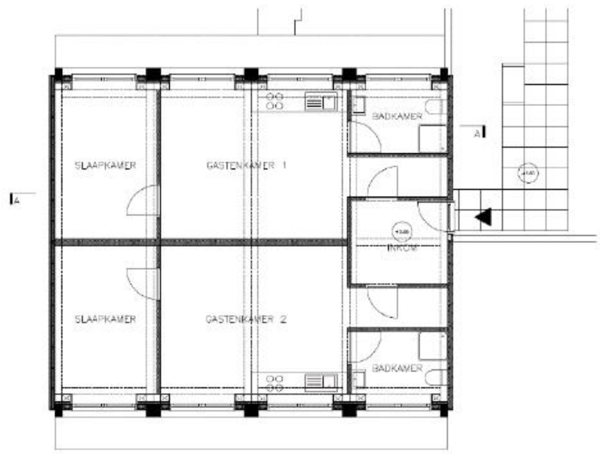

Figure 22: first floor - eco guesthouse

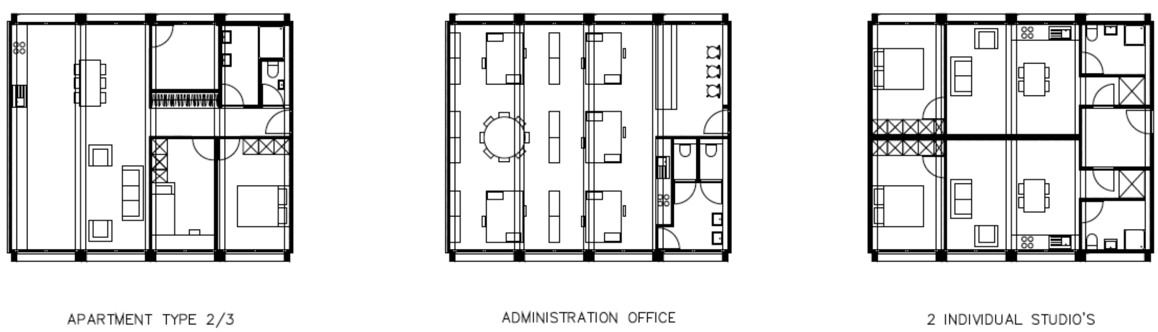

Figure 23: possible transformations

2.5 Building Reversible In Conception (BRIC)

Focus: 1) Reversible Building Design supporting the transformation in shape, size and function.
2) Training different construction professionals in Reversible Building and circular economy.

Type of construction: New construction

Size: minimum size: 55m²; maximum size: 80m²

Function: Office and meeting space (1st Scenario)

Office and meeting space + showroom (2nd Scenario)

Country: Belgium

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 642384.

2.5.1 Description

In Brussels, Belgium, a sustainable and reversible teaching module will be built as part of an education centre – Espace Formation PME (EFP). Construction is one of the important pillars of the EFP's course offerings, providing training relevant to 12 professions of the construction sector. The education centre trains 6500 persons a year, of which one third within the construction sector. The reversible construction education module will allow course offerings to be further enhanced through hands-on experience opportunities.

This pedagogical module will be used as an information and teaching tool through its design, construction, use and deconstruction, integrating the sustainable management of resources and different aspects of circular economy and circular building in the training of future contractors. In 2015, the Brussels Capital Region developed the Regional Plan for Circular Economy (PREC) which focuses on 5 axes, amongst which construction. Within this framework, the EFP aims to integrate circular economy and circular building in their training packages.

The overall objectives of the module are:

1) Investigate and demonstrate the effectiveness and possibilities of circular and dynamic building design

   a) Through the construction of a sustainable and reversible module, the pilot is to investigate and demonstrate Reversible Building Design approaches and techniques. Possible transformations of the building and frequent (dis)assembly of parts of the construction will enable testing the possibilities of circular and dynamic building design.

   b) Improve the recovery value of materials as well as improve maintenance savings by designing for assembly and disassembly. Practical solutions will be designed and implemented with material producers working on the project.

2) Involve local actors and stimulate the circular industry: local architects, (future) contractors, producers and suppliers will be involved in the development and implementation of the project.

3) Education, awareness and training of the future generation of the construction industry.

   Together with other educational institutes (Bruxelles Formation, CDR and Syntra), teaching courses are to be developed.

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The module, consisting of a wooden frame structure, will be constructed, redesigned, deconstructed and transformed yearly. A variety of students (carpenters, masonry contractors, painters, interior designers, electricians, installers of sanitary and heating units …) will be involved in the construction and deconstruction of the module to learn how to implement sustainable materials; disassemble and transform constructions; and better manage resources, materials and products in a circular economy. Furthermore, the module will enable teachers, students and construction manufacturers to investigate together how different products can be implemented. The yearly redesign, construction and deconstruction will also enable the integration of the latest evolving techniques and products in the training module. Therefore, the project will be focusing on:

- Reversible Building Design
- The use of new circular building products/elements and reclaimed/reused products/elements - local producers and continuous loops
- Circular design focusing on high energy performance and the sustainable use of water

After the module is built, it will be temporarily used as a reception desk and information centre to show the used techniques. It will raise awareness and foster circular thinking within the future generation of local construction stakeholders.

2.5.2 Design scenarios and plans

Figure 24: 3D views after first design workshop

The first construction phase (i.e. BRIC 1) will consist of a support office and meeting facilities.

The design of the wooden structure is mountable/demountable, and in a logic of reversibility of the building elements, which allows the reuse of the wood for future modules 2 and 3.

The extensive use of woodworking techniques has been deliberately chosen to give the students the opportunity to work on different types of skeletons: a classical principle of beams and columns, and prefabrication with joining boxes in the carpentry work space.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 642384.

The surface of BRIC 1 is 55m². The interior rooms include a 9,5m² kitchen; a meeting room of 19m² with the space for 10-12 people; a technical room, a compost toilet with a technical space for composting and a carport with an electric plug. The plan also shows the ventilation systems with supply/return by means of an air-air heat pump.

The roof of the large volume is 25° inclined, covered with interlocking roof tiles. These tiles will be purchased on a second-hand network.

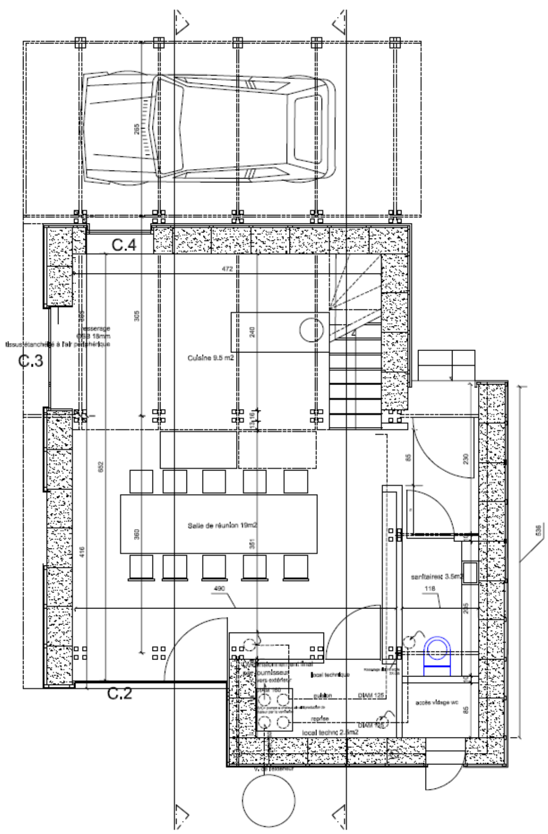

Figure 25: BRIC 1 - ground floor

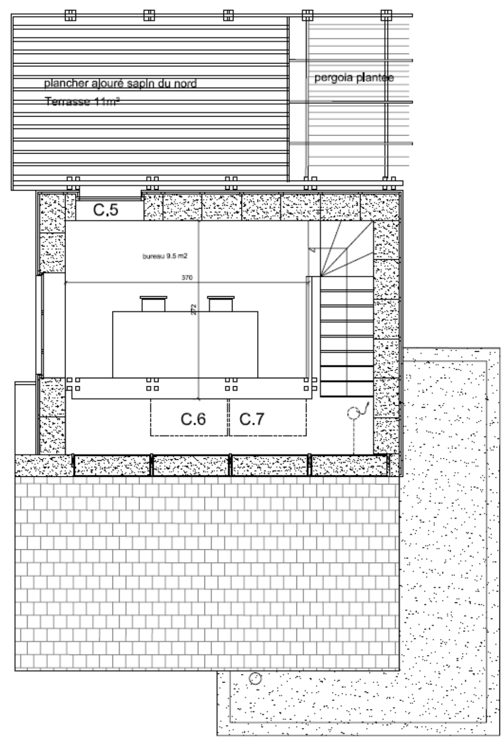

Figure 26: BRIC 1 - first floor

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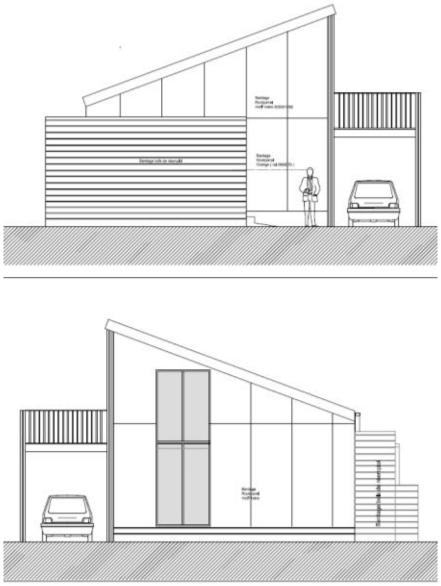

Figure 27: view west-east

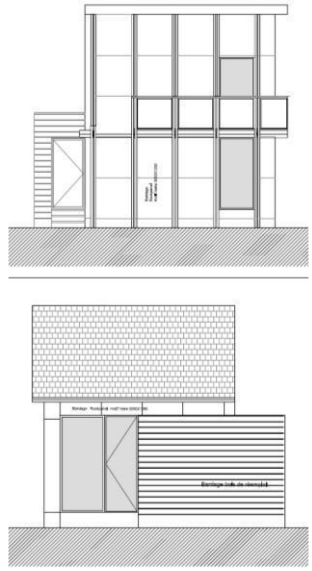

Figure 28: view northeast - southwest

In the second construction phase (i.e. BRIC 2), the BRIC 1 module will be enlarged with a showroom and a complete first floor instead of a carport and a mezzanine. The sloping roof will be transformed into a flat roof enlarging the space of the upper floor. This will generate extra space to organize an exhibition space and a shop for products made within the education centre. Also, there will be extra space for offices on the 2nd floor. The actual materialization of BRIC 2 will depend on the new and continuous collaborations with manufacturers and suppliers, the aim of the pilot being to involve new (innovative) products in the different designs.

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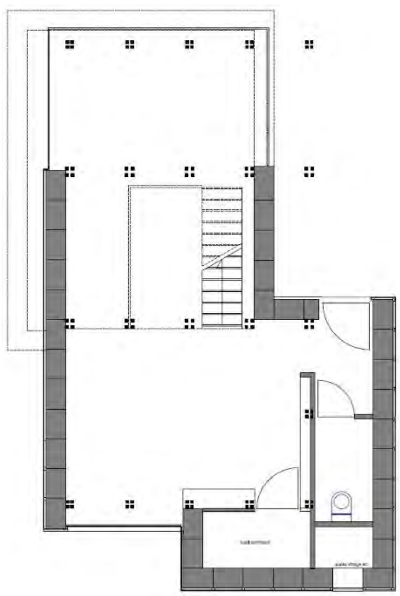

Figure 29: BRIC 2 – ground floor

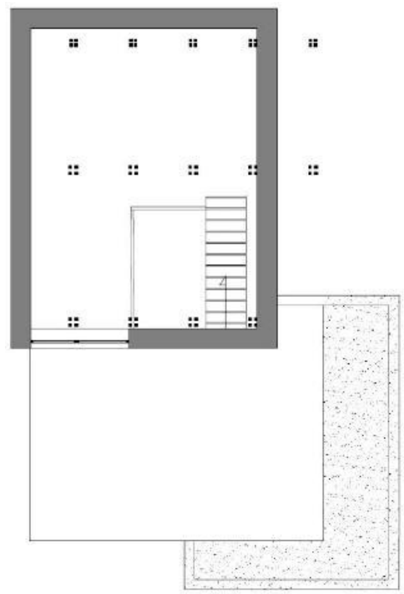

Figure 30: BRIC 2 - first floor

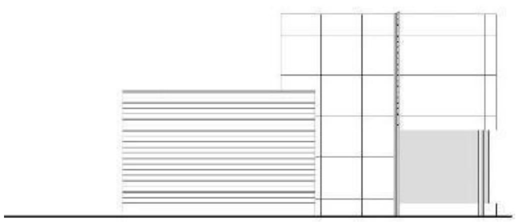

Figure 31: BRIC 2 - east view

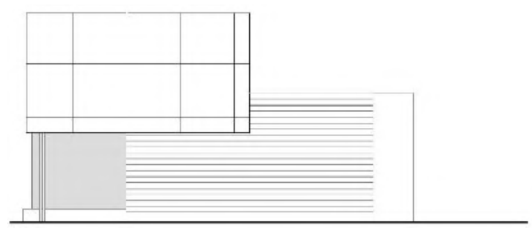

Figure 32: BRIC 2 - west view

2.6 New Office Building

Focus: 1) Reduction of future deconstruction waste through high recycling potential
2) Reversible Building Design supporting flexibility in floor plan configuration and disassembly of facade elements
3) Investigation of business model needs and requirements of the local stakeholders participating in the project

Type of construction: New construction

Size: 9598 m²

Function: Office

Country: Germany

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 642384.

2.6.1 Description

The Pilot Project “new office building” is located in Essen, Ruhr-area in Germany, directly on the UNESCO world heritage site of “Zeche Zollverein”, a former coal mine industrial complex, visited by over 1,5 million people per year. The demolition of pre-existing structures has already taken place (before 2015), and the building client has taken over the site as a prepared brown field. The New Office Building will host over 200 high quality office spaces for the RAG Group. The total gross floor area will be approx. 9598 m^2, with a total gross volume of approx. 38781,87 m^3.

The Pilot Project is developed as a best practice under the current German market standards and regulations, e.g. EnEV 2016[3]. The building will be certified according to the DGNB Standard (German Sustainable Building Council), for which it is intended to reach the highest level (Platinum Standard).

Figure 33 Visualisation of building "Neubau Zollverein", kadawittfeld architecture (Aachen 2016).

[3] Energieeinsparverordnung 2016

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Figure 34: Construction site on "Zeche Zollverein" Essen, Germany.

The project wants to be a pilot for sustainable design with a special focus on the Cradle to Cradle design principles, respecting recyclable design, healthy materials and the use of Materials Passports. Parts of the building are also planned to be accessible by the public (e.g. rooftop garden of approximately 3000 m²).

2.6.2 Design scenarios and plans

The building is shaped as a two-storey design with two courtyards. One of these courtyards is for the office space of the user RAG Foundation. The other courtyard is reserved for the employees of RAG-AG. The multifunctional rooftop garden, which can also be interpreted as a lying eight, is freely accessible via a staircase outside the main building. In the junction between the two parts, an entrance hall with a common reception, cafeteria and community space is situated.

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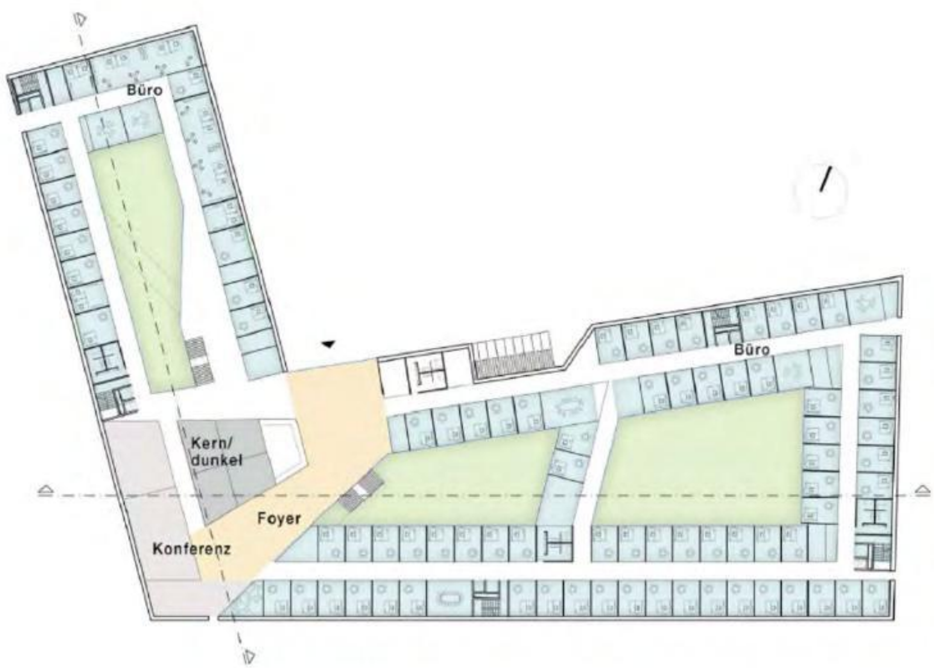

Figure 35: Floor plan ground level. kadawittfeld architecture (Aachen 2016)

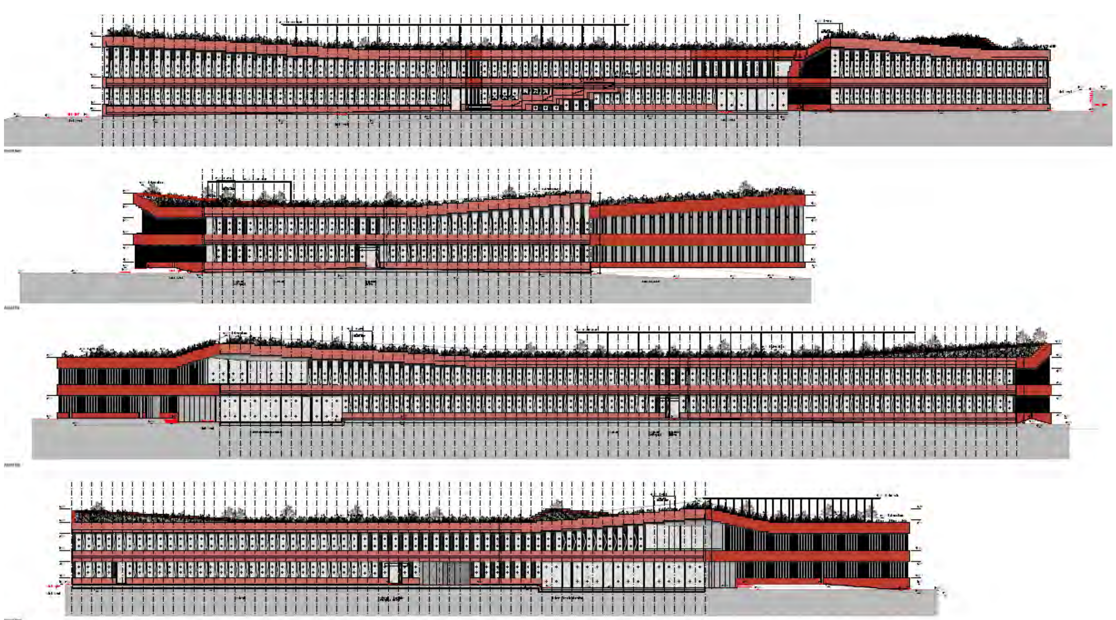

Figure 36: Elevations. kadawittfeld architecture (Aachen 2016)

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As a request of the building client, in the course of the project's design, the goal idea "Building as a Material Bank" was interpreted in the direction of recycling as a transformation scenario. As a consequence, the scenarios for re-utilization were developed only as preliminary forms. The main focus has been on designing the building to guarantee the potential for recycling.

Therefore, the project is focusing on the following main approaches:

1. Use of recyclable products: this requires a strong interaction with the supply chain (manufacturers as well as recycling companies).
2. Design for disassembly and recycling by an appropriate planning approach. This basically reflects what we call "circular engineering" and also includes Reversible Building Design conditions.
3. Each supplier is asked to provide a take-back or end-of-life scenario for his product.

Furthermore, the design enables the inner transformation of the building into different uses. Two potential, theoretical transformation scenarios are presented hereunder.

Scenario 1: In the first scenario, the building will remain an office, but room layout, zoning and the operator models will be fundamentally different.

Scenario 2: In the second scenario, the building's function is being fundamentally adapted. An office building will become a hotel.

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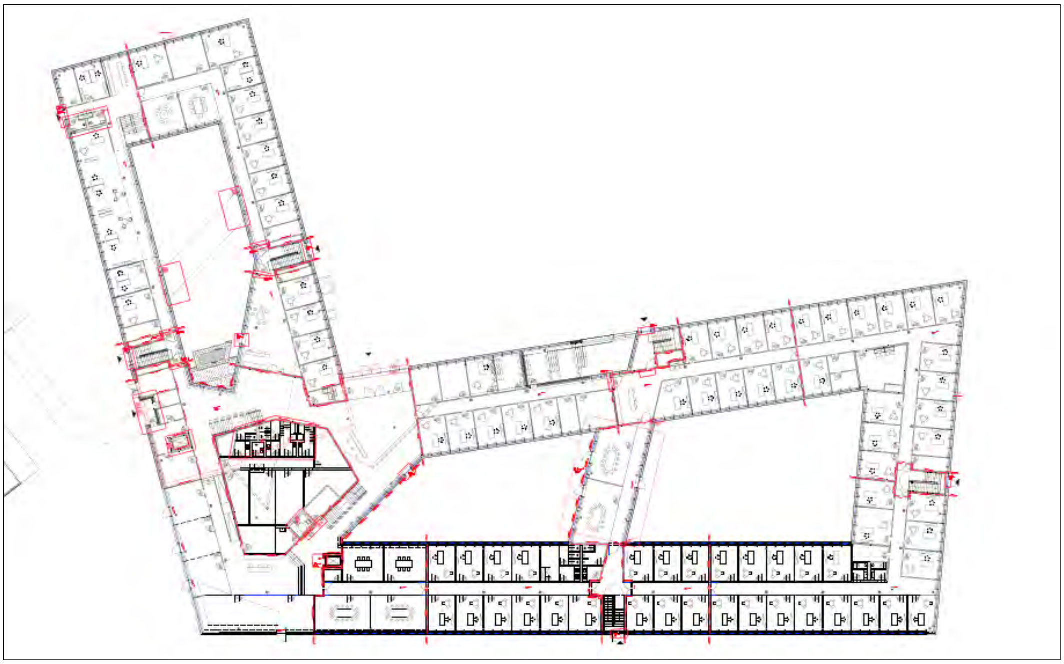

Figure 37: Current floor plan of the New Office Building, kadawittfeld architecture (Aachen 2016)

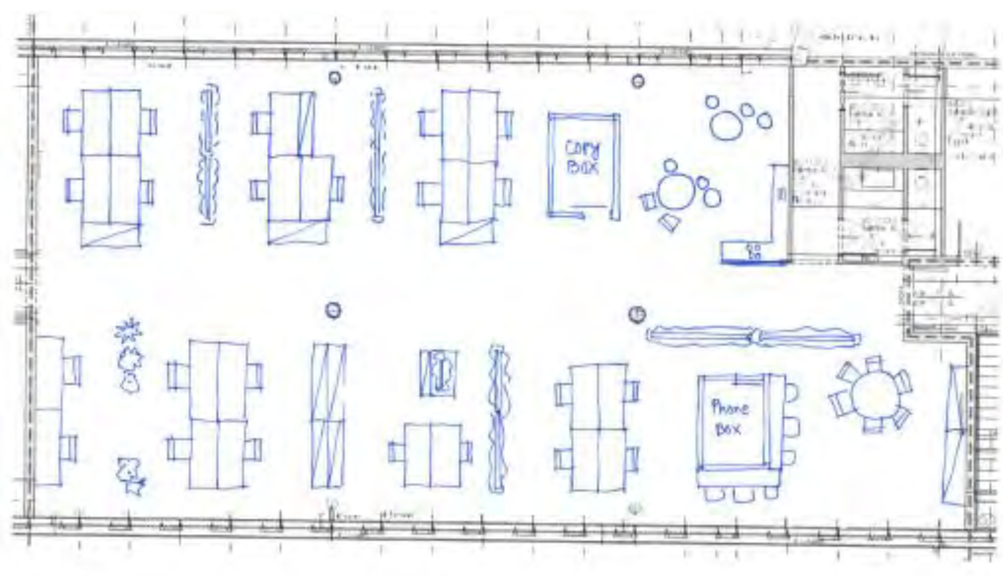

Figure 38: Floor plan scenario 1

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Figure 39: Floor plan scenario 2

These potential transformations are being supported by the design of the internal walls and integrating technical supplies in the floor. The internal walls were defined as transformation clusters. They can be disassembled easily and repositioned at any other place in the building. This can happen without major changes to other parts of the building because the walls have no technical cables or any other connections to functional units, which need to be replaced as well.

The design of the cavity (or hollow box) floor illustrated below enables easily changing the functions and adapting the technical services (water, heating, electricity, etc. supply).

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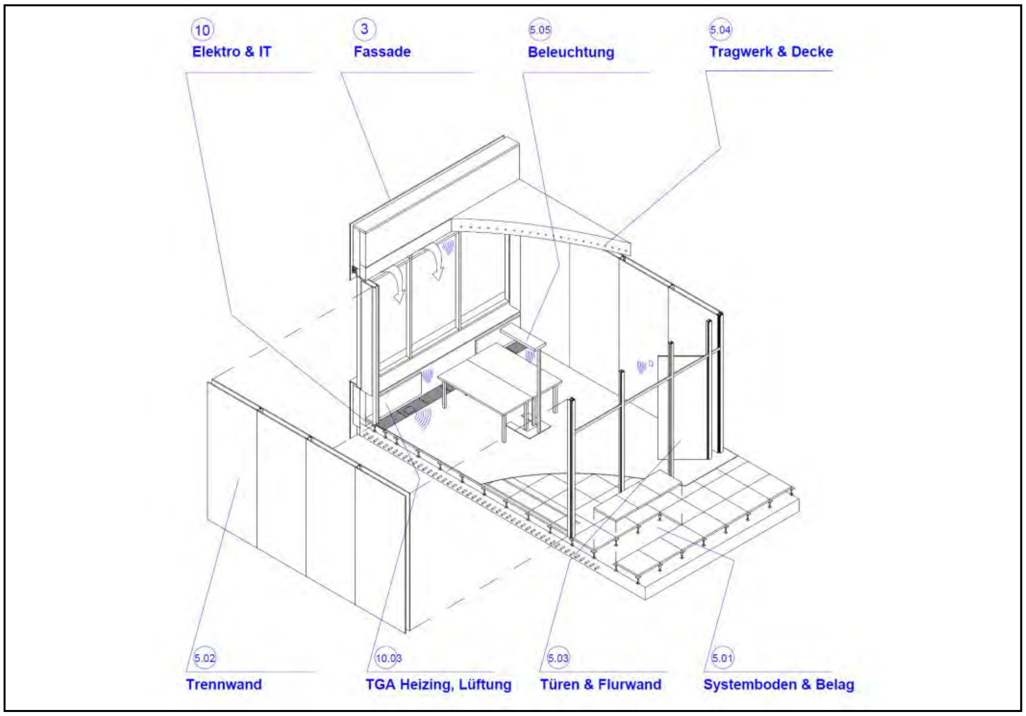

Figure 40: Exploded view of an office cell

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3 Change supporting and reversible building concepts

Within this chapter the different approaches to integrate dynamic and circular building concepts are illustrated. Important aspects regarding Reversible Building Design, Materials Passports and new business models used in the pilots will be discussed.

3.1 Reversible Building Design

***Reversible Building Design** is the design strategy that has the ambition to realise buildings whose parts follow material loops and facilitate building alterations and support changing user needs.*

Emphasising the ability of buildings and their components to return to an earlier state, this strategy strives for high resource productivity. It includes a spatial dimension, in which the building can be efficiently refurbished, as well as a technical dimension, wherein the building's components can be disassembled and reused, or deconstructed and recycled or biodegraded."

In all Pilot Projects, the design guidelines and criteria developed within Work Package 3, focusing on the development of Reversible Building Design tools, have been integrated. The eight design directives developed within the BAMB project are listed below (*add cross reference*). However, there is not a unique way to design buildings for reversibility and disassembly. Different design approaches have been investigated and applied within each of the Pilot Projects. Furthermore, some Pilot Projects actually demonstrate that these design approaches can be combined with each other.

The **8 design directives** developed within Work Package 3 (Reversible Building Design) are listed below:

1) **Functional independence**: separation of functions that have different changing rates and use expectancies
2) **Systematisation**: clustering of elements into an independent module based on functionality, assembly/disassembly, life cycle coordination of elements and their assembly per expected use life cycle
3) **Relational dependency and relational pattern**: minimisation of the number of relations representing functional and technical dependencies between elements within a building
4) **Basic element of the configuration**: design of a basic element that functions as an intermediary between the elements within the configuration
5) **Life Cycle Coordination of elements**: coordination of use and technical life cycle of elements within buildings in relation to their disassembly sequences

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6) **Assembly/disassembly sequences**: allowing for more parallel than sequential assembly within a building
7) **Geometry and morphology**: design the geometry of products' edges that will allow for recovery of elements without damaging themselves or elements, and geometry of products' edges which is suitable for reuse.
8) **Type of connections**: use type of connection that will allow for separation and the easy recovery of elements.
An overview of the different design approaches and construction methods, applied in the different Pilot Projects and the possible combinations is developed below.

3.1.1 Kit-of-parts

The kit-of-parts design approach not only attempts to achieve flexibility in assembly and efficiency in manufacture, but also by definition requires a capacity for deconstruction, disassembly, and reuse. Kit-of-parts structures can be assembled and taken apart in a variety of ways like the well-known construction toy brand, 'Meccano', which is a construction system that consists of reusable basic elements, connected with dry connections, such as nuts, bolts and screws. It doesn't only enable the disassembly of the elements but also the reassembly of the elements according to another configuration, shape and function. In order to enable the reconfiguration of the elements, standardisation in dimensions and geometry of the elements, as well as for the design of the connections, is key. As a result, the detailed design of the elements/ components, as well as their standardisation, requires a longer preparation period and a thoughtful design. The standardisation also easily supports preassembly and prefabrication.

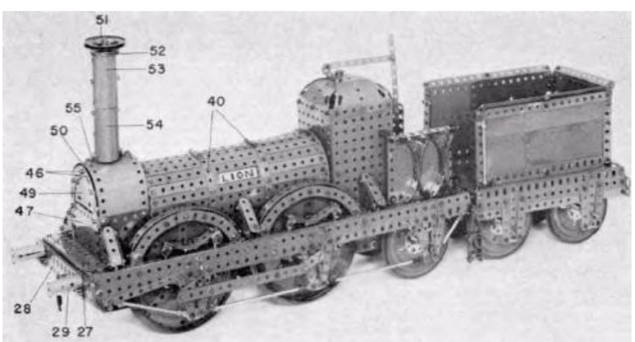

Figure 41: building plan for Meccano train

The **BRIC** pilot is designed as a kit-of-parts building system. It consists of a standardised wood frame structure and prefabricated wooden boxes for the walls, the floor and the roof. All these boxes are standardised prefabricated building elements that will be dry connected to each other with screws, bolts and nuts. The prefabricated boxes are designed to be easily disassembled from

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each other and reconfigured in a different way, but each box can also be disassembled into its basic elements.

The systematic design grid and the composed squared columns and beams enable a versatile/generic use of the floorplan as well as ease of transformation. The standardised dimensions of the grid are key. As the pilot will be assembled and disassembled 3 times, all parts will be numbered and reused in a different building design. Other configurations of the columns, beams and boxes will compose the second and the third module. A numbered building plan, as well as Materials Passports, will make it easy to reconfigure and rebuild the module as well as to maintain and repair where necessary.

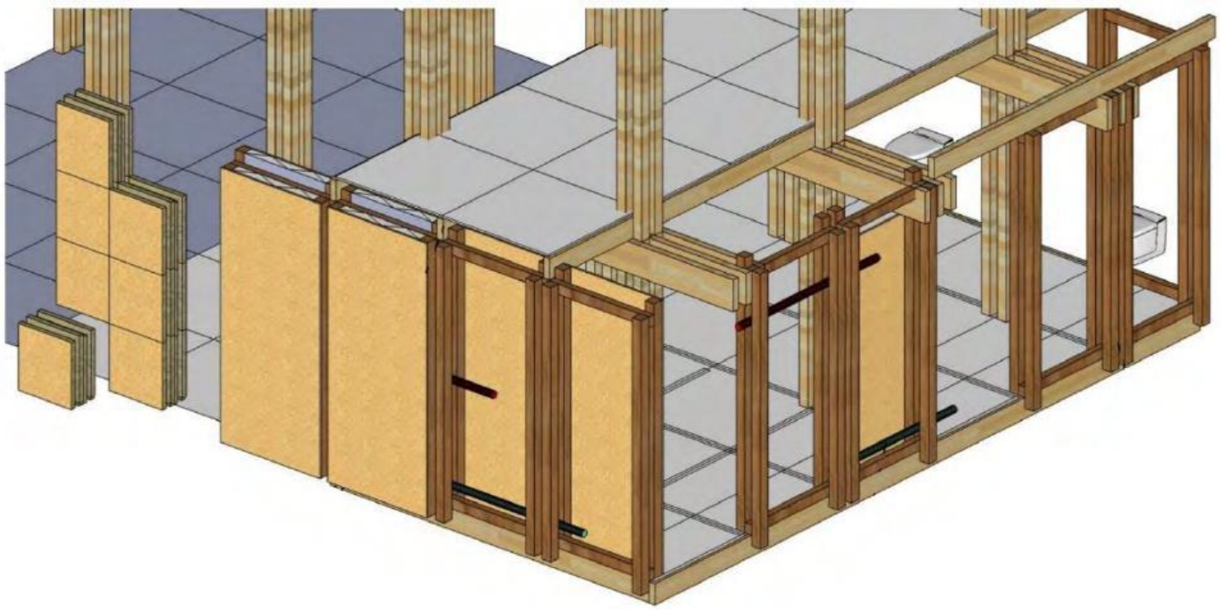

Figure 42: BRIC - prefabricated boxes assembled with dry connected

Within this Pilot Project, specific attention has been given to the design directives (3) Relational dependency and relational pattern; (4) Basic element; (7) Geometry and morphology; and (8) Type of connections.

The kit-of-parts design approach has the advantage of supporting the direct reuse of elements and transformation. However, dismantling every building element to be reused and reconfigured can be time-consuming. In order to reduce the assembly and disassembly time, elements can be clustered into prefabricated modules such as the facade, floor and roof modules (design directive 2). In order to enable the ease of assembly and disassembly by the students of the training centre, the dimensions of the basic components have been standardised.

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3.1.2 Modular

A modular building system is a design approach that can be used to develop complex systems using similar components. These components, also called modules, contain features that make it possible to connect them so that they can form a complex system as a whole. Modular design can be seen as a process for producing modules that can contain different functions, and when coupled, can form a whole that performs a variety of functions. Modular design also emphasizes the minimization of interaction between modules, so that it is possible to produce and use modules individually.

An existing example within the pilots of modular building is the VARIEL system, used by architect Willy Van Der Meeren for the student units at the VUB. These units form the basis for the pilot 'Circular Retrofit Lab'.

However, it has to be emphasised that *modular* building design only, doesn't guarantee change-supporting, nor circular, buildings. Modular building design is often related to prefabricated building components or 3D parts of buildings, which are not always connected to each other in a reversible way. However, the standardized dimensions and the use of a modular design grid – design directives (7) *Geometry and morphology* – and (2) *Systematisation* – is supporting Reversible Building Design when combined with other design directives such as (8) *Type of connections* and (6) *Assembly/disassembly sequences*.

Figure 43: VARIEL System at VUB

The Pilot Project **REM** has been designed as a modular building system. A basic module has been developed and will be repeated at least 15 times and until the desired configuration has been reached. The module is built from a metal frame and wooden panels / fiber board. The different modules are dry connected with each other. The units are re-assembled, and can be arranged in different floor plan patterns. The brown modules in the floorplan (*Figure 45*) show the modules that are necessary to form the minimum exhibition. All white modules can be removed.

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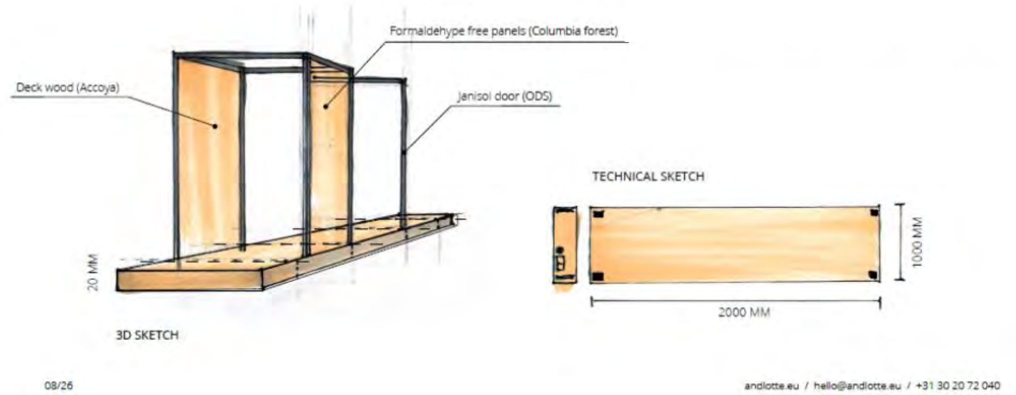

Figure 44: REM - basic building unit

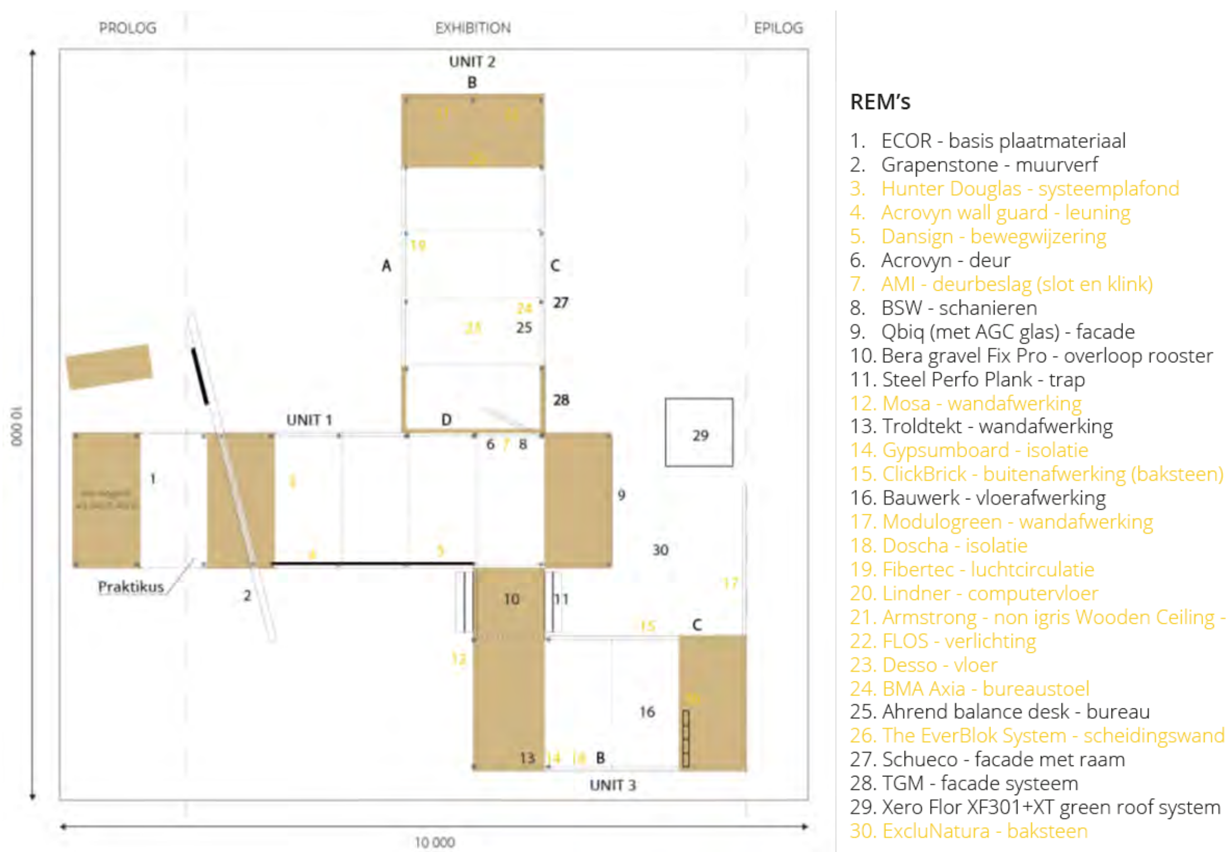

Figure 45: REM - configuration of different modules

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It has to be emphasized that each module can be disassembled into its basic components.

3.1.3 Core & units

Within this design approach, the core is seen as the basis for a Reversible Building. Units can be added to the core, so that the building can be transformed and enlarged integrating multiple functional options. The core is designed to support transformation without major changes to it, thus facilitating adaptation by reducing the time and cost of each transformation.

It is important that the structural core provides sufficient daylight, natural ventilation and has sufficient stability to carry changeable loads when changing function. This approach is similar to the widely spread application of concrete staircases as the structural core in a lot of large scale buildings. However, within a circular and dynamic building approach, the core is designed to also be reversible and transformable so that its elements can easily be reused.

According to the design directive (2) *Systematisation*, the core is clustering technical and functional elements, such as e.g. staircases, elevators, sanitary, technical pipes for electricity, ventilation, heating…

This design approach has been used for the design of the **GTB Lab**. A vertical core structure with horizontal rings for the distribution of services has been developed. The horizontal rings connect four vertical installation ducts. The core is able to support functional changes of the surrounding units. Installation services can be plugged into the horizontal rings enabling the connection of the technical services of the surrounding units. At the same time, units can be developed independently from the main climate and energy net of the core.

The units can be designed according to a modular and kit-of-parts design approach.

The core has been designed to carry main structural loads, has the capacity to integrate and distribute technical services with easy accessibility, provides access to natural light to all spaces and provides natural ventilation for all spaces. Finally, it supports different spatial configurations accommodating different functions.

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Figure 46: GTB Lab - ground floor core

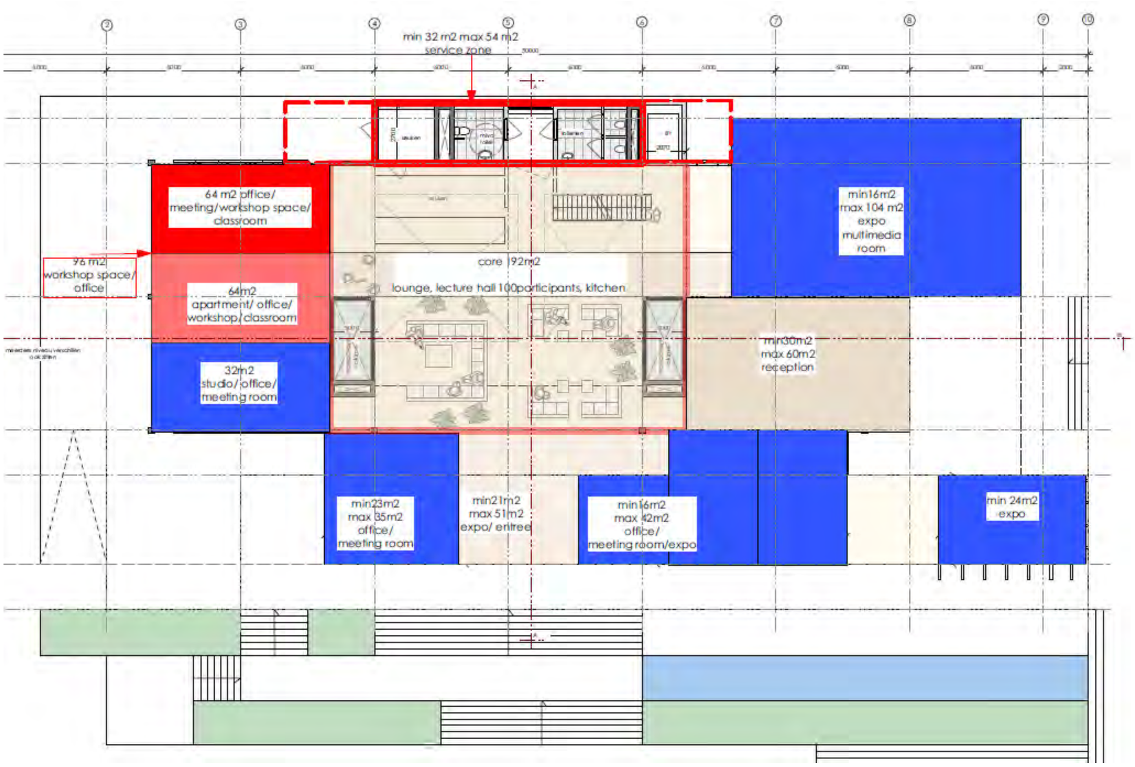

Figure 47: GTB Lab - ground floor core + units presenting the minimum floorplan (red units) and maximum floor plan (bleu + red units)

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For the design of the **Green Design Centre**, a core construction with a raised floor for flexible integration and adjustability of the technical services is foreseen. Vertical portals will provide the vertical distribution of techniques and will function as the loadbearing part of the core of the first floor. For the first transformation, several units will be used to extend the Green Design Centre. The primarily exhibition space will be rearranged into meeting/office spaces. On the ground floor, a workshop space connected with the outside terrace will be developed.

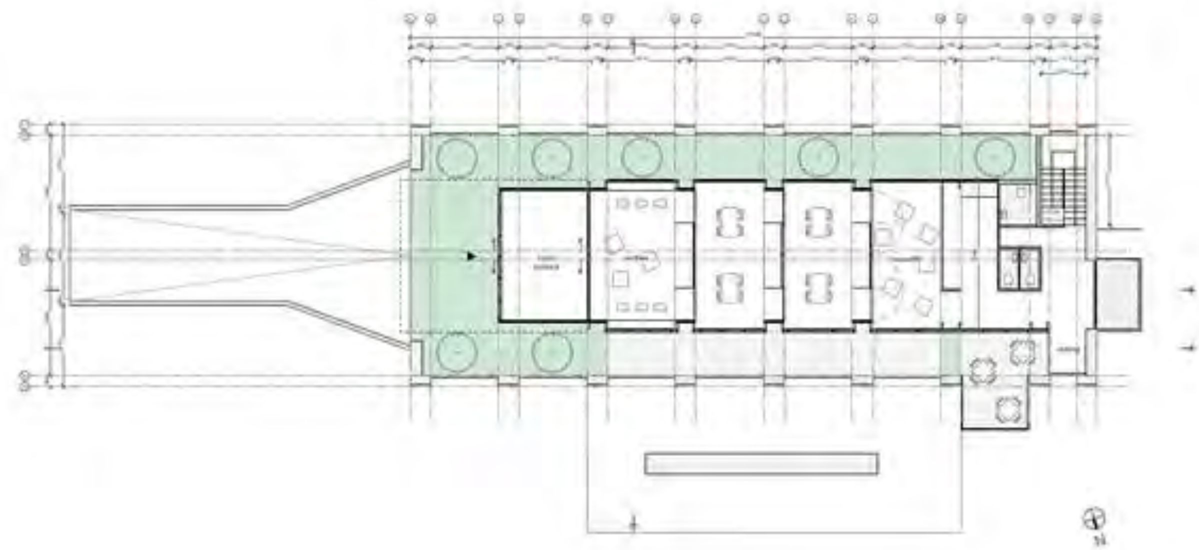

Figure 48: GDC – floor plan core

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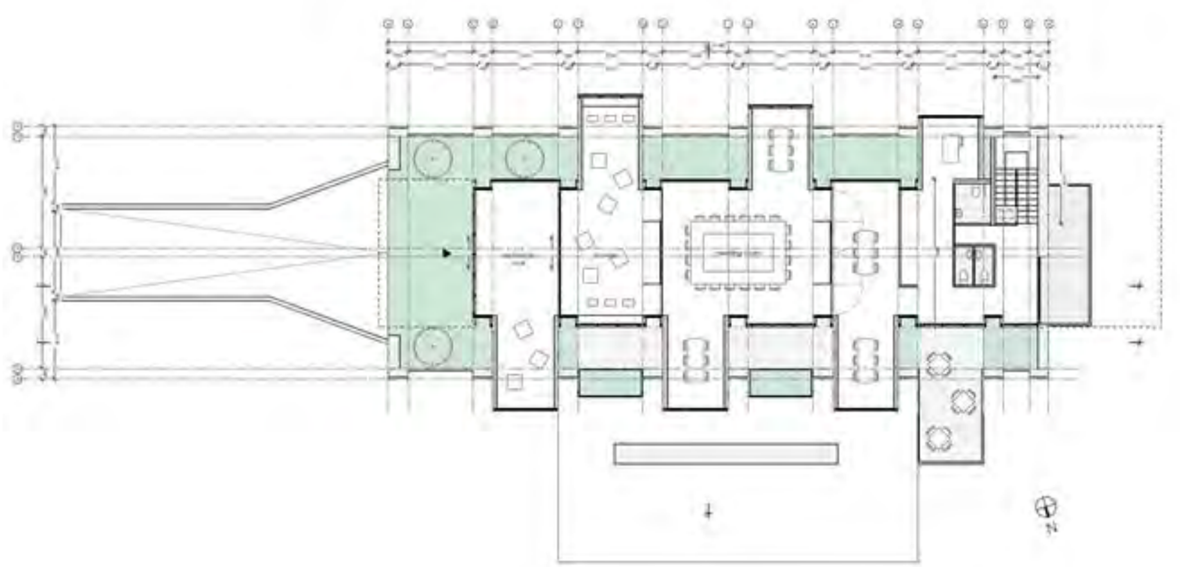

Figure 49: GDC – floor plan core + units

Clustering technical functions and technical devices in a core offers the advantage to facilitate the technical transformation of units surrounding it. As a result, the transformations are less time-consuming, supporting frequent transformation and enabling the building to meet the changing requirements in a qualitative way.

3.1.4 Support & infill

A basic and structural framework of beams and columns is the base for the design. The frame ensures the bearing function and has a more permanent character, whereas the infill wall serves to separate inner and outer space, filling up the boxes of the outer frame. The bays of the frame are infilled with walls that may or may not be mechanically connected to the frame. The infill are non-load bearing and transformable. The frame and exterior infill have the same thermic and acoustic performances.

The Frame and infill approach has been followed for the refurbishment of an existing modular system of the **Circular Retrofit Lab**. The existing student units will be stripped down to the frame. The concrete frame will be the basis of the pilot. A flexible infill system has been developed for the inner and the outer walls. Both wall systems have been designed according to a kit-of-parts approach enabling the wall elements to be easily adapted to the different technical requirements.

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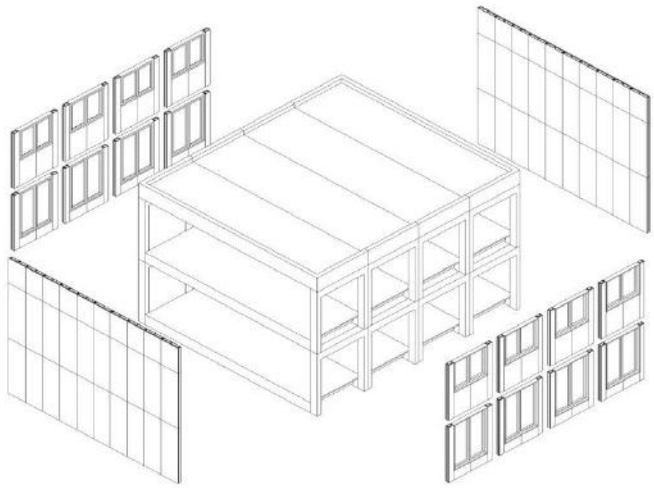

Figure 50: Circular Retrofit Lab - frame + exterior infill

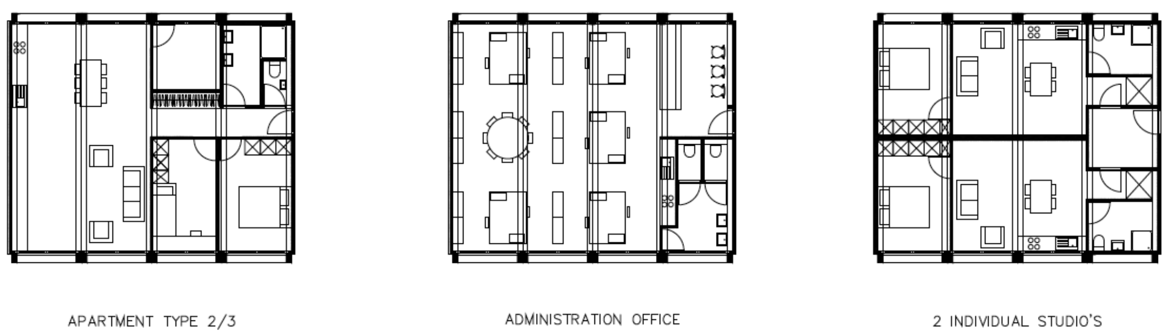

Figure 51: Circular Retrofit Lab - frame + different interior infill possibilities

The pilot **New Office Building** is designed to comply with changing usage requirements. It has a support grid that is loadbearing. The interior and exterior infill is designed according to a flexible floor and facade plan and can be transformed. The open-format offices are designed independently of the facade, the interior wall system and technical installations.

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Figure 52: New Office Building – different interior infill

3.2 Materials Passports

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.

They are a marketplace mechanism 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.

3.2.1 Products with Materials Passports

During the feasibility phase of the Pilot Projects, the Materials Passports platform was still under construction. The collection process was then conducted based on the input workbook developed as part of Work Package 2 (Materials Passports). Each pilot leader selected between three to five construction products for which a Materials Passport is being developed.

An overview of created passports, within each of the six Pilot Projects, is shown in the following table. Combinations of different types of products (e.g. window systems, doors, heat pumps, insulation) were selected to gain an understanding in the varying data requirements.

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Pilot	Product	Product name	Manufacturer
Green Transformable Building Lab / ZUYD	Light installation	Unknown	AMMANU
	Aerogel-based insulation sheet	bluedec®	bluedec®
	Thermally-insulated steel system for mullion/transom constructions	Viss	Jansen AG
	Window	Unknown	NSG Group - Pilkington
	Groen	Unknown	Woltering Group
Reversible Experience Modules (REM) / EPEA	composite stone window frame	Holonite	Holonite B.V.
	Bio based thermal insulation	Doschatherm	Doscha
	LEDlight armature	BB Light LEDpipe ECO	BB Light Concepts
	Doors	Acrovyn Doors	Construction Specialties
	Signing system	plansign	Dansign
Green Design Centre Building / SGDF	Heatpump	Unknown	AlfaTherm
	Wood-aluminium window	75DA	Feal
	Wood cluster	Unknown	Mostar
	Sheep wool	Unknown / Wool line	Sheep wool
	HEA steel profile	Unknown	Unknown
Refurbishment Lab / VUB	Textile floor covering	DESSO Airmaster	Desso B.V.
	Partition wall structure system	GIS	Geberit AG
	Injected insulation	Insulsafe Plus	Isover Saint-Gobain
	Decentralised ventilation unit	ComfoAir 70	Zehnder Group
BRIC / IBGE	Facade cladding	Rockpanel	ROCKWOOL B.V. / ROCKPANEL Group
	Wooden structure	Chimsco	Chimsco
	Floor structure: slab of clay	Béton de terre	Béton de terre
New Office Architecture / Drees & Sommer	Floor system - raised access floor	NORTEC	Linder Group KG
	Thermally insulated mullion / transom façade system	FWS 50.SI	SCHÜCO INTERNATIONAL KG
	Aluminium window	AWS 75.SI+	SCHÜCO INTERNATIONAL KG
	Ecological bituminous sheeting	Climavine®	W. Quandt GmbH & Co. KG
	Mounting System with rails, brackets, assembly pieces and pipe clamps	Varifix	Würth Group
NexusHouse / TUM	Gypsum board	DensGlass® Sheathing	Georgia-Pacific Gypsum LLC
	Ceramic floor tiles (unglazed)	Terra Maestricht	Royal Mosa
	Gutters and downspouts	prePATINA form PATINA line (colour: blue grey or graphite grey)	RHEINZINK GmbH & Co. KG
	Indoor wall painting	ECODOMUS MATTE from ROMABIO	ROMA Eco-Sustainable Technologies
	Window Wall	Series 600	Western Window Systems

Figure 53: Overview of created passports for the Pilot Projects

The development and use of Materials Passports is further detailed for 2 Pilot Projects.

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REM

The REMs main focus is to demonstrate and test Materials Passports. Therefore this exhibition module will consist of at least 30 physical building products, for which Materials Passports are developed. Another 40 Materials Passports will be developed for building products exposed through posters or other visualizations.

One of the intentions of the REM pilot is to aid visitors in understanding Materials Passports by demonstration. Visitors of the pilot learn about products or interact with them. Through a handheld device the passports related to the products in the pilot can be assessed. This will be combined with a use scenario perspective, taking into account the latest developments in Work Package 2 on the specific subsets of data relating to certain users, in turn generating important feedback for Work Package 2 on refining the subsets on users, value propositions and potentially build phases. Passports are thus an integral aspect in the design of this pilot.

The demonstrated products (REMs) will illustrate both the reversibility of the product, as well as the possibilities of the Materials Passports.

As a result of collaboration between Work Package 2 and the REM pilot, the data sets for five of its products have been generated. The lessons learned from this will be taken into account in the development of the data and metadata carried out during the continuous modification and updating of the framework, software and Materials Passports of Work Package 2. The interaction of the REM pilot with Work Package 3 (Reversible Building Design) in regard to its design for deconstruction already in this phase provides insights in the aspects of the passports relating to products in their context and location in a building. Looking at a specific example of a data set collected for one of the products of the REM pilot – BB-lightconcepts LED lightpipe – the data set enables learning how the product is designed for easy (de)installation, or taking the product 'into/out' of the building, and for (dis)assembly, or putting together/taking apart the product, which are some of its most important USP's.

Materials Passports also provide interesting information on the agreements between the manufacturer/supplier and the building owner/occupant for recovering value from the product(s). In the case of the BB-lightconcepts LED light pipe, 20% of the market price of the aluminium will be paid back by BB-Lightconcepts on return of the product. No fixed estimate or absolute amount is given.

Statements in the data sheet are backed up by supporting documents such as a Technical Approval containing technical information about the products such as generic material composition, dimensions, and technical specifications such as the light color and dim range. Key aspects such as the fact that it is Cradle to Cradle certified, its protection class and vandal

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resistance are also highlighted here. Other possible attachments are the Cradle to Cradle certificate supporting statements about reuse potential and material health, and a marketing brochure highlighting relevant product properties and USP's, including that a product is maintenance free, easy to install and many other aspects.

Furthermore, the visitor will be invited to disassemble the product and re-assemble it, so they can experience in real time the reversible possibilities of a product. Through a chip system, it will be possible to test and learn about the Materials Passport of a product.

The passports will provide the instructions for disassembly and re-assembly. For example, in the passport, the type of connection to the direct environment is pointed out. In addition, the passport mentions which components within the product are detachable from others, thus visitors understand by reading/viewing the passports which parts of the products in front of them they may take out. This information is not directly readable from a product alone, the passport is an integral part of the exhibition in the sense that it is necessary to reveal the reversibility of the products per se as well as within the building. Take-away cards at the entrance of the exhibition will be provided for visitors, with questions printed on them concerning the material content and reversible features of the products on display in the exhibition. The answers to these questions can only be found by consulting the Materials Passports of the products.

New Office Building

The pilot 'New Office Building' has integrated the concept of Materials Passports in the development of the project. Since the construction of the New Office Building was planned for May 2016, it was not possible to wait for the development of the Materials Passports Platform. At the same time, there were aspirations to build onto the existing processes of planning and construction in Germany and to view the Materials Passport as a consistent and evolutionary development of existing systems. Therefore, an online instrument that had already been developed by Drees & Sommer has been used, combining a) the component catalogue[4] of building physics and b) LCA (Life Cycle Assessment) – focusing mainly on energy related aspects. This online tool has been extended to include some of the BAMB attributes such as material health /building biology; recyclability / reparability; transformation / reuse potential; resource value potential.

[4] The component catalogue, as known traditionally in Germany, is a document summarizing all relevant standard details of the building in a document. It is basically used by the building physicists to secure energy standards and referred to by other planning disciplines.

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However, the developed tool is composed of less parameters than those integrated in the BAMB Materials Passports developed within Work Package 2, reducing the potential for recovery and reuse. The client and user of the building required the development of a tool that enables him to have an overview of all the materials and products within the building as well as their potential for recovery. Therefore the Materials Passports are approached from a building level compiling Materials Passports information for the whole building.

The lessons learned from the use of this tool enable to improve and update the BAMB Materials Passport Framework, Materials Passport Platform and Materials Passports developed within the framework of Work Package 2.

Furthermore, the compilation of the product information for a whole building in this project can help to inform the development of the Building Level Integrated Decision Making Model and BIM Resource Productivity Prototype which are combining Reversible Building Design criteria and Materials Passports to support the resource productivity of buildings.

Furthermore, it has also to be emphasised that the online tool developed by Drees & Sommer is building upon the German component catalogue which is providing a large part of the required information and thus less suitable to be used in other countries.

3.3 Circular business models

In the current, linear economic system a take-make-waste approach is apparent, in which natural resources are used to create a product, which ends as landfill or is incinerated after use. This linear system uses certain, well-known, business models, generally described as 'transactional business models'. The most recognized example is selling, where a product changes ownership from manufacturer to consumer upon sale. (based on van Renswoude et al. 2015, Circular Business Models – Part 1: An introduction to IMSA's circular business model scan). A circular business model describes how companies can generate revenue or make profit, including the way it operates and finances its activities, within a circular economy.

Uncommon to the business models typical of a linear economy, circular business models describe how, for example, offering services, leasing components and taking back materials are profitable activities. Therefore, the models should identify, in the idea of a circular economy, the cost of those activities and the (market) value of the involved components and materials."

3.3.1 Circular business approaches

In the **New Office Building** pilot, a tender document was created, where the manufacturers were asked to provide a set of information on the products they want to use. An extra clause was added to the tender document, in which each supplier was asked to provide a take-back or end-of-life

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scenario for its product. A reporting table was prepared that the manufacturers had to fill out. The answers could be classified as follows:

- No answer. Manufacturers do not provide any information on take back or recycling
- Manufacturers provide a waste key according to AVV[5] (this is the most common answer).
- Manufacturers provide an idea for a recycling pathway, but do not offer a specific solution.
- Manufacturers provide a take back system via service provider (e.g. Aluminium A/U/F initiative, PVC recycling initiative, Interseroh for electric components, etc.)
- Manufacturers provide their own take back system (e.g. Lindner, Desso, Würth, etc.)

Even though there was no completely new business model conducted in the pilot 'New Office Building' a lot of discussions took place in that field. A couple of manufacturers which where integrated in the project started thinking about new models and agreed to offer them for any new project.

- Lindner raised floor NORTEC, C2C Certified Silver: A take back system is offered already. The company can also offer the product as a leasing system. The double floor can be dismantled easily. The floor panels can be refurbished or recycled within Lindens plant in Dettelbach, Germany.
- Schueco International KG, Aluminium facade, C2C Certification Silver: The Pilot Project was the first building using the new Schueco C2C Certified facade. While the chosen business model is conventional, Schueco is now preparing to offer a facade as a leasing system as well. However the German legislation makes it difficult to do so. The consulting of legal experts is in progress.
- Adolf Würth GmbH & Co KG, Varifix: The Würth GmbH now offers a take back system for their VARIFIX mounting system.

As one of the main results of the discussion with the manufacturers, suppliers and real estate finance experts, the following conceptual graph was developed, summarizing the principles of BAMB for manufacturers and clients.

[5] The European Waste List (EWL), which governs waste designations for all EU member states, mainly classifies waste according to source of generation. The list was transposed into German law via the Waste Classification Ordinance (Abfallverzeichnisverordnung - AVV). The purpose of waste classification, which involves assigning a given waste to a waste type and a waste identification code, is to harmonize the designations for all types of waste in the EU. A given waste's classification also defines its hazardousness, which in turn governs the register and reporting obligations for all waste disposal actors. (http://www.umweltbundesamt.de/en/topics/waste-resources/waste-management/waste-types/waste-classification)

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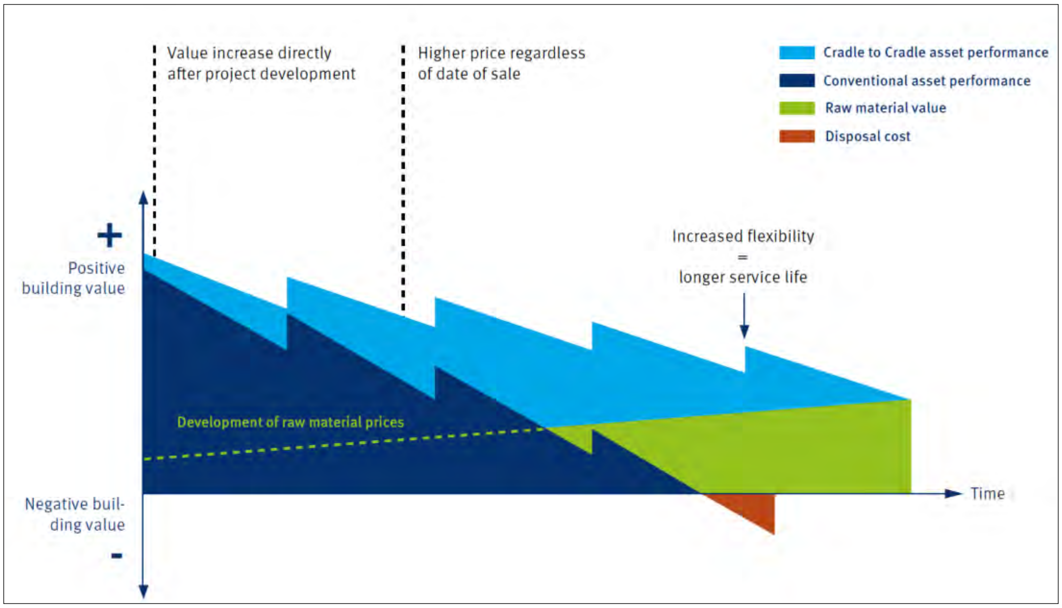

Figure 54: Development of the buildings asset (without site)

The graph shows a comparison of the asset performance of a conventional property (building fabric excluding site) with a building designed in accordance with C2C principles and a Reversible Building Design approach: Both buildings fall in value over the years as the quality of the building fabric deteriorates. However, in contrast to the conventional building – which at some stage may even enter negative territory of value because the hazardous materials it contains have to be disposed of at considerable expense – the residual value of the raw materials in the Reversible Building is retained, or may even increase in the event of a long-term positive price development. The value increase is present immediately after project development and at any point when the property is sold. In addition, when designed according to Reversible Building Design principles the building has a longer service life as the result of its transformation capacity.

Within the **BRIC** Pilot Project, all stakeholders were asked if they were interested in the implementation of new business models. All other stakeholders were interested, however, the following concerns and doubts were expressed:

- No/limited knowledge on circular business models: manufacturers and suppliers don't know if it is possible to e.g. lease their products/ set up a take back system.
- No/limited knowledge on the financial aspects of their products: how much is their product worth on a monthly base (amount to ask for leasing their product), what is the residual value of their product after 1-2-3 years... Manufacturers don't know how to apply leasing contracts.
- No/limited logistics or room at/near their facilities to store used materials.
- No/limited reliable market to resell the used materials.

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- No certifying system to recertify the used materials, so energy or technical performances can be guaranteed.

As a result, most of the providers saw the development of the BRIC Pilot Project as an opportunity to experiment and learn about the above mentioned points.

This was amongst others the case for a Belgian company providing and installing solar panels, who agreed to provide the photovoltaic solar panels and the maintenance of the panels during the time of the project (4 years) for free. The same type of agreement was made for the electrical home automation equipment and access control. During the project, they will also provide the maintenance of their equipment. The small size of the module limits the investment cost while enabling the gain of insights in the different innovative aspects related to circular business models.

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4 TECHNICAL ASPECTS

This chapter focusses on the technical aspects in regards to Reversible Building Design investigated by the different Pilot Projects. The technical aspects related to the design and construction of Reversible Buildings have been separated into two levels:

- The building level comprising spatial reversibility, the functional requirement and the impact of technical systems on Reversible Building Design. The building level will be illustrated based on two Pilot Projects: the GTB Lab and the Circular Retrofit Lab;

- The element/system level which has been subdivided according to the layer structure developed by Brand: foundations, structure, skin and partitioning walls (space plan).

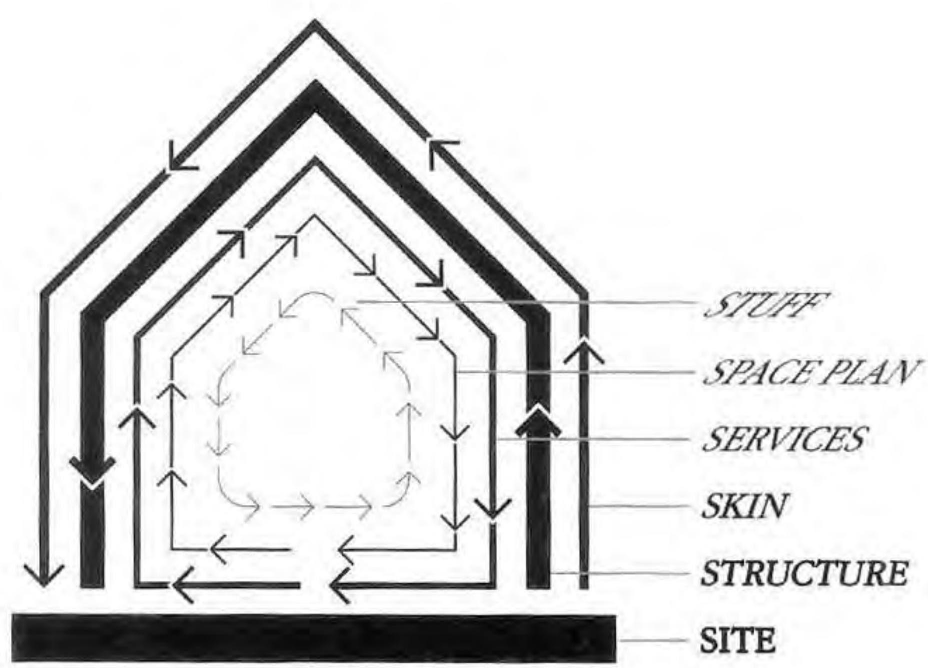

Figure 55: Layers of change – Stuart Brand (1994)

4.1 Building level

The functional requirements for the **GTB Lab** have focused primarily around spatial requirements for three functions: housing, offices and education. In order to meet these requirements, optimisation of width and length of the minimum spatial module has been investigated in order to ease the change of function. The spatial parameters have been analysed in

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relation to the construction method applied and the height. After extensive typological analyses, a space of 6x6m², which is the minimal spatial module, has been identified as the space that can accommodate all three functions.

GTB Lab spatial requirements

	Scenario 0: Core/Carrier of tranformation model			**Scenario 1:** Education and research facility for dynamic and circular buildings			**Scenario 2:** Education and research facility for dynamic and circular buildings			**Scenario 3:** Education and research facility + office hub for dynamic and circular buildings + appartments			**Scenario 4:** Education and research facility		
	Function	**nr**	**m2**	**Function**	**nr**	**m2**	**Function**	**nr**	**m2**	**Function**	**nr**	**m2**	**Function**	**nr**	**m2**
VARIABLE				teamwork/mini classroom space	1	30	teamwork/mini classroom space	2	30	teamwork/mini classroom space	2	30	teamwork/mini classroom space	2	30
							office space	2	15	open office space for 20 work places	1	160	office space	2	15
	Subtotal		*0*	*Subtotal*		*30*	*Subtotal*		*90*	*Subtotal*		*220*	*Subtotal*		*90*
	vertical circulation for people		0	vertical circulation for people	1	15	vertical circulation for people	1	30						
	Subtotal		*0*	*Subtotal*		*15*	*Subtotal*		*30*	*Subtotal*		*0*	*Subtotal*		*0*
				apartment/studio with possible integration into one and extendibility in the second phase to 160m2 (internal transformation scenarios of appartment units)	2	35	senior appartment (internal transformation scenarios of appartment units) (1st/2nd floor)	2	70	senior appartment (internal transformation scenarios of appartment units) (1st/2nd floor)	2	70	senior appartment (internal transformation scenarios of appartment units) (1st/2nd floor)	2	70
							senior appartment (internal transformation scenarios of appartment units) (1st/2nd floor)	1	120	senior appartment (internal transformation scenarios of appartment units) (1st/2nd floor)	1	120	senior appartment (internal transformation scenarios of appartment units) (1st/2nd floor)	1	120
							appartment	1	115						
	Subtotal		*0*	*Subtotal*		*70*	*Subtotal*		*375*	*Subtotal*		*260*	*Subtotal*		*260*
FIXED	public lounge (meeting, lecture, exhibition) with attached snack, coffee, copy, wifi facility	1	70	public lounge (meeting, lecture, exhibition) with attached snack, coffee, copy, wifi facility	1	70	public lounge (meeting, lecture, exhibition) with attached snack, coffee, copy, wifi facility	1	70	public lounge (meeting, lecture, exhibition) with attached snack, coffee, copy, wifi facility	1	70	public lounge (meeting, lecture, exhibition) with attached snack, coffee, copy, wifi facility	1	70
	Subtotal		*70*	*Subtotal*		*70*	*Subtotal*		*70*	*Subtotal*		*70*	*Subtotal*		*70*
	technical spaces including vertical installations	1	20	technical spaces including vertical installations	1	20	technical spaces including vertical installations	1	20	technical spaces including vertical installations	1	20	technical spaces including vertical installations	1	20
	storage	1	10	storage	1	10	storage	1	10	storage	1	10	storage	1	10
	toilet groups	2	15	toilet groups	2	15	toilet groups	2	15	toilet groups	2	15	toilet groups	4	15
	green garden 1st floor			green garden 1st floor			green garden 1st floor			green garden 1st floor			green garden 1st floor		
	energy/climate roof			energy/climate roof			energy/climate roof			energy/climate roof			energy/climate roof		
	water storage below deck			water storage below deck			water storage below deck			water storage below deck			water storage below deck		
	Subtotal		*60*	*Subtotal*		*60*	*Subtotal*		*60*	*Subtotal*		*60*	*Subtotal*		*90*
	Total		**160**	**Total**		**260**	**Total**		**625**	**Total**		**610**	**Total**		**510**

Figure 56: GTB Lab - functional requirements

The design for the different scenarios has been defined based on the functional requirement, design based research focusing on volume dimensions, the positioning of the core, the required capacities to carry loads and provide space for services, taking into account the desired upgradability and use scenarios. Furthermore, the design of the core has been refined in order to guarantee sufficient natural light and air provision for all defined functional scenarios.

The different stages of the GTB Lab transformations are presented with different colours in the Figure 57: 3D decomposition illustrating the different scenarios. The figure left shows technical decomposition of the core elements and their hierarchy in the first stage of construction. The linear service core and the two air and light chimneys are connected by a horizontal ring that distributes technical services between the vertical cores (marked as green boxes in the 3D model).

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The figure to the right illustrates the different stages of transformation presented in grey, yellow and red colours, positioning the different spatial units around the core throughout time. The figure shows which parts of the building are affected by changes.

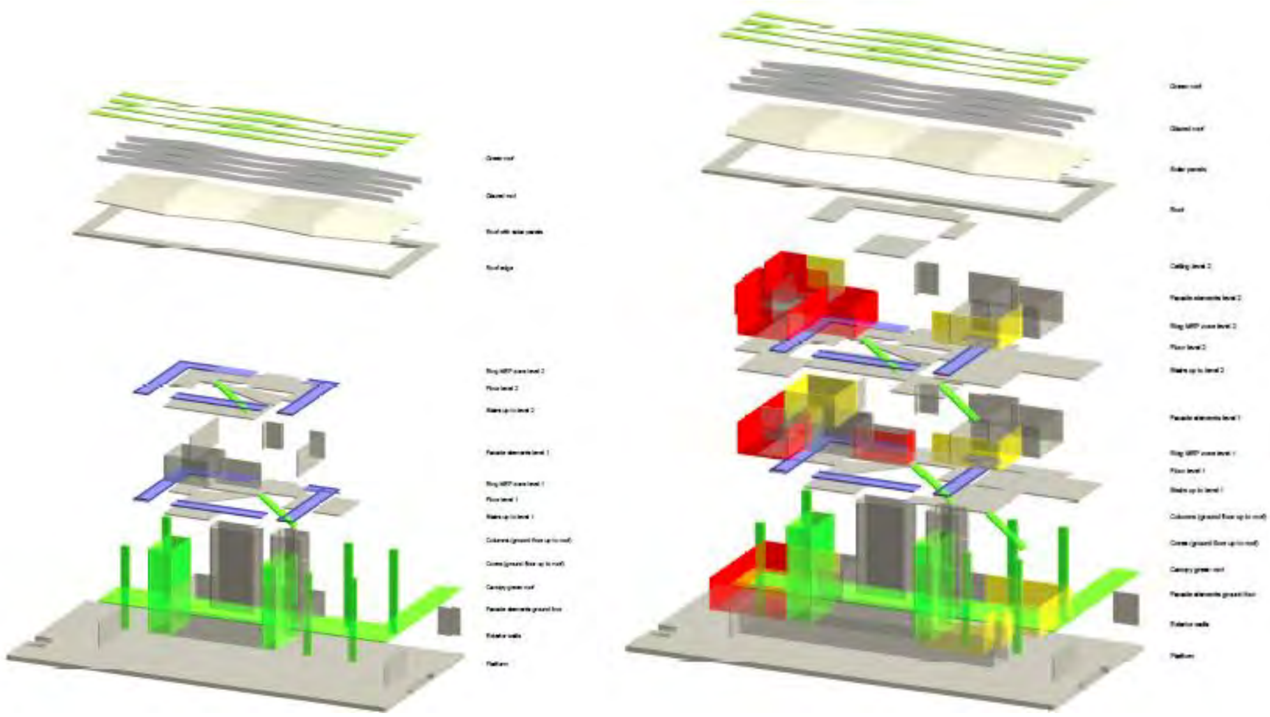

Figure 57: 3D decomposition illustrating the different scenarios

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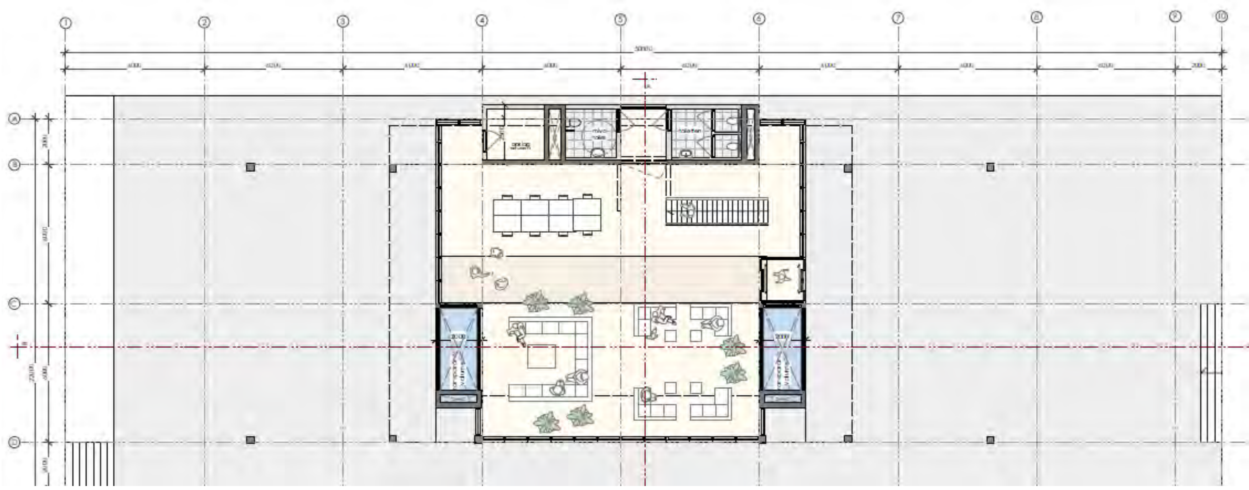

Figure 58: Ground floor of core element

Figure 58: Ground floor of core element shows the structural core elements on the ground floor: two air and light chimneys, four vertical technical ducts with integrated stability elements, and columns. *Figure 59: Section through the air and light chimneys* illustrates the position of the air and light chimney being used for natural light and ventilation.

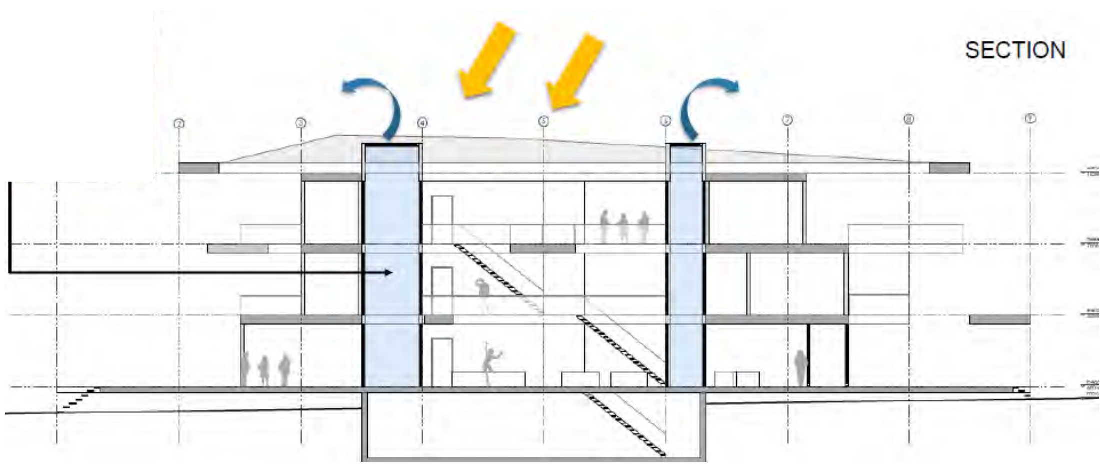

Figure 59: Section through the air and light chimneys

Although the plan of the existing modular structure of the **Circular Retrofit Lab** was not designed to support future changes, the internal organisation can vary a lot, based on the integrated functions. Where residential functions will fragment the structure into smaller spaces, the more public and professional functions require bigger spaces. The analysis of the functional requirements of the Circular Retrofit Lab are summarized in Figure 60: overview on the functional requirements of the

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different scenarios of Circular Retrofit Lab. This analysis enables investigating the technical requirements in regards to water, heating, electricity and ventilation supply.

Scenario 0: Existing situation

Space organisation
mainly smaller spaces: bedrooms, living room, bathrooms, storages

General	nr	m2
living room	1	30
bedroom	4	12
subtotal		78

Bathroom	nr	m2
bathroom with toilet and shower	2	4
subtotal		8

Kitchen	nr	m2
open kitchen in the common living space with sink, cooker, extractor and fridge	1	-
subtotal		

Other functions	nr	m2
storage space	2	2
subtotal		4

Scenario 1 (ground floor): Dissemination space

Space organisation
mainly bigger spaces: common space, supporting services (bathroom, kitchenette, etc.)

General	nr	m2
common space	1	70
subtotal		70

Bathroom	nr	m2
single toilet	2	2
bathroom with sink	1	4
subtotal		8

Kitchen	nr	m2
basic kitchen with sink (minimum of 3 modules of 60x60cm)	1	6
subtotal		

Other functions	nr	m2
storage space (in closets)	-	-
subtotal		

Scenario 2 (1st floor): Guestrooms

Space organisation
mainly smaller spaces: living room, bedroom, kitchen, bathroom, hall

General	nr	m2
living room	2	27
bedroom	2	12
subtotal		78

Bathroom	nr	m2
bathroom with toilet and shower	2	3
subtotal		6

Kitchen	nr	m2
equipped kitchen with sink, cooker, extractor (minimum of 5 modules of 60x60cm)	2	-
subtotal		

Other functions	nr	m2
storage space (in closets)	-	-
subtotal		

Scenario 3 (ground floor): Office space

Space organisation
mainly bigger spaces: working space, meeting room, supporting services (bathroom, kitchenette, etc.)

General	nr	m2
common space	1	70
subtotal		70

Bathroom	nr	m2
single toilet	2	2
bathroom with sink	1	4
subtotal		8

Kitchen	nr	m2
basic kitchenette with sink (minimum of 3 modules of 60x60cm)	1	-
subtotal		

Other functions	nr	m2
storage space	2	3
subtotal		6

Figure 60: overview on the functional requirements of the different scenarios of Circular Retrofit Lab

Figure 61 derives from analyses made of different organizations of the plans based on the imagined scenarios from the initial research by design. These plans furthermore show that functions such as bathroom, kitchen and entrance are often located in a similar position within the different scenarios. This is due to their specific requirements in terms of daylight, position in relation to technical services and/or entrance doors.

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Figure 61: Analyzing the position of bathroom, kitchen and entrance within the different plan organizations drawn as research by design

Applying this knowledge in a proper way could simplify the transformation in between the different scenarios in terms of speed, cost and complexity.

Based on this analysis, the design team decided to approach the whole as a combination of smaller scale components connected into a whole. In collaboration with BAO house[6], a sanitary unit for a residential function with a toilet, bath, shower, and sink can transform into a unit with multiple toilets and a smaller kitchenette. Therefore, a maximum of standardized modules for the surrounding closet walls is used.

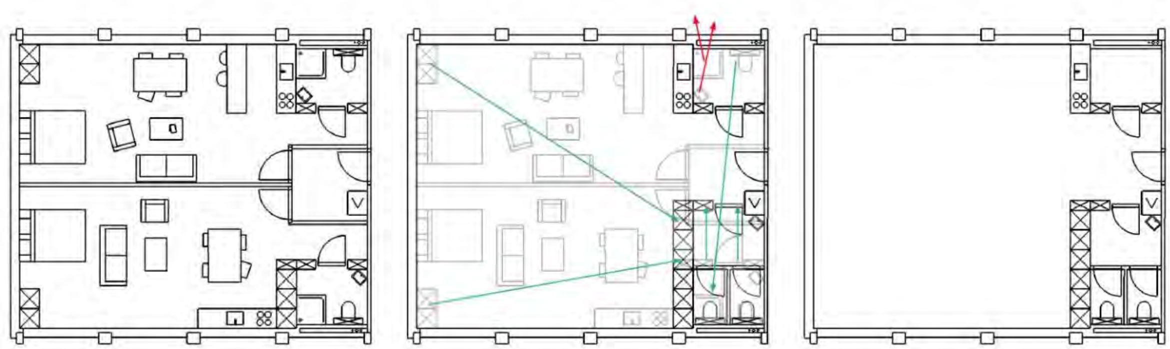

Figure 62: Study of transformation of the sanitary and kitchen of the eco guesthouses into a plugin office

[6] http://baoliving.com/

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Technical services are often a limitation on the transformation capacity of existing buildings. The amount and positioning of plugs, switches, data, light, heating, ventilation, etc. are very different according to the functions/scenarios and mainly determined by their internal organization.

To tackle this limitation, based on the research by design analysis, a basic grid is set up per floor and per technical service, onto which can be connected and disconnected according to the needs of the building's current function. Depending on the type of service, the grid is positioned along the ceiling, floor and/or the facade.

The vertical transport of services is organized in technical shafts along the facade of the building. The starting point was to provide vertical service shafts on a regular basis in the building with multiple plug-in points that facilitate the introduction of multiple building functions, e.g. office spaces, a guestroom, a bar, a lecture room, etc. In the first sketches, the team imagined providing a service shaft behind each structural frame portal (see *Figure 63*). This would provide the freedom to introduce a wide variety of plan layouts, independently of their technical requirements. These shafts would be implemented over the two building floors by making openings in the floor behind each structural column, in a zone of 25 x 25 cm where no reinforcement bars are present.

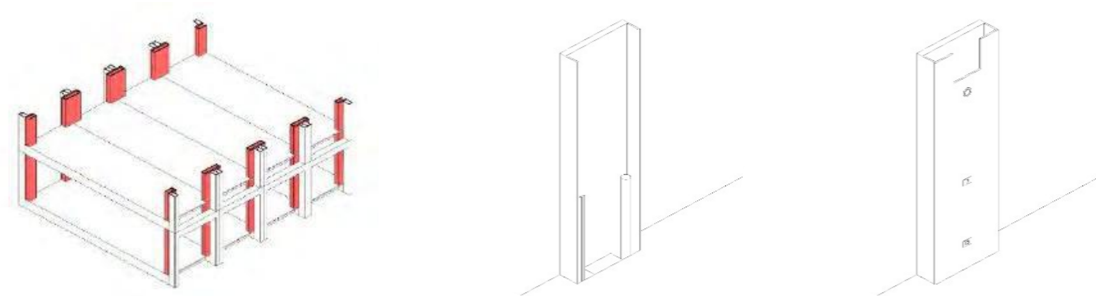

Figure 63: Initial concept of potentializing the existing frame of the building by introducing series of vertical shafts in the Circular Retrofit Lab

However, further on during the detailing phase of these technical shafts, concessions had to be made in regard to their number, size and location. Due to the choice for interior insulation of the building facade (in order to keep the structural frames visible and maintain the heritage aspect of the building), the envisaged vertical openings of 25cm would narrow the space down to non-useful dimensions for the integration of water drainage, ventilation, etc. Also, the multitude of openings would ask for a large financial investment that maybe would not be proportionate to the envisioned transformations. Therefore, the number of vertical shafts was reduced to four, introduced in the four corners of the buildings (see Figure 64). The location of these openings is based on the floor openings that already exist on two places, i.e. behind the current prefabricated concrete bathrooms. Two more openings are added, in order to increase the number of possible future layout plans. The

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idea of these openings is that for each building function, it can be decided in which zone a technical distribution is required, and non-relevant openings can be closed.

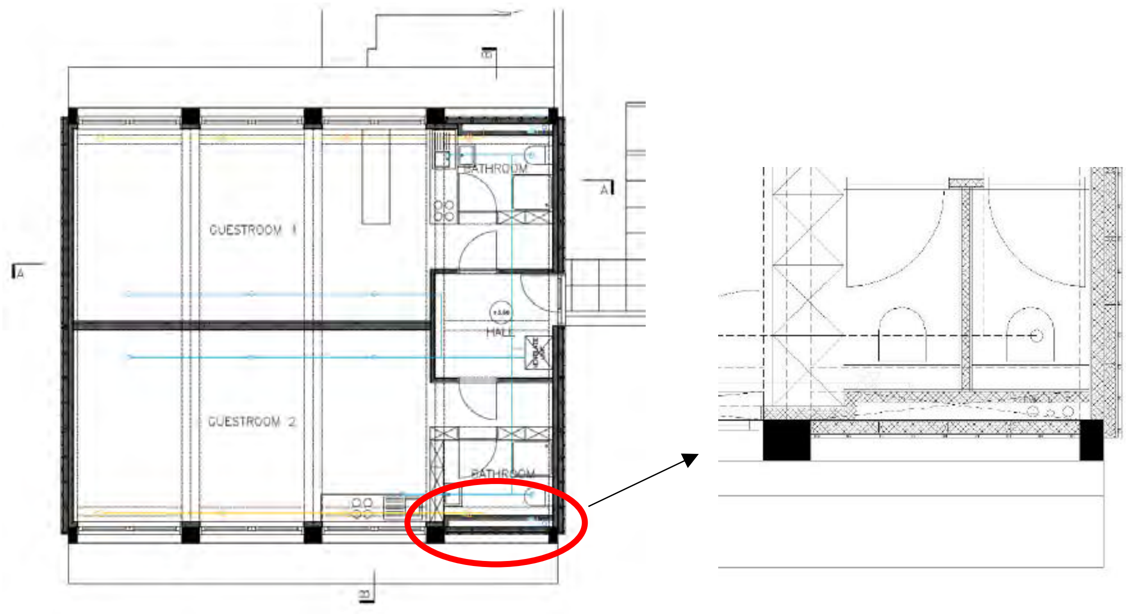

Figure 65: Use and detailing of a technical shaft in the Circular Retrofit Lab

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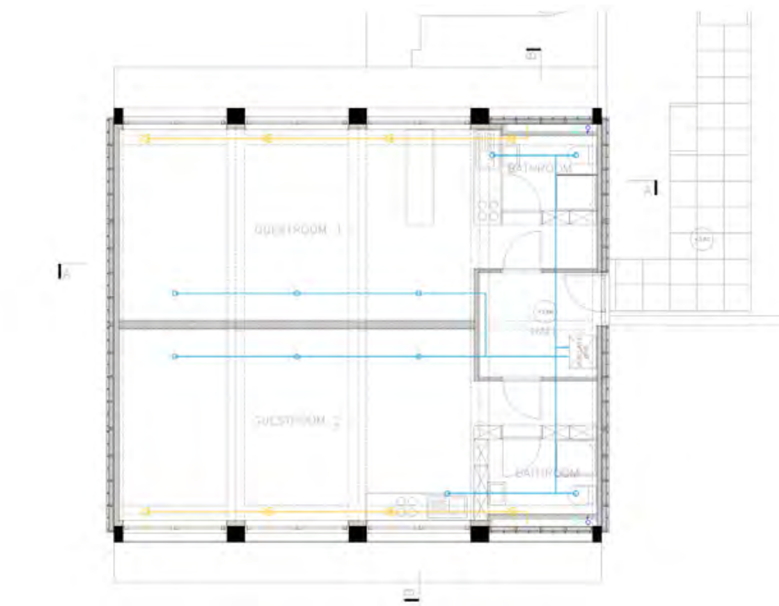

Figure 66: Grid of ventilation and heating to which can be plugged on

4.2 Element / system level

The different Pilot Projects have experienced the same issues in regard to the limited availability on the market of building solutions and products that enable anticipating changes during the life cycle of a building and the optimisation of reuse potential. The existing solutions that are on the market focus on the initial performance that is requested by architects and clients. Adaptation and reuse of building products are rarely considered as important requirements, and therefore, are not anticipated. This means that most building products do not anticipate future disassembly and reuse of products, and therefore the solutions will generate large waste streams in the future building's life cycle.

However, different types of companies, from SMEs to multinationals, have been identified that have been or are developing building solutions with reversible properties.

As a result, the solutions further discussed are a mix of:

- existing products and systems;
- innovative products tested within the Pilot Projects;
- newly developed solutions for the Pilot Projects.

Furthermore, in different Pilot Projects it was investigated how reclaimed materials and products or secondary raw materials (such as recycled concrete aggregates) could be used.

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4.2.1 Foundations

In order to increase the reversibility of the building, the BRIC Pilot Project will be built on reversible foundations. An innovative screw-based foundation system developed by a local company is being tested in collaboration with the Belgian Building Research Institute. The foundations will be certified and put on the market.

Based on the soil analysis of the building site, the most suitable technology has been chosen and improved. The prototyping solution has been tested and will be implemented in the BRIC Pilot Project. It has to be emphasized that the use of such reversible foundation systems is feasible as a result of the reduced size of the building and the restricted weight of the structure.

The selected foundation components are screws with a length of 1120mm, with a connector, made from stainless steel, to the wooden foundation beams of 160x60x3mm.

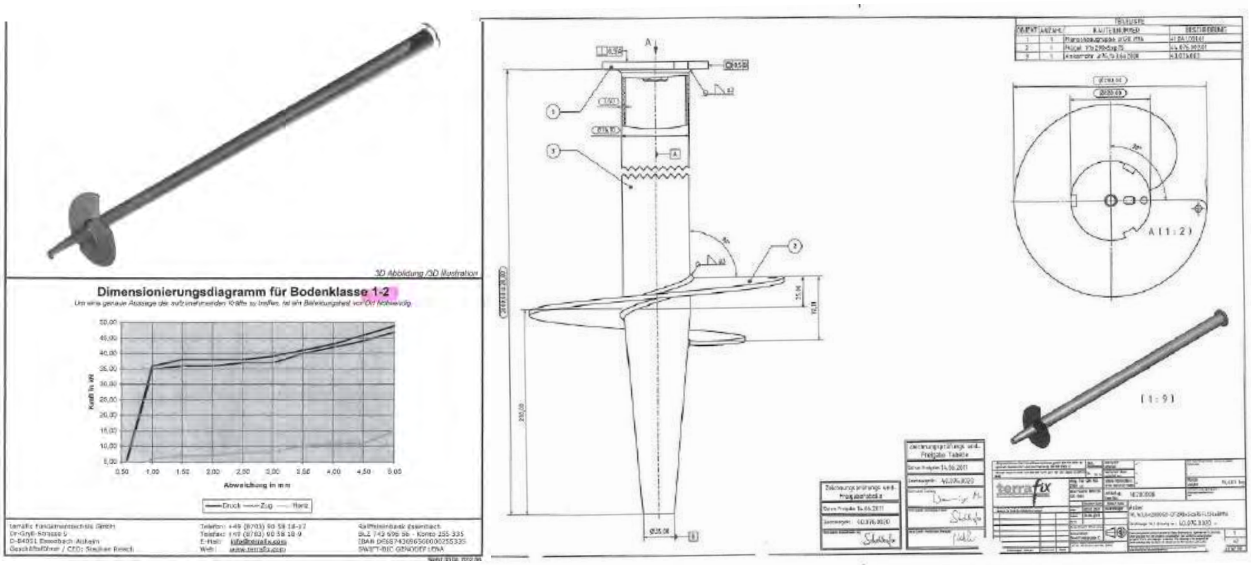

Figure 67: prototyped screwable foundation system

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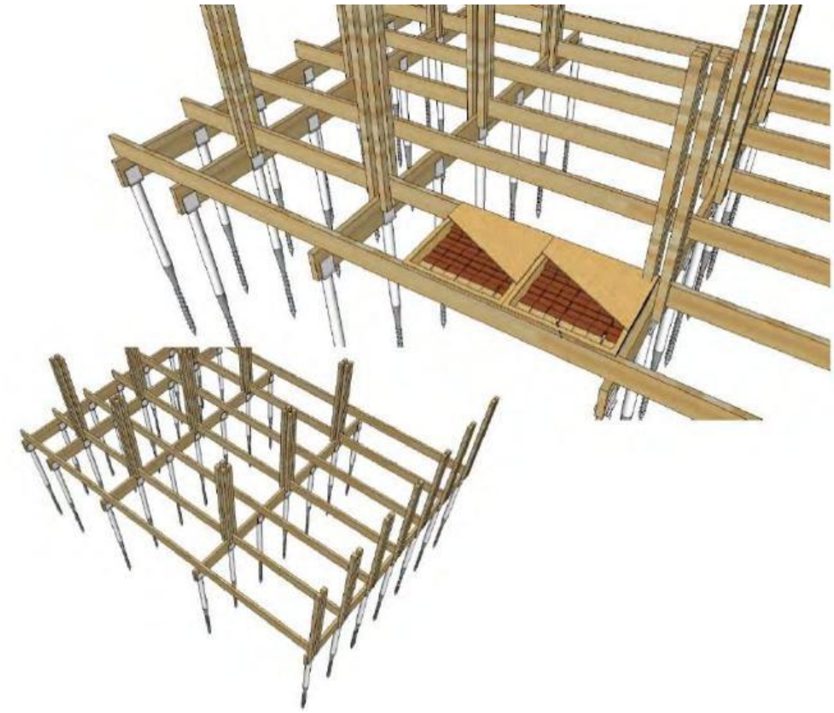

Figure 68: wooden beams on screw foundation

4.2.2 Structure

As described in § 3.1 the **New Office Building** is designed according to an open floor plan consisting of concrete columns and floor slabs. Since the use of recycled concrete is of paramount importance within the material balance of the Pilot Project, the goal is to build as many components for the building project as possible using recycled concrete aggregates.

Supplying recycled concrete aggregates to the Essen site represents one major challenge. While other regions in Germany, for example the greater Stuttgart area, already have several suppliers with experience using recycled concrete that currently is available at cost-neutral prices, no single supplier of recycled concrete aggregates currently exists in the entire state of North Rhine-Westphalia.

Since, for ecological and economic reasons, recycled concrete cannot be supplied from distances in excess of several hundred kilometres, it was necessary to find a local supplier for the Pilot Project. Following an extensive research phase, a potential supplier has been identified. However, this particular supplier would have claimed about €100,000 in additional costs. This is why although the use of recycled concrete with the highest possible proportion of recycled aggregate (Current building standards in Germany allow recycled

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aggregates to be contained in concrete in proportions of up to 45% by mass) is technically possible, this option could not be realised due to financial constraints.

The necessary one-off investments associated with appropriate plant technology were cited as the justification for this enormous increase in costs. It can therefore be assumed that an increased demand for recycled concrete aggregates in shell construction tenders can ensure a significant reduction in costs and thus a competitive offer in the Essen area.

An additional design requirement specifies that all the concrete components should be suitable for use as recyclable concrete aggregates after dismantling. Therefore, a 'recycling friendly' installation of concrete has been implemented, allowing the concrete to be dismantled in clean fractions at the end of the life cycle. The concrete components are e.g. not plastered with gypsum or contaminated with other impurities, but are only provided with a thin mineral surface coating, which does not negatively affect the recycling process.

Figure 69: Uncoated concrete walls facilitate their future potential recycling

The structure of the **REM** Pilot Project consists of dismountable aluminum modules. The basic frame consists of welded aluminum beams to which the legs and the upright beams are fastened with wingnuts. The overhead beams are clamped to the upright beams. Modules can be connected by sharing legs and upright beams, either on the long side or on the short side.

The elements have been designed to support the ease and speed of mounting and dismounting the modules.

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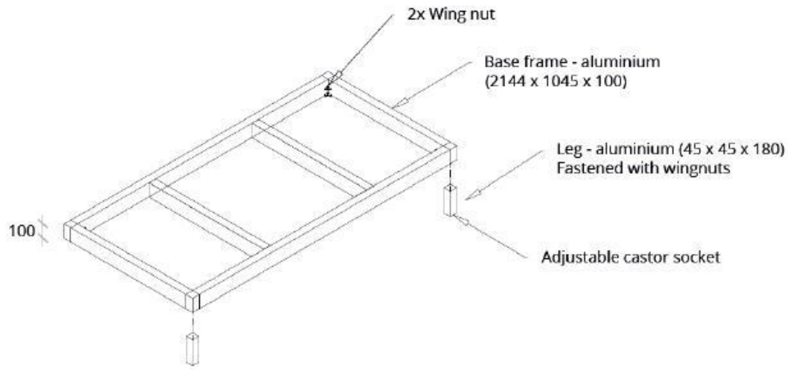

Figure 70: Basic frame

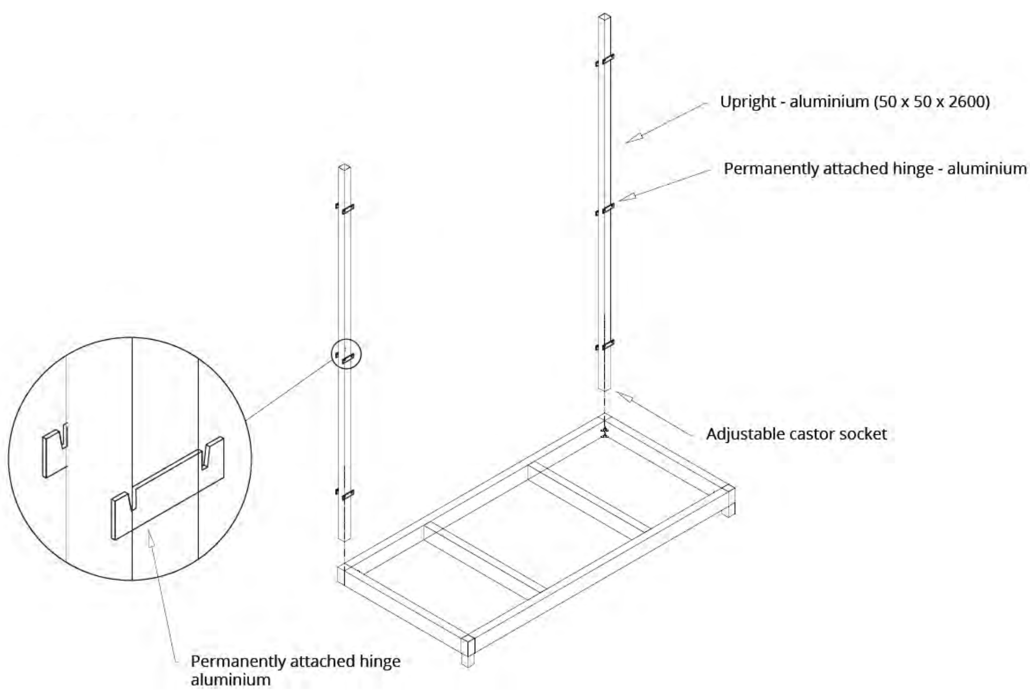

Figure 71: Connection of uprights on base frame

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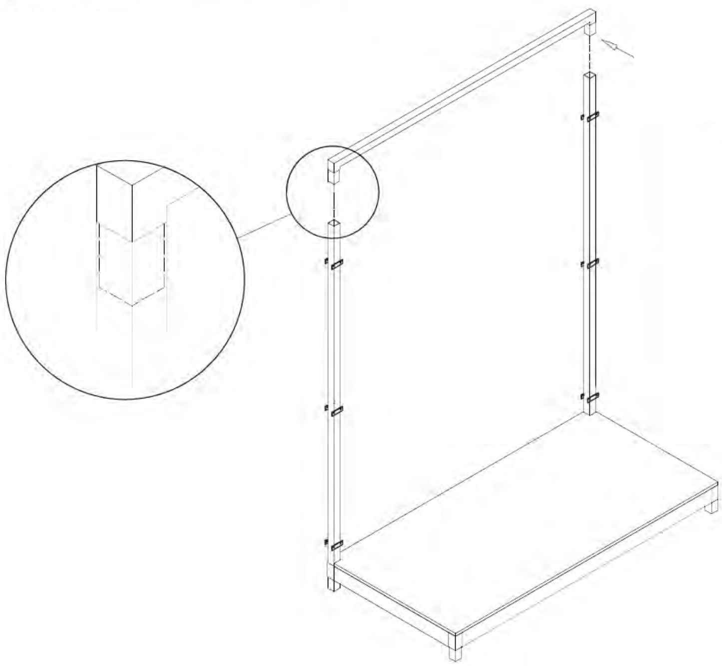

Figure 72: Connection of overhead beams

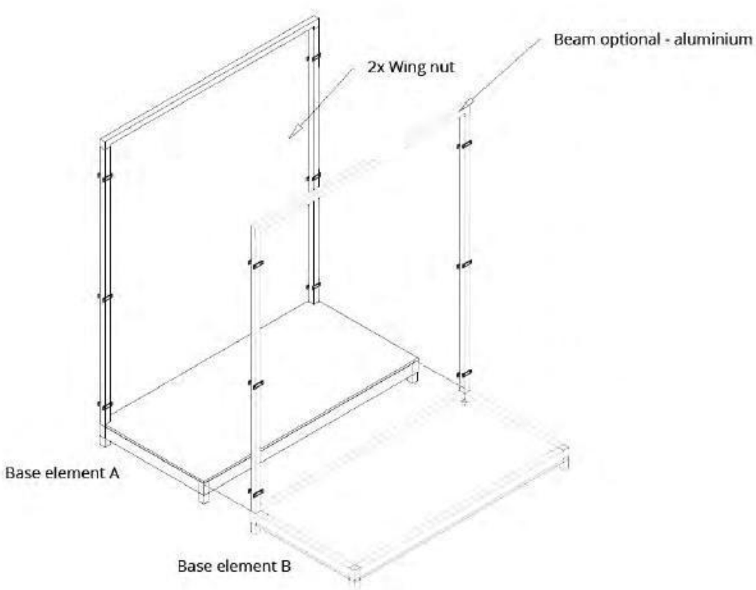

Figure 73: Connecting modules to each other

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The connection hinges attached to the structure of the module enable attaching cladding directly to the frame. The cladding only needs to be foreseen with the compatible fitting holes and compatible dimensions.

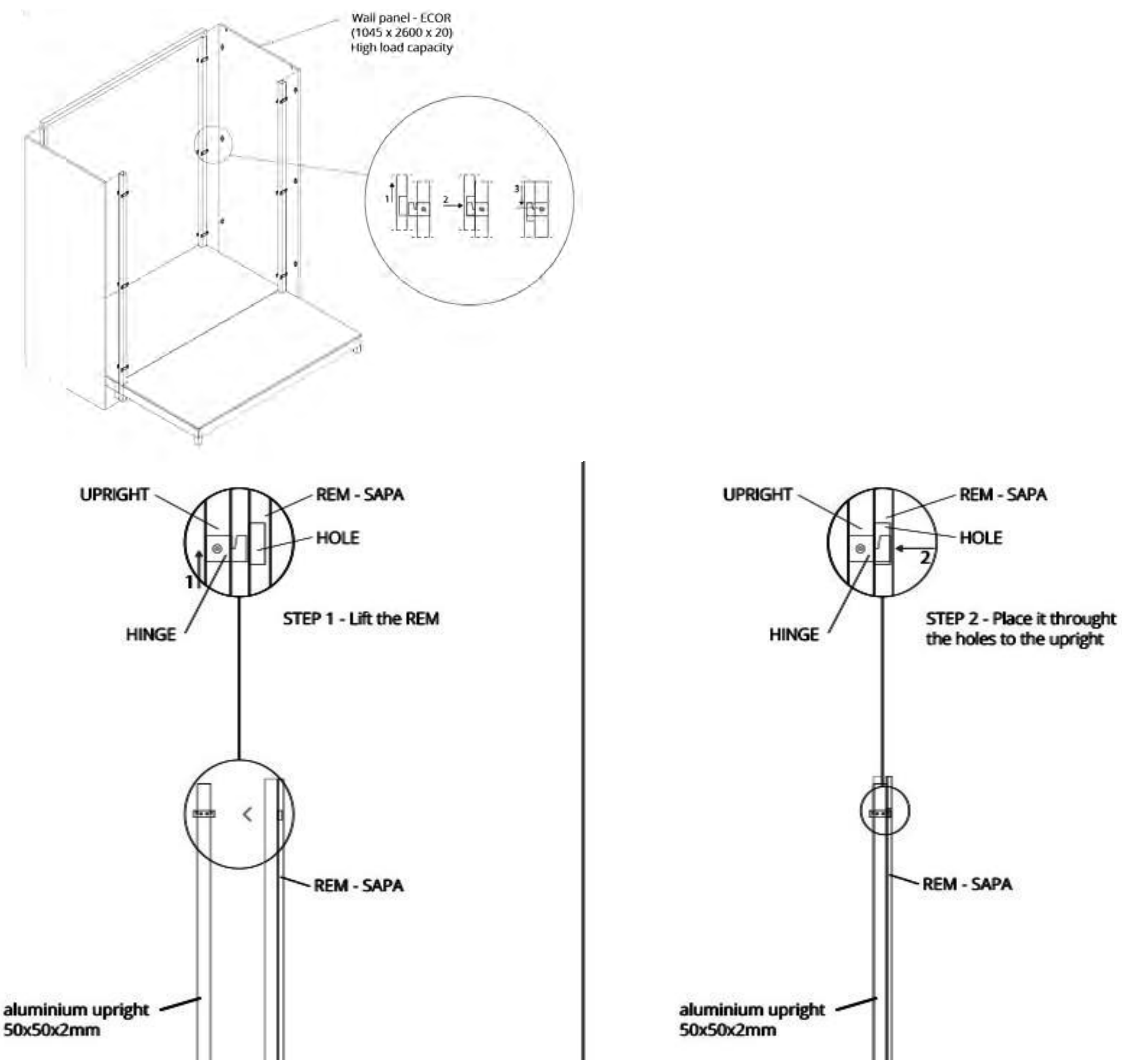

Figure 74: Detail of connections on the structure

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Within the **BRIC** Pilot Project, 4 determining design choices were made to guarantee the reversibility of the building as well as the reconfiguration of the elements into different designs enabling a change of shape and function of the building.

A standardization in dimension and in the type of elements is required to support the transformation potential of the building. Therefore, the wooden skeleton structure has been designed according to a systematized grid with dimensions of 1.2 m by 1.2 m.

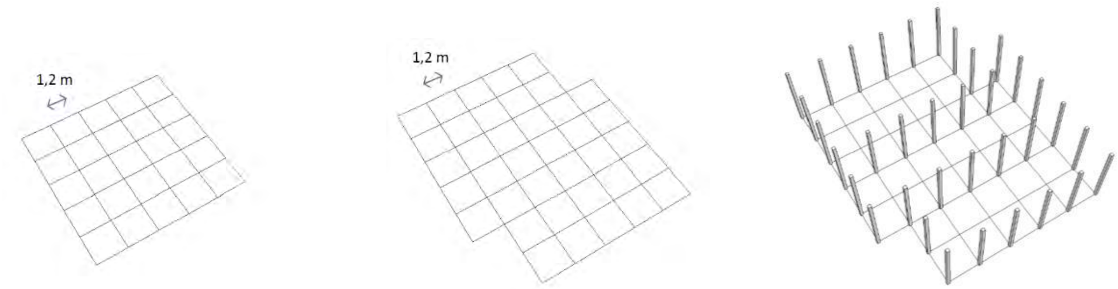

Figure 75: BRIC - Design grid

The columns consist of 4 square shaped beams that are fastened to each other by steel connectors. The positioning of the beams enable easily adapting the direction and angle of the loadbearing horizontal beams.

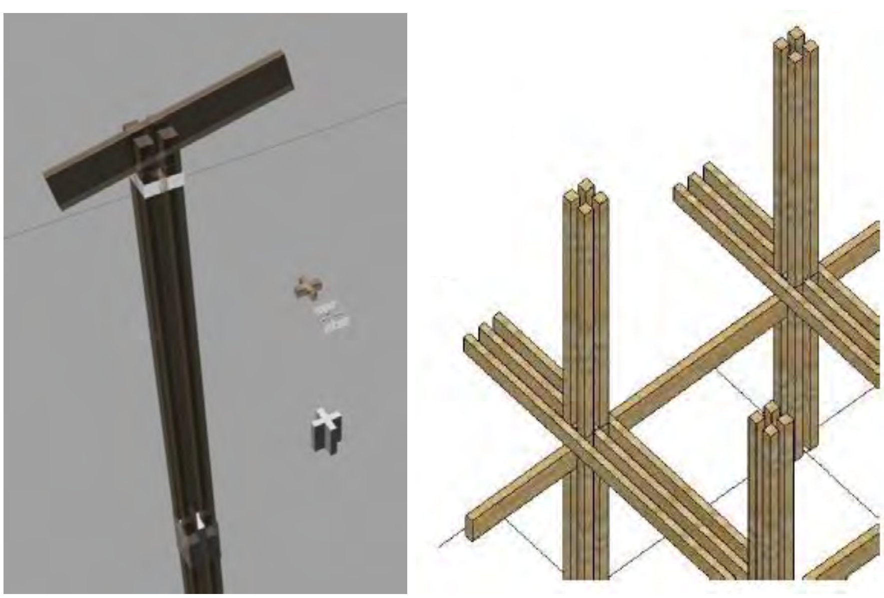

Figure 76: BRIC -Versatile column design

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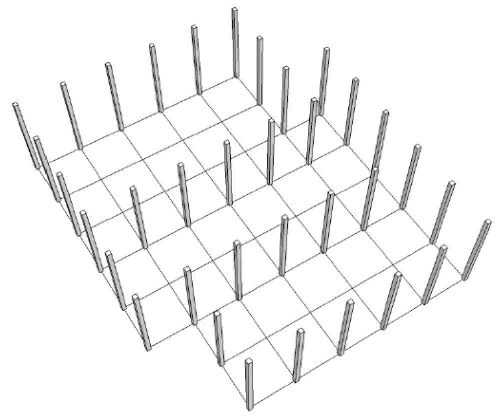

Figure 77: BRIC - structured grid

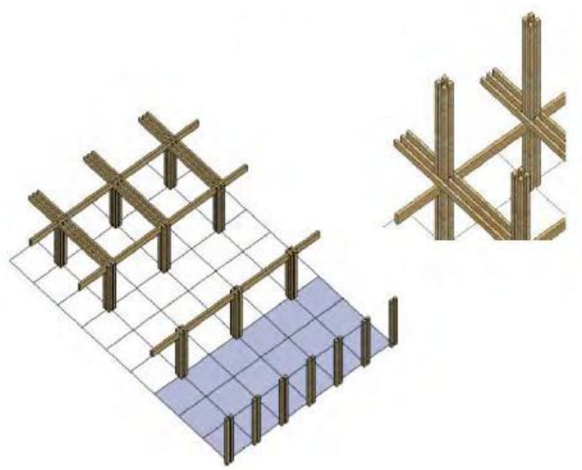

Figure 78: BRIC - 4 squared columns

4.2.3 Skin

<u>Roof</u>

The roof structure of the **GTB Lab** consists of a laminated wooden grid structure that is supported by 8 columns. This grid structure enables the integration of different functions in the roof design, while reducing the initial cost. A clear division is provided between the standardised openings for natural light and the zone for placement of solar panels. By placing stand-alone PV panels around the openings for natural light, the architect integrated PV panels with the rainwater collection zone optimising in this way the compact use of the roof service and introducing a high level of standardisation.

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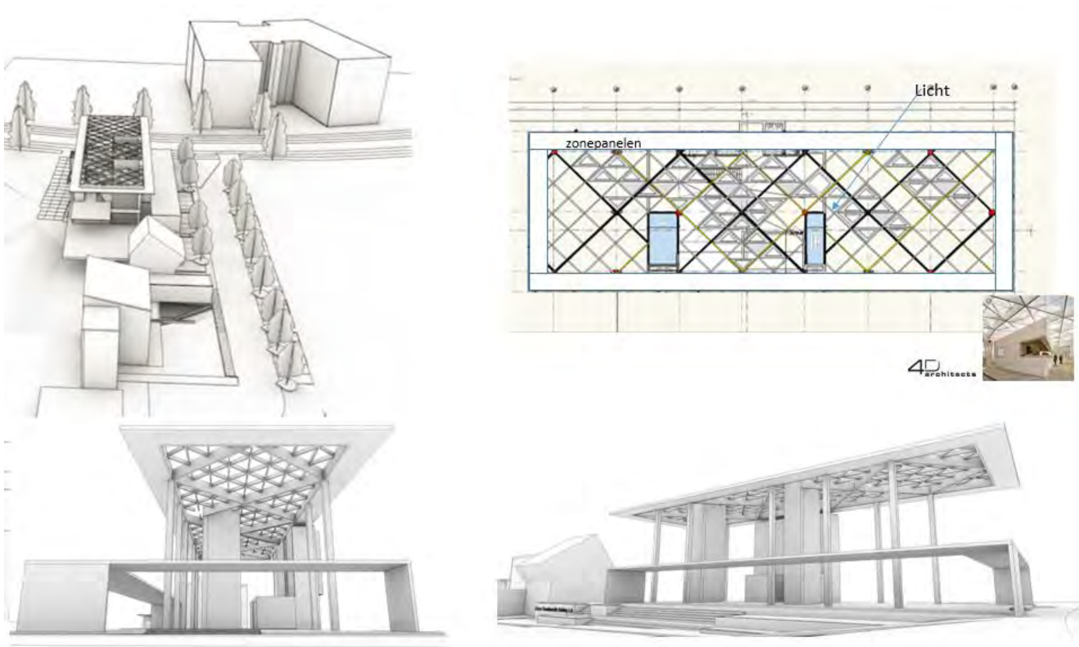

Figure 79: Design of the multifunctional roof

Facade systems

Within the design of the GTB Lab, 2 different types of facade systems are being investigated and analysed with regard to their reuse potential: a steel facade of ODS[7] and a wooden facade system of De GrootVroomshoop[8].

[7] http://kloecknermetals.nl/nl/index.php
[8] http://degrootvroomshoop.nl/

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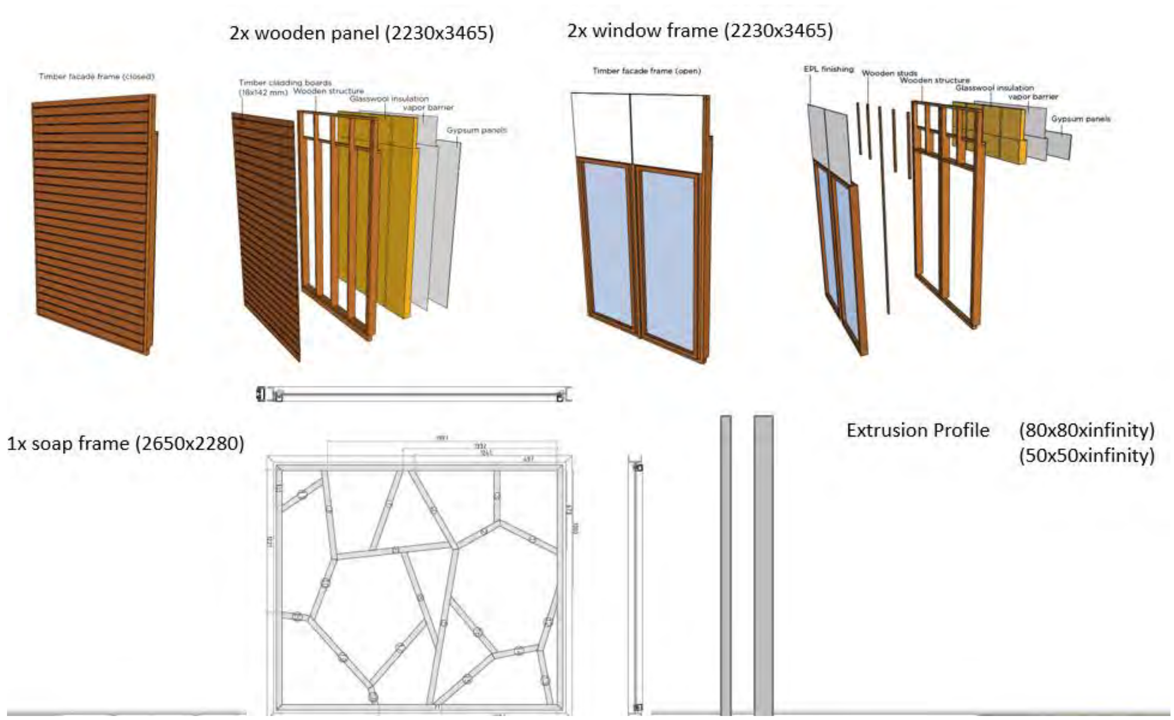

Figure 80: GTB Lab – Facade elements

Furthermore, different extension modules have been developed, which enable enlarging the space.

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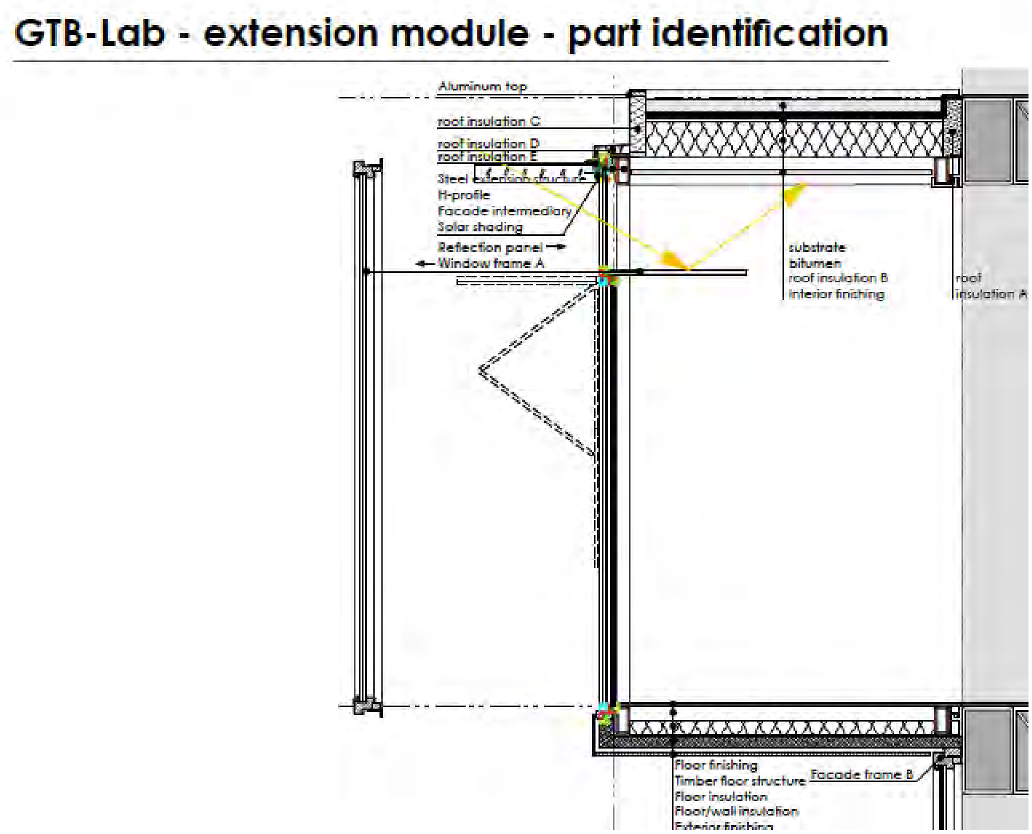

Figure 81: GTB Lab – Facade module

The steel profiles of ODS are being re-engineered in order to make them more generic and increase their reuse potential. The size, the loadbearing capacity, geometry and connection points have been investigated and will be further investigated through prototyping before using them as facade modules.

Furthermore, individual units are being developed for the housing units, incorporating their own technical boxes and solar panels. This will enable them to be energy sufficient.

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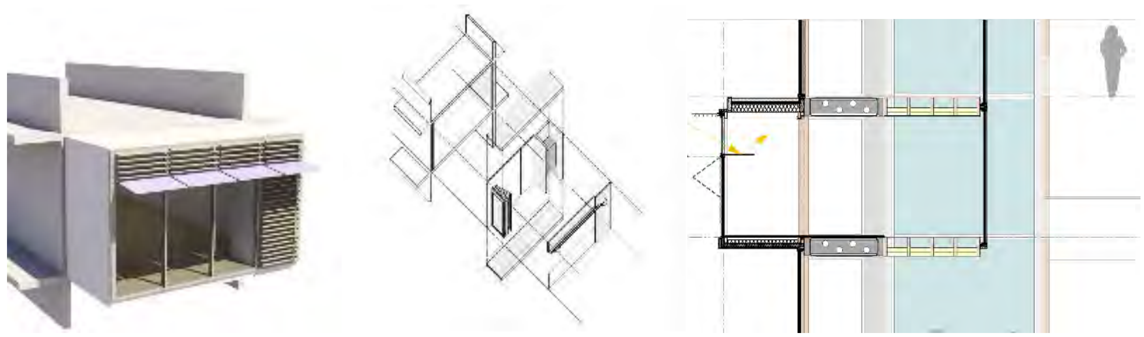

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Figure 82: GTB Lab – Facade module

The **New Office Building** consists of a modular facade system. The newly designed facade system from Schüco has specifically been optimized for the Pilot Project in accordance with the C2C and Reversible Building Design principles and has been specially certified for use in this new building.

The following main changes where conducted:

- substitution of toxic or non-recyclable parts of the facade system, especially within the rubber and coating components
- implementation and expansion of a recycling and take-back system within the A/U/F Initiative[9]
- adaptation of the selected materials and conversion of the fastening systems to purely mechanical, detachable elements in the opaque components (armor)

[9] The purpose of the A|U|F is the sustainable promotion of the disposal and treatment of dismantled aluminium components / building profiles, windows, doors and facades for the purpose of material reuse. The aim is an environmentally friendly and resource-saving recycling process of aluminium. The association is nonpartisan and independent.

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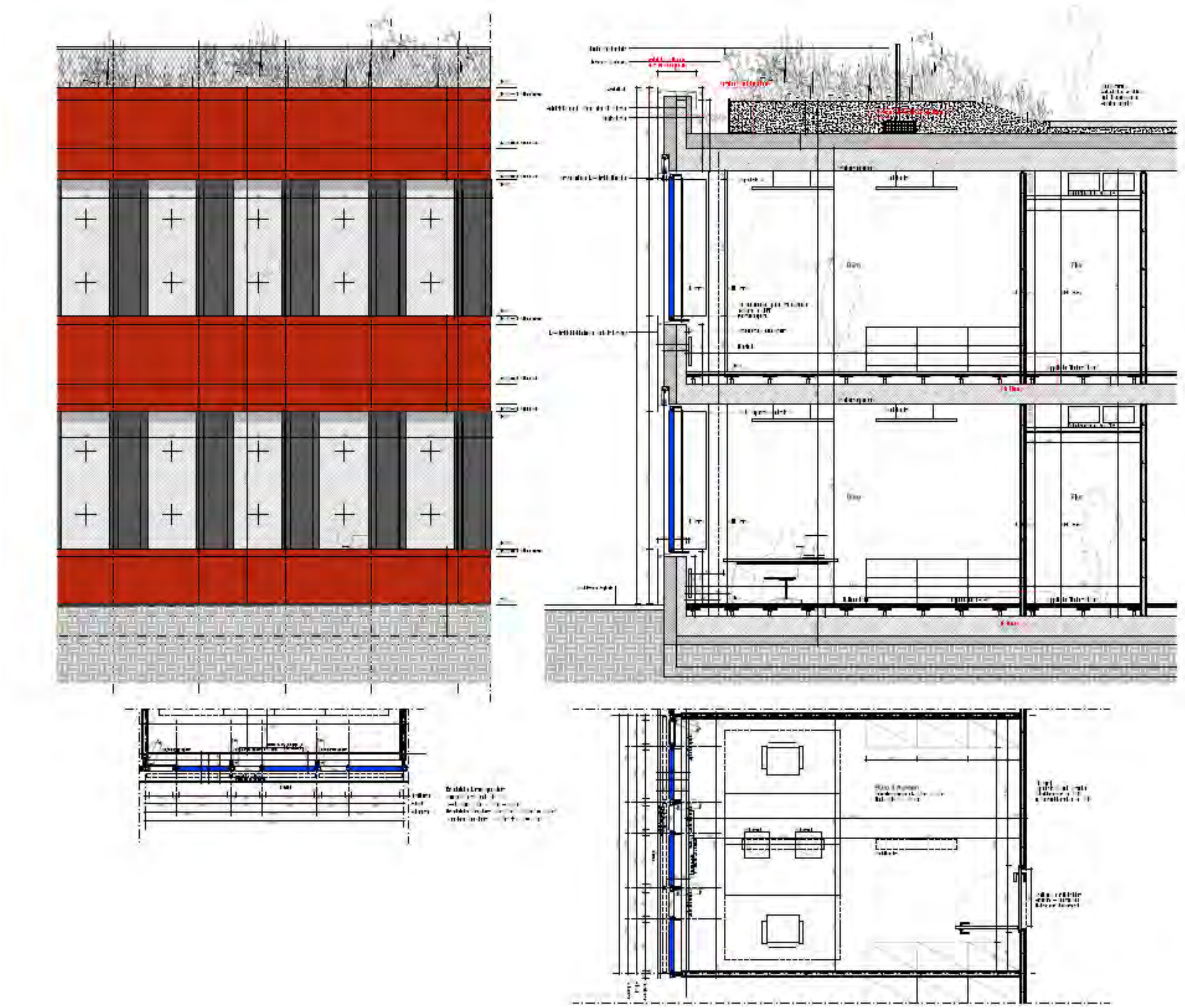

Figure 83: New Office Building Facade details.

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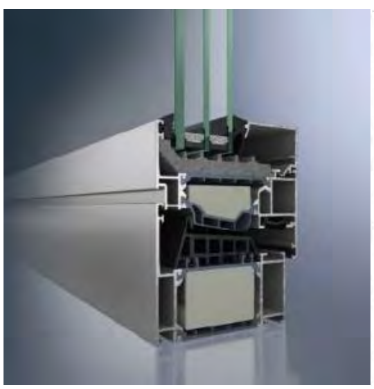
Figure 84: New Office Building – Facade module

As the design was slightly different, an additional, standalone C2C certification for the Pilot Project was conducted reaching the following C2C targets. The targets were to build healthy and adaptable/transformable workplaces and to construct a building that is beneficial for humans and nature.



Criterion \ Tier	Basic	Bronze	Silver	Gold	Platinum
Material			✓		
Material Reutilization / Design for Environment				✓	
Energy				✓	
Water				✓	
Social Responsibility			✓		
Overall			✓		

Figure 85: Cradle to Cradle rating chart for the Schüco facade system

It was proven that this innovative facade system can compete under realistic market conditions. No additional costs were accepted by the owner for this extended C2C quality.

The **Circular Refurbishment Lab** has given special attention to the detailing of the insulation and air tightness of the newly designed facade system, taking into account the impact this has on the reversibility, as well as on the changing aesthetics of the historic modules.

In collaboration with MK engineering, a comparative study was made on the possible principles for insulating its facade, in relation to the energetic regulations to be applied. Four options were evaluated, ranging from total exterior insulation (wrapping) to total interior insulation inside the existing concrete structure:

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- Exterior insulation (wrapping): the most commonly known and applied solution to insulate existing buildings. Thermal bridges and loss of space in the interior are avoided. Its downside is the drastic change in the look of the building exterior in materiality and/or dimensions.
- Insulation between the portals: specific for structural and open facades. The principle avoids a drastic change in the look of the building exterior. When insulation is only foreseen in between the portals, thermal bridges exist around the structural portals.
- Insulation between & behind the portals: similar to the previous option, with the addition of an insulation layer behind the structural portals. This not only minimizes the amount of thermal bridges, but also facilitates the airtight sealing of the joints between the portals and the preassembled components, including insulation, in between the portals.
- Interior insulation: is an insulation principle mainly used when exterior insulation of a building is not possible because of its external thickness or the heritage character of the existing building. Its downsides are the drastic change in the look of the building interior in materiality and the decrease of interior space. In many cases, this principle is not able to completely avoid thermal bridges.

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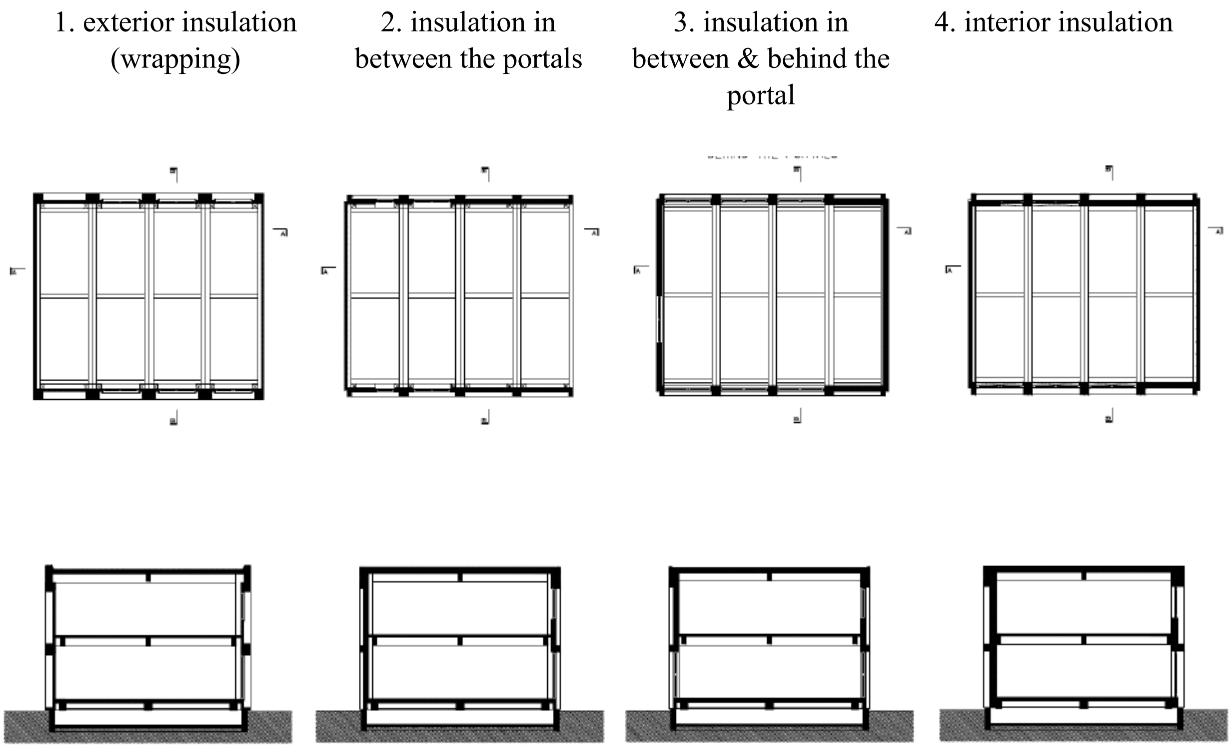

Figure 86: Comparative study of the insulation and air tightness principles for the facade

Based on a series of quantitative and qualitative parameters (insulation level K-value, impact on the architectural value, technical feasibility, etc.) the choice was made for a combined solution (method 1 & 3): replacement of the existing non-load-bearing facade by preassembled components to which additional insulation and an airtight membrane is added from the inside. The chosen solution results in an optimal compromise between a better thermal performance and the original architectural qualities of the prefabricated modules.

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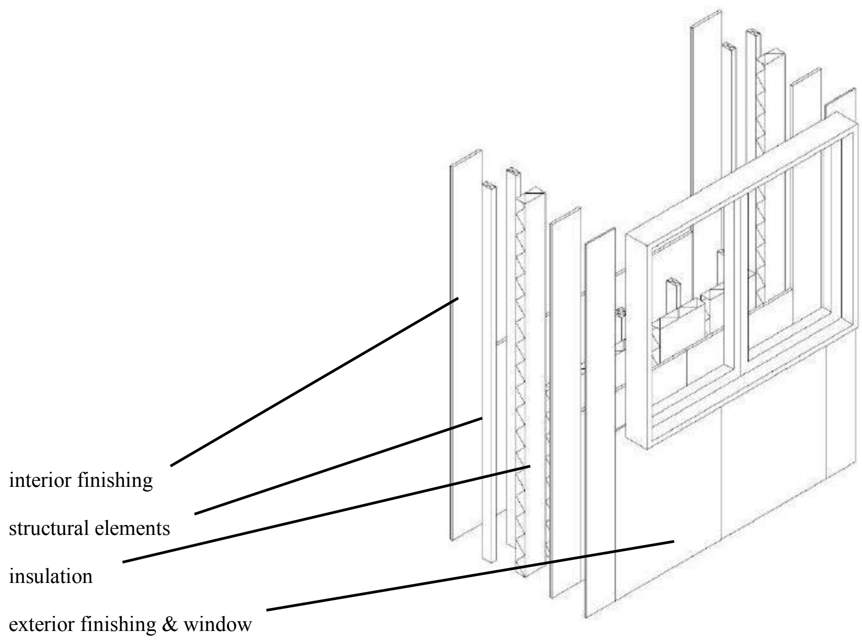

Figure 87: Principal exploded view of pre-assembled components used as infill facade and curtain facade

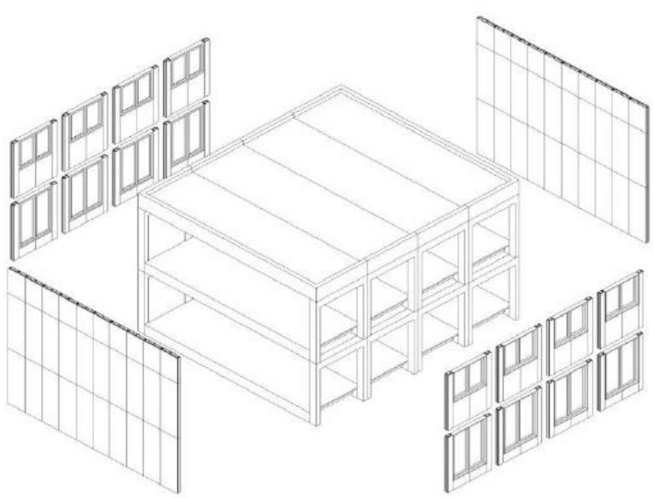

Figure 88: Pre-assembled components used as infill facade and curtain facade

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A preassembled wooden unit is being developed that can be connected in a reversible way to the building facade, so it can be removed or adapted in the future. Although the facade modules are pre-fabricated to speed up and ease the building process, the modules can easily be dismantled and upgraded or transformed. This enables meeting the changing requirements e.g. in regards to natural lighting when changing function. This preassembled unit will also consist of physical layers that can be demounted and reused as much as possible. For the insulation materials, different materials will be investigated. For the exterior cladding of the building, a solution will be integrated, like coated facade cladding plate for outdoor applications, such as Rockpanel[10], which enables a reversible connection and corresponds to the current architectural look of the building.

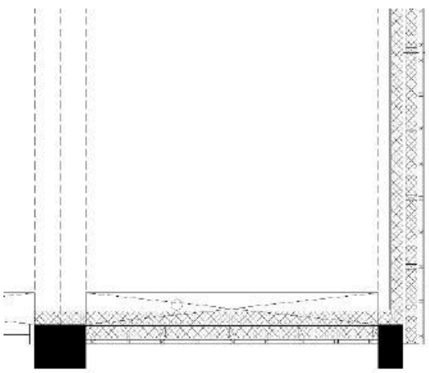

Figure 89: Facade detailing based on an internal and external layer

4.2.4 Partitioning walls

Within the **Circular Retrofit Lab,** different partition wall systems will be developed/implemented in order to assess the technical feasibility, benefits and obstacles.

Different qualitative and quantitative criteria were set up, amongst which the most important are listed below:

- *low initial environmental/financial impact*
- *low life cycle environmental / financial impact*
- *possibility to demount and reuse*
- *use of reclaimed building materials (e.g. reclaimed finishing panels, profiles, etc.)*
- *high assembly speed (e.g. preassembly, fast connection techniques, etc.)*

[10] http://www.rockpanel.nl/

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- *standardised solutions*

The selection of solutions is the subject of a multi-criteria analysis, depending on their integration in the space plan and a LCA/LCC analysis.

Furthermore, the components need some specific characteristics to meet the current functional and comfort requirements:

- Components can easily be connected in between each other
- Components can be connected to floor and ceiling
- They can be manipulated by no more than 2 persons
- They can handle tolerances within the context of renovation
- They can be disassembled to basic elements to repair damaged elements in the component
- They meet the acoustical and fire safety requirements, depending on the functions.

It was decided to work as much as possible with preassembled wall modules, because the existing student modules have a strong modularity in which the integration of standardised modules are suitable. This will enable speeding up the assembly (and disassembly) of the proposed solutions, reduce the loss of material cuts on-site, reduce the financial costs, and ensure a better quality of the solutions.

The three retained solutions are the following:

- a cardboard stud solution (Wall LinQ) with gypsum plasterboard or ClicWall (Unilin)
- a preassembled wooden stud solution with gypsum plasterboard (Gyproc or Habito)
- a (preassembled) steel stud solution with GIS profiles (Geberit) and demountable finishing panels (reclaimed or reusable)

These three solutions will enable giving new insights in the use of different materials for the studs, the finishing, the reversibility of the solutions, etc. Because these solutions are not all available on the market, prototyping of wall solutions will be done.

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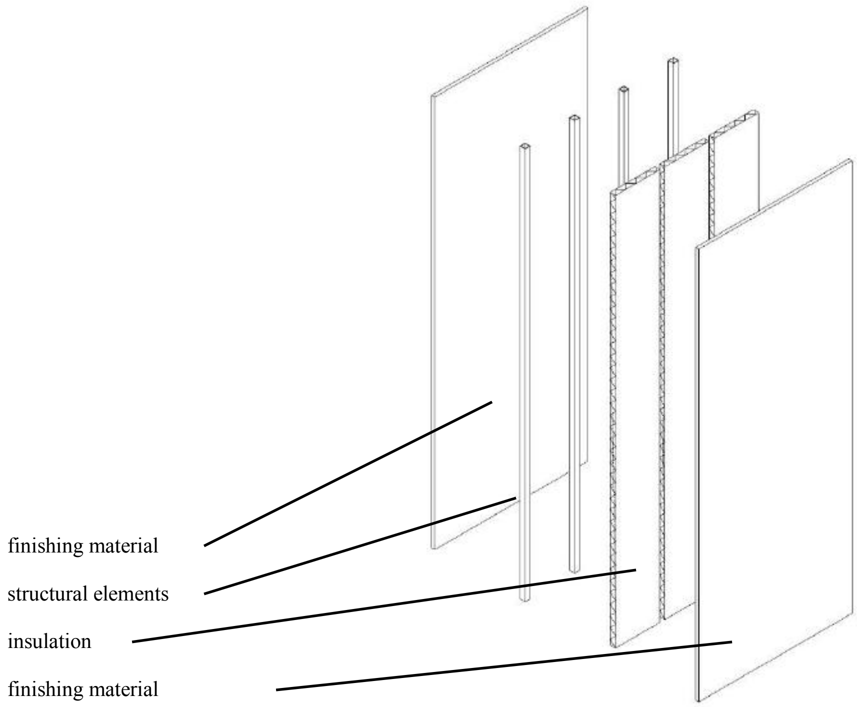

Figure 90: Principal exploded view of pre-assembled partition wall component

A changing internal organization demands partition walls that can easily be mounted in one location and dismantled to move it to another location.

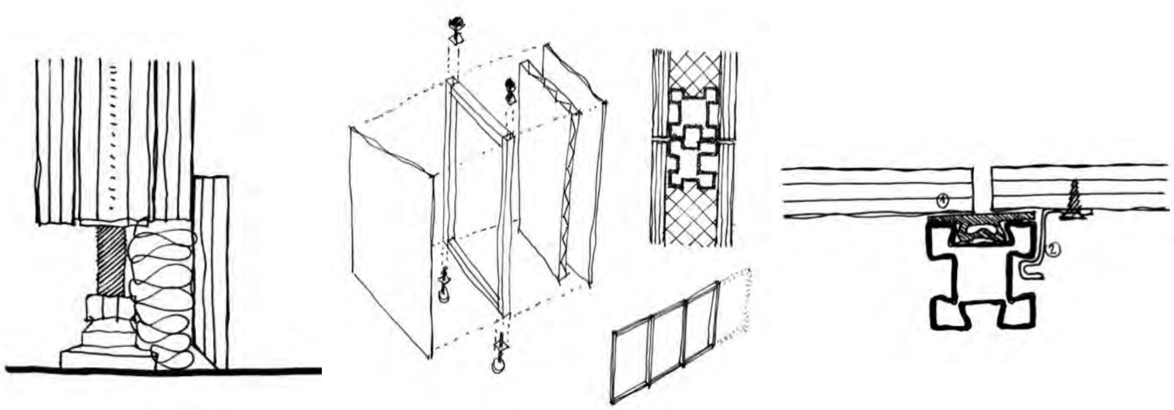

Figure 91: Sketches of detailing of interior wall components using the GIS profiles of Geberit

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Figure 92: Wall solutions for the Circular Retrofit Lab: GIS system (Geberit) & wall-linQ with cardboard profiles.

This module of the **REM** is built from a metal frame and wood or fibreboard. Fibreboards are a cost-efficient, lightweight and impact resistant wall material, when compared to heavier weight ceramics, or impact sensitive metals or gypsum.

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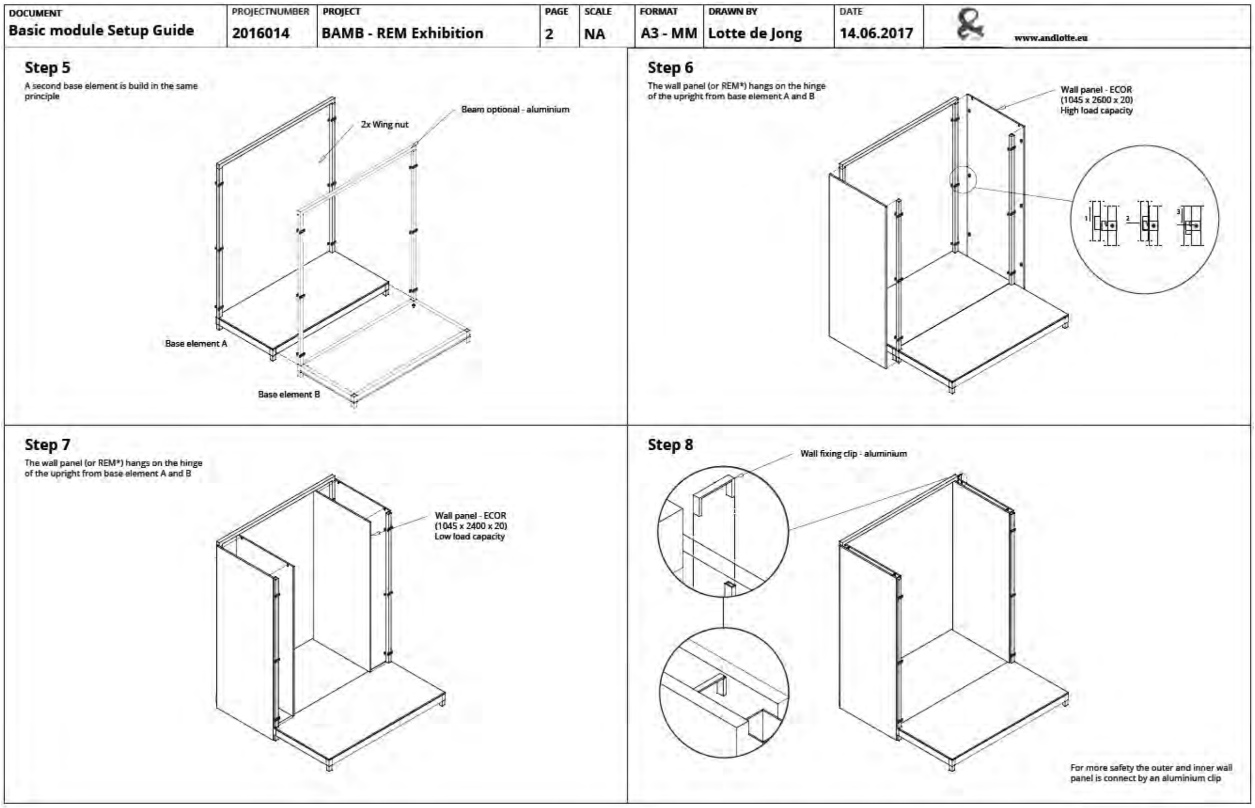

Figure 93: roadmap to (dis)assembly the REMs

To connect the exposed products to the frame of the basic module, a system of connections was developed. In this case, the Mosa Facade is connected using the frame construction as part of the Mosa facade, and screws connect the constructions to the ECOR panel.

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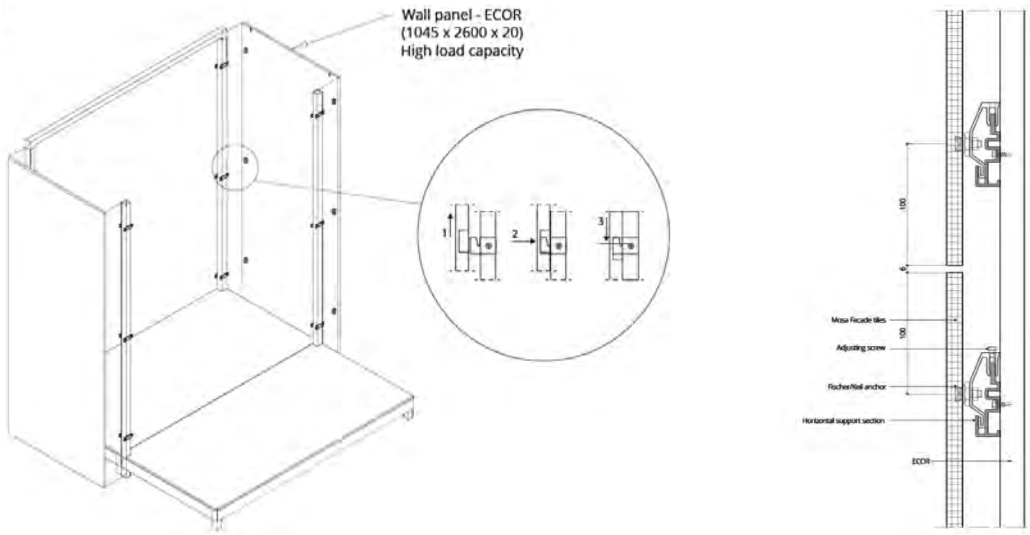

Figure 94: connection of REM to base frame

The MOSA panels are attached to an ECOR panel, which is slid on the base module like all other ECOR panels. Other products can be attached in a similar fashion to the base modules. When products are as large as a panel (for example the SAPA, Schueco and Janisol REMs), the products are directly attached to the base-frame. The products will be prepared with a fitting-hole, which slides over the connection `hinge` on the base-frame.

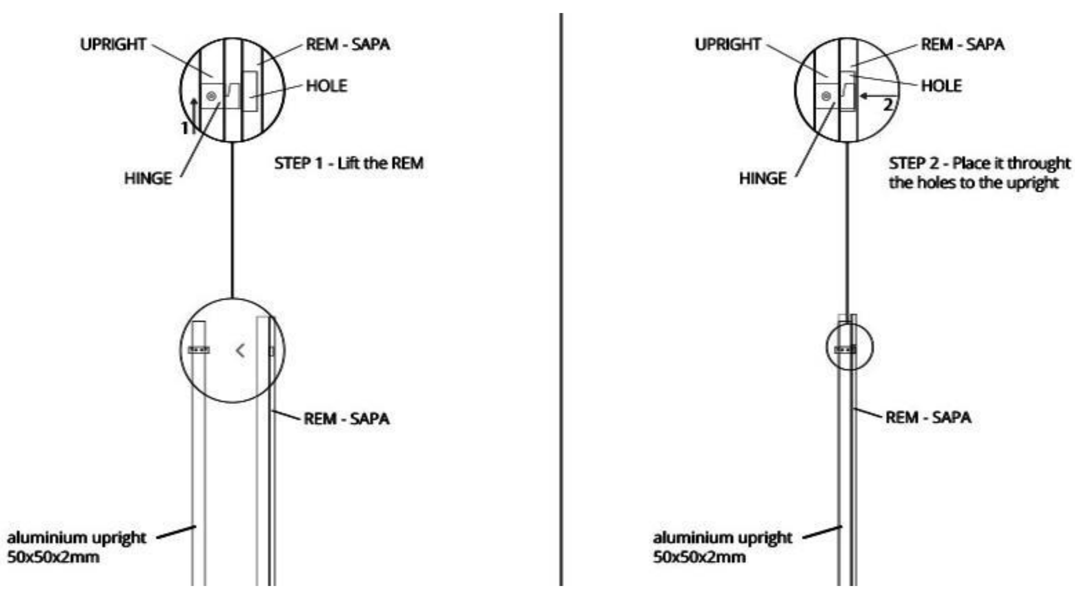

Figure 95: connection of large REMs to base frame

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5 IMPACT ASSESSMENT

5.1 Waste reduction

Within the feasibility report, a qualitative assessment of the potential waste reduction was done. Depending on the Pilot Projects, this qualitative assessment will be complimented with a quantitative assessment in a later stage of the project, in the framework of the deliverables D13 and D14.

The assessment was based on the 5 key principles of Design for Resource Efficiency developed by WRAP[11] for Design review workshops. A waste assessment template was drafted with key questions for building projects. The key principles for resource efficiency are applied at the building level, but also on the different layers of the building. Furthermore, the performed analysis also investigates which design directives developed within Work Package 3 (Reversible Building Design) have been essential to achieve the required resource efficiency: Functional independence, Systematization, Relational dependency and relational pattern, Basic element, Life cycle coordination of elements, Assembly/disassembly sequences, Geometry and morphology, and Type of connections.

This qualitative waste assessment of all Pilot Projects enables exposing trends and identifying opportunities and barriers.

The following key criteria, as developed by WRAP's Resource Efficiency assessment, were investigated:

1. Design for Reuse and Recovery
    a. Elements can be retained and refurbished.
    b. Materials from demolition of structures or other construction phases are reused in the design.
    c. Materials can be reused at their highest value.
    d. *A cut and fill balance is achieved. Removal of spoil from site is avoided.*
    e. Equivalent materials and products are available with high recycled content.
    f. *Grey water or rain water can be used in the construction and/or operation of the building.*
2. Design for offsite construction
    a. Parts of the design can be manufactured off site.
    b. On site activities can become a process of assembly rather than construction.
3. Design for Resource optimization
    a. The design, form and layout is simplified without compromising the design concept.

[11] http://www.wrap.org.uk/

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   b. *The form, layout and building fabric offer 'in use' savings in energy or water.*
   c. The building is designed to standard material dimensions.
   d. Sustainability of supply, durability, embodied carbon and embodied water is considered when specifying materials.
4. Design for Resource efficient Procurement
   a. Research is carried out by the design team to identify where on site waste arises.
   b. Construction practices and plants are used to reduce emissions, energy, water use and waste on site.
   c. Specialist contractors are consulted during the design process to contribute ideas from their experience.
   d. Specifications are reviewed to ensure elements/components/materials are selected which contribute to the project's resource efficiency objectives.
   e. The program allows time for the incorporation of resource efficiency measures adopted.
5. Design for Future
   a. The design ensures that the building is flexible in use and easily adaptable to changes of use over its life span.
   b. Building elements and components can be maintained, upgraded or replaced without creating excessive waste.
   c. The design allows building elements/components/materials to be easily disassembled.
   d. The potential has been maximized for components and materials being reused/recycled at their end of life.
   e. A Building Information Modelling (BIM) system or building handbook can be used to record which and how elements/components/materials have been designed for disassembly.
   f. The durability can be optimized to service life, or the design life can be extended.

The above points marked in grey and italic are less relevant to the objectives and concepts of the BAMB project and will therefore not be further developed in this report.

'Design for Reuse and Recovery'

The table below summarizes the application of the different principles for '*Design for Reuse and Recovery*' within the Pilot Projects.

	GTB Lab	REM	GDC	Circular Retrofit Lab	BRIC	New Office Building
a.	√	√	√	√	√	√
b.	√	×	√	√	√	×

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c.	√	√	√	√	√	√
e.	×	×	×	×	×	×

a. Elements can be retained and refurbished.
b. Materials from demolition of structures or other construction phases are reused in the design.
c. Materials can be reused at their highest value.
e. Equivalent materials and products are available with high recycled content.

All the Pilot Projects have been designed in a reversible way, enabling the elements to be retained and refurbished as well as the reuse of the materials (and products) at their highest value. The design criteria ‘Functional independence’, ‘systematization’, ‘Type of connection’ and ‘Relational dependency and relational pattern ’ seemed to be the most crucial design criteria for these requirements.

Most of the Pilot Projects have been using reclaimed or recycled materials except for the REMs, which are focusing on new products, and the New Office Building for which the use of recycled concrete aggregates, as was initially aimed for, was not feasible for logistical, economic and ecologic reasons (see § 2.6.1.).

The most difficult point to address in the above assessment is to find equivalent materials and products available with high recycled content. Not many building solutions exist, which anticipate changes during the life cycle of a building and optimise the reuse potential. The solutions that are on the market focus on the initial performance that is requested by architects and clients. In addition, not a lot of building products on the market are composed of recycled materials. The main reasons are that there is not always an economically feasible alternative for primary materials and the availability of secondary materials is often too low to adapt production techniques.

As a result, it is difficult to find alternatives that enable supporting the Reversible Building Design requirement while containing recycled content.

‘Design for offsite construction’

The table below summarizes the application of the different principles for ‘*Design for offsite construction’* within the Pilot Projects.

	GTB Lab	REM	GBD	Circular Retrofit Lab	BRIC	New Office Building

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a.	√	√	√	√	√	√
b.	√	√	√	√	√	√

a. Parts of the design can be manufactured off site.
b. On site activities can become a process of assembly rather than construction.

All pilots have been designed for offsite construction. Through mainly systematization and functional decomposition, building elements and systems were prefabricated and could be preassembled offsite. The 'Geometry and morphology' and the 'Type of connections' are also essential to guarantee smooth on-site assembly.

Design for Resource Optimization

The table below summarizes the application of the different principles for '*Design for Resource Optimization*' within the Pilot Projects.

	GTB Lab	REM	GBD	Circular Retrofit Lab	BRIC	New Office Building
a.	√	√	√	√	√	√
c.	√	√	√	√	√	√
d.	√	√	√	√	√	√

a. The design, form and layout is simplified without compromising the design concept.
c. The building is designed to standard material dimensions.
d. Sustainability of supply, durability, embodied carbon and embodied water is considered when specifying materials.

In all Pilot Projects the design form and the layout has been simplified without compromising the design concept. However, it has to be emphasized that the simplification is analyzed in equilibrium with rationalization and Reversible Building Design.

All pilots are also designed to standard material dimension where possible. The lack of multi-modularity between different design levels and different types of suppliers, however, is posing a challenge to enable designing all elements at all levels to standard dimensions. Although a modular grid is used on each of the design levels separately, the relationship between them is weak, creating dimensional problems where the grids overlap.

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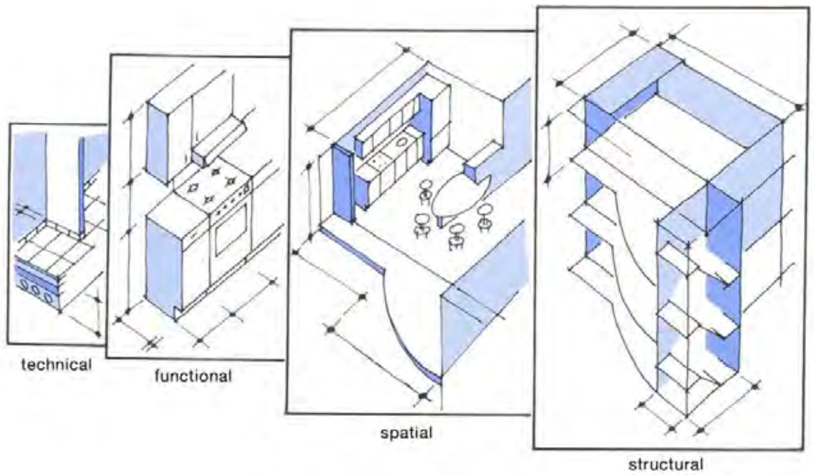

Figure 96: Design levels: technical, functional, special and structural level [De Troyer 2002]

The dimensions of spatial units enabling changing functions are for example not always compatible with the standardized dimensions on a technical or structural level.

Furthermore, within refurbishment projects, the dimensions of the existing building do not always make it possible to follow industry driven standard dimensions.

Sustainability criteria are key to the specification of the materials and products. An LCA assessment has e.g. been supporting the material procurement for the **New Office Building**. Environmental impact analyses will also be performed for the other Pilot Projects. It has to be emphasized, that within the scope of the BAMB project, this impact assessment cannot be performed separately form the reuse, transformation and recovery potential.

For the **Circular Retrofit Lab**, a life cycle assessment will be performed for different Reversible Building Design solutions taking into account different reuse scenarios. Because it is difficult to find one solution that meets all the criteria (i.e. *low initial environmental/financial impact; low life cycle environmental / financial impact; possibility to demount and reuse; use of reclaimed building materials; high assembly speed ; standardised solutions),* a selection of three wall solution types was made, each with different properties in relation to these criteria. The selection of solutions will be subject to a multi-criteria analysis.

Within the **New Office Building** pilot, LCA calculations have been performed for the DGNB Certification. All material-specific information were implemented at the planning stage and results of the LCA provided the basis for an ecologically motivated product and material selection. However, these LCA calculations could have had a more positive influence in the choice of the products. For the loadbearing structure, for example, the LCA showed benefits for a

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wooden construction. Because of an insecurity in regards to extra costs, bad acoustics and the feasibility in space & time, it was decided not to proceed with a wooden loadbearing structure. The use of normal cement versus CO_2-reduced eco-cement (CEM III instead CEM I) was also discussed.

Furthermore, financial life cycle cost calculations were done within the New Office Building design to compare a standard drywall with a C2C certified flexible wall system. The LCC study showed that the flexible system would be profitable after the 3rd repositioning. Due to this result, it was not selected within the project. This is supporting the need to perform LCC studies, taking into account several different use scenarios.

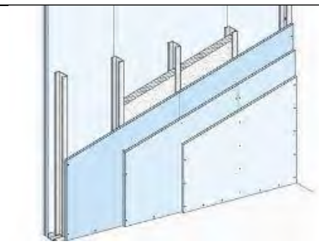
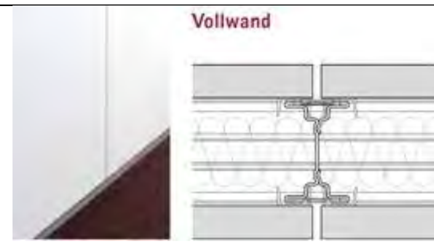
	 Standard dry wall system (eg.: System Knauf)	 System wall (eg.: Strähle System 2000 eco)
Initial production	€ 80,08	€ 170,10
Scenario 1: wall 1x repositioned	€ 184,53	€ 238,10
Scenario 2: wall 2x repositioned	€ 288,98	€ 306,10
Scenario 3: wall 2x repositioned	€ 393,43	€ 374,10

Figure 97: Calculations on comparison between standard drywall and flexible wall system

The integration of environmental impact assessment and Reversible Building Design is also part of the work performed in WP5A1 which will test the developed methodology on different Pilot Projects.

'<u>Design for Resource Efficient Procurement</u>'

The table below summarizes the application of the different principles for '*Design for Resource Efficient Procurement*' within the Pilot Projects.

	GTB Lab	REM	GBD	Circular Retrofit Lab	BRIC	New Office Building

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a.	×	×	×	×	×	×
b.	×	×	×	×	×	×
c.	√	√	√	√	√	√
d.	×	×	×	×	×	√
e.	√	√	√	√	√	√

a. Research is carried out by the design team to identify where on site waste arises.
b. Construction practices and plant are used to reduce emissions, energy, water use and waste on site.
c. Specialist contractors are consulted during the design process to contribute ideas from their experience.
d. Specifications are reviewed to ensure elements/components/materials are selected which contribute to the project's resource efficiency objectives.
e. The program allows time for the incorporation of resource efficiency measures adopted.

Although none of the design teams of the Pilot Projects have at this stage carried out specific research to identify where on site waste arises, all pilots have given attention to the construction modes in order to reduce the production of waste on site. Pre-fabrication is seen as an efficient way to reduce emissions, energy, water use and waste on site. It has been preferred by many Pilot Projects to reduce the waste production on site. For the New Office Building, groundwork construction machines with low emissions were selected, to reduce the impact on site.

In order to integrate circularity within the building design, construction and management, cooperation and sharing of information between the different stakeholders is key. This is especially true for the design stage in which the cooperation with specialist contractors, manufacturers and product suppliers are essential to enable not only the design of circular products but also develop the corresponding strategies in regard to the use, maintenance and transformation logistics and business models.

Since most of the Pilot Projects have not started the construction phase yet, and are currently preparing the procurement phase, the design and construction specifications are not yet fully reviewed to ensure that the elements/components/materials which contribute to the projects' resource efficiency are selected. For the **New Office Building**, however, the contracts and specifications have received special attention in order to guarantee that the project meets its objectives (see §7.5)

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‘Design for Future’

The table below summarizes the application of the different principles for ‘*Design for Future’* within the Pilot Projects.

	GTB Lab	REM	GBD	Circular Retrofit Lab	BRIC	New Office Building
a.	√	√	√	√	√	√
b.	√	√	√	√	√	√
c.	√	√	√	√	√	√
d.	√	√	√	√	√	√
e.	√	√	√	√	√	√
f.	√	√	√	√	√	√

a) The design ensures that the building is flexible in use and easily adaptable to changes of use over its life span.
b) Building elements and components can be maintained, upgraded or replaced without creating excessive waste.
c) The design allows building elements/components/materials to be easily disassembled.
d) The potential has been maximized for components and materials being reused/recycled at their end of life.
e) A Building Information Modelling (BIM) system or building handbook can be used to record which and how elements/components/materials have been designed for disassembly.
f) The durability can be optimized to service life, or the design life can be extended.

Design for future is the essence of the BAMB project and thus the Pilot Projects which are aiming to implement and investigate the circularity approaches developed within the BAMB project.

‘Functional independence’, ‘Systematization’, ‘Relational dependency and relational pattern’, and the ‘Type of connections’ are the most relevant design directives required to meet the principles of ‘*Design for Future’* as described above.

It was also investigated for which layers the above mentioned principles have been applied.

Reversible design is most difficult to reach for the *groundworks* and foundation. Only the pilot BRIC could take some substantial action on this layer. BRIC used screwable foundations, which

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can be reused after dismantling the construction. This type of foundation can currently only be used for light and small modules.

For all other layers (Structure, technical services, building skin and infill), the resource efficiency requirements were met, thanks to the use of the Reversible Building Design guidelines developed within Work Package 3.

The main effort has been focusing on the design of the structure and skin since these two layers are usually not designed according to circular and dynamic building design principles. Dismountable solutions for infill are more common, even though they are often not designed for reuse of transformation, reducing the recovery potential.

Following the approach of functional adaptability, which supports changing functions, and the principle of layering, the loadbearing structure and techniques are designed to support versatility and transformation without a major impact on this layer. However, even if the transformation rate is limited, they are still designed to be disassembled and recovered.

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6 INTERACTION WITH THE VALUE NETWORK

Besides the testing of circular building design concepts and the BAMB tools, the Pilot Projects also aim to involve stakeholders in the design and (de)construction of dynamic and circular buildings in order to:

- Confront the concepts and results with the reality of the construction sector
- Receive feedback from different stakeholders through real life field experiments, through active involvement in the development, manufacturing, construction and use of the reversibly designed buildings, components and materials.
- Give the opportunity to stakeholders to become pioneers in circular and dynamic building solutions and by doing so inspire other stakeholders.

Furthermore, as has been described above, the development of a Reversible Building within a circular economy approach, requires the involvement of all of the different stakeholders from the early stages of the project on, as well as a cooperative work process in which information is shared and stakeholders can learn from each other while improving the quality of the building, its components and materials.

6.1 Stakeholders

6.1.1 Joint partnership

Within the **GTB Lab,** a joint platform for innovation, a platform that brings together industry partners, knowledge institutions and governance was founded. Together, the stakeholders aim to work on the following questions concerning the transition to a circular economy:

- *"How to transform the built environment, which is perceived as rigid and static with no ability to modify itself without massive demolition operations and the consumption of resources, into a dynamic and circular built environment that can be upgraded without having a negative impact through the loss of materials and capital invested in the initial construction?"*
- *"How to transform design for one end of life of a building (demolition) into design for multiple lives of buildings and its materials?"*

In order to answer such fundamental questions that affect the design process, the construction process, the manufacturing process, logistics and the operation of buildings, the creation of a physical lab has been initiated.

For the **Circular Retrofit Lab**, a steering group was set up to check at any time if the initial aims are being respected during the development of the Circular Retrofit Lab's solutions, and to evaluate the feasibility of the planning and budget. The group consists of the building owner (VUB), the TRANSFORM research team (VUB), the architect (Kaderstudio), IBGE (as the Work Package 4 leader), the general construction coordinator (Groep Van Roey) and the engineering

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office (MK engineering). Groep van Roey, a general building provider, joined the steering group as an industrial partner of the Circular Retrofit Lab. Their aim is to detect opportunities and barriers during the development of the pilot, in order to apply these useful lessons to their own business case. MK engineering is an engineering office that offers a consultant service in the field of energy, sustainability and technical services (heating, ventilation, air conditioning, electricity, sanitary fittings …). Their role is to give advice to the steering group as an expert in low energy buildings and as an EPB[12] expert.

Furthermore, a group of stakeholders, including industrial partners, has been put together for this specific Pilot Project, enabling the stakeholders to work together on the development of innovative dynamic and circular solutions.

For the **GDC**, Sarajevo Green Design Foundation (SGDF) has set up a consortium in collaboration with the city of Mostar. This consortium consists of the municipality of Mostar, two universities of Mostar, a local NGO (Architectural Dialog Association) and SGDF. Besides the public consortium, a cluster of local industries has been initiated that includes the wood cluster (an association of 30 local companies which are producing wooden products), the energy consortium Alfa Therm (consists of an engineering department and production department for the production of installation of heat-pumps) and the local aluminium industry (which produces aluminium profiles for the local and international market).

6.1.2 Industry partners

To inspire industry partners to collaborate with the Pilot Projects, two different types of meetings were organized. First, in addition to a general BAMB stakeholder network event, stakeholder meetings have been organized for each pilot, where the project was presented and the possibilities of collaboration, together with the participating stakeholders were investigated. Second, face-to-face meetings were fixed with partners who showed a profound interest, to investigate the actual collaboration. This appeared to be necessary, because all interested partners have different objectives to participate and a partnership that is beneficial for both parties had to be found. Also, during these meetings, innovations or expertise of the stakeholders could be discussed. The collaborations have been translated into different kinds of conventions and contracts (see chapter 6.1.5).

Most stakeholders are not familiar with Reversible Building Design principles, and it is difficult to convince them to apply the required techniques. Within the **REM** pilot, the interaction between the design team and the builder, who were not in direct contact with EPEA, resulted in a discussion on how strictly the design principles should be followed: the contractor preferred well-known and tested solutions and discarded the provided construction details as not critical (such as

[12] Energy Performance and Indoor Climate

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100% glue-free construction). Based on this experience, the detailing and building of the prototypes and exhibition will from now on be done within a building-team, through which EPEA will be in direct contact with all actors involved in the design and construction of the modules.

A particular challenge of the **New Office Building** Pilot Project is to bring together a complex organizational and management structure with a high demand for sustainability. No direct contractual relationship exists between the client and the responsible construction companies. This leads to additional effort. The project is characterized by a highly complex settlement structure. Several levels of sub-commissions exist, all of them have the risk of debilitating the objectives. However, these difficult market conditions reflect the reality of the German construction industry. The implementation of sustainability requirements and recyclability will therefore be tested under difficult, but realistic conditions.

The following graph shows the organisational structure of the New Office Building pilot:

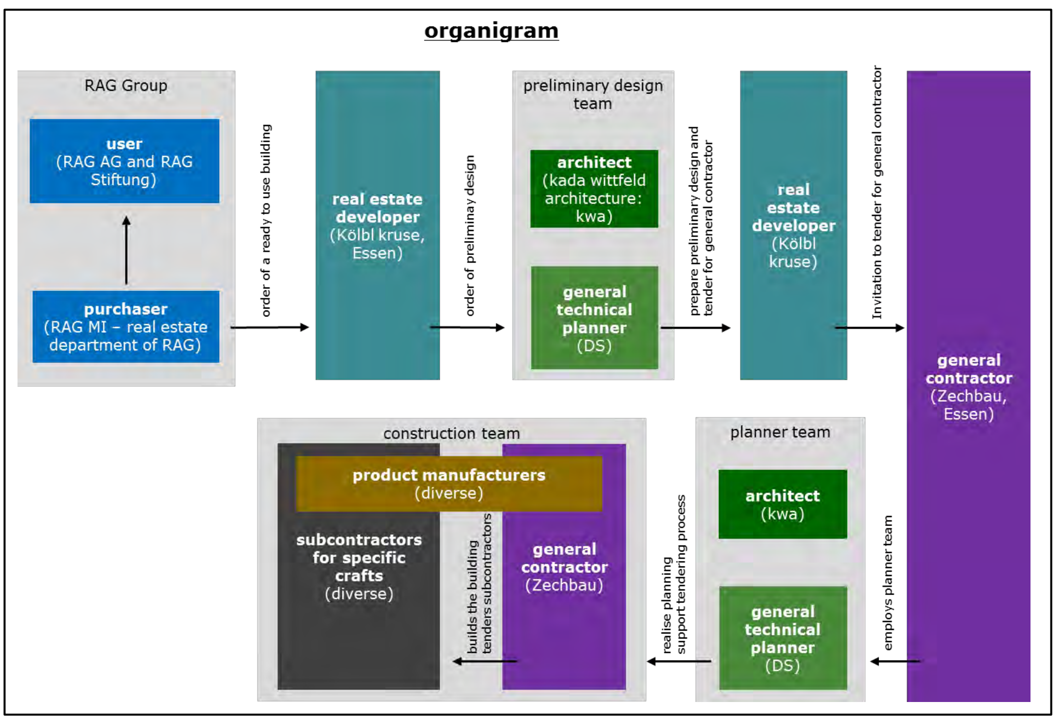

Figure 98: Organigram of the pilot project "new office building" in Essen

Explanation of the organisation structure of the projects:

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- At the top is RAG Montan Immobilien GmbH (RAG mi) as a real estate division of the RAG Group. They are responsible for the construction on behalf of the future users (RAG Aktiengesellschaft and Rag Stiftung).
- In turn, RAG MI awarded project development to the Essen project development company Kaiser Kruse GmbH. Kaiser Kruse GmbH guarantees users the completion of a move-in-ready building in accordance with the agreed conditions specific to quality, quantity, costs and deadlines.
- In order to move the project forward, Kaiser Kruse commissioned a design team consisting of Kadawittfeld Architecture (Aachen) and Drees & Sommer/DS-Plan for all engineering services commissioned to push planning forward to facilitate obtaining all permits and approvals.
- On the basis of this plan, a general contractor tender was then carried out and awarded the tender to Essen-based company Zechbau GmbH.
- Zechbau decided to continue with the creation of the planning team (Kadawittfeld and DS plan) and to carry out implementation planning and to supervise the tendering and awarding process.
- In a final step, Zechbau commissioned various sub-contractors to work on the facade, drywall and to perform technical installations.

Against the backdrop of the BAMB research project's objectives, the intricate network of contractual dependencies and responsibilities was a special challenge. One important focus of the work was therefore the integration of BAMB topics into all phases of the tendering process.

6.1.3 Municipalities

In the **GTB Lab** pilot, as well as in the **GDC**, the municipalities of Heerlen and Mostar respectively play an important role.

Public bodies (IBA, the Province of Limburg, the municapility of Heerlen and Parkstad) support and promote the development of the **GTB Lab**. They form a network that help to define the pilot and spin-off projects. IBA is promoting the GTB Lab at all of its international events in Germany and in their newsletters. IBA is also suporting the GTB Lab by providing assistance in legal issues, business models and communication with legislative bodies for the building permits. Parkstad is promoting the GTB Lab to stakeholders in Limburg and assists in negotiations with respect to the location and future exploitation of the GTB Lab. The province of Limburg is assisting, by looking at how to embed the GTB Lab in strategic programs for circular economy to boost the development of the Limburg Province. The municapility of Heerlen is assisting with location and legal issues with respect to the permits.

The city of Mostar has dedicated a plot of ca 4000m² for the development of **GDC**, 2 km outside of the city centre. The plot was a former military building site and will be transformed into a city

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recreation zone and innovation park along the river site, according to city planning. The City of Mostar will be the owner of the GDC, but a joint ownership with contractors & material suppliers is being investigated.

The GDC has a written agreement with the municipality of Mostar concerning issues that will be covered by the municipality of Mostar (location, preparation of the construction site, building permit procedures and taxes). The two universities in Mostar have been assigned by the municipality to provide initial studies on the capacity of the existing structure, a geological report and a contribution to the final design.

Both municipalities are supporting these innovative and experimental circular building projects for the same reasons. The first being the aim to make themselves known as circular building pioneers. Furthermore, both municipalities see in the experiments the opportunity to support the local building industry in the transition towards a circular economy. Increasing the competitiveness of the local companies will also foster the local economy.

6.1.4 Designers

For the Pilot Projects in which external design offices have been involved, which aren't experts on Reversible Building Design, workshops were necessary for experts to support them in the integration of reversible and change supporting design aspects. A shift in design culture is needed. Not only mentally, but also in regards to the timing of the different phases in the design process and the organization of the construction process.

For the **REM** Pilot Project, a design team with in-depth knowledge of Reversible Building Design could not be found. It was decided to work with a team specialized in exhibition design, and implement the knowledge of EPEA in the design process to ensure the correct application of Reversible Building Design principles. Also, a design workshop with Work Package 3 (Reversible Building Design) and several teleconferences with Elma Durmisevic were organized. The different possibilities of including Reversible Building Design principles in the REMs were investigated and discussed. It was concluded to focus on reversibility on the product level rather than on the building level, which resulted in a modular design. This allowed for complimentary cooperation between the Green Transformable Building Lab and the REMs, both focusing on specific topics of BAMB.

The architect responsible for the design of the **BRIC** project wasn't familiar with Reversible Building Design concepts at the start of the project. To give the essential support, design workshops were organized with Work Package 3 (by the VUB transform team). However, it was very difficult to stimulate a shift in thinking and let go of the 'traditional' way of designing. Several meetings had to be organized to explain the necessities of dry connections, and the importance of standardized dimensions and standardized connections. Furthermore, the reversed

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logistics and reconfiguration of the elements into a new module requires in depth detailing of different scenarios at an earlier stage of the design process than would be the case in a 'classic' approach during which construction details are sometimes only developed during the construction process. From this experience, it can be concluded that a shift in mind set and the need for a different design approach still is an important step to tackle.

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7 FEEDBACK ON BAMB OUTPUTS

The 6 Pilot Projects developed within the BAMB project aim to investigate different aspects related to buildings which can be materials banks. Besides the market readiness and the practical application of circular and dynamic building design with stakeholders, the different outputs and tools developed within the BAMB project are analysed and tested within the Pilot Projects. This chapter develops the lessons learned from the feasibility studies of the Pilot Projects in regards to circular economy in the built environment, and the use of Materials Passports, Reversible Building Design tools and circular business models.

7.1 Challenges resulting from the transition from a linear to a circular economy

Within the **GTB Lab** pilot, a workshop was organized, together with 9 stakeholders and VITO, to discuss how to stimulate circular ideas through the participating companies and to identify the innovation needs and potential challenges when turning ideas into circular business models.

After extensive discussions with the GTB Lab partners, where they could share their challenges and ideas on circular constructions, three points for further debate have been identified:

1. Competition in the building sector is mainly based on costs.
2. Transparency and trust in the building supply chain is needed.
3. Legislation forms barriers.

These challenges, which have been confirmed within other Pilot Projects, could be summarized into three categories defined as a part of the systemic change towards circular economy: 'mind-shift', 'co-creation', 'integrated decision-making'.

<u>Mind-shift (Competition in the building sector is mainly based on costs):</u>

The following barriers were identified:

- People are not willing to pay for additional engineering (which is needed to calculate possible transformations).
- Additional costs for transformable building components are perceived as high.
- Uncertainty regarding residual costs of buildings and building components makes it hard to use residual value in the economic model as an argument.

The proposed solutions are:

- Find the right customers (that are more open to understanding the benefits of sustainable and transformable building): their experience can help convince others.
- Standardization (especially, in the short term for connections) can help lower the costs and increase the residual value.
- Need for bank/insurance guarantees on residual value.
- Need to substantiate the financial business case with appropriate risk factors

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- Secondary resources and reused components are perceived as low quality, therefore a mind shift is needed: testing, certification and Materials Passports can play a role in addressing this.

Co-creation (Transparency and trust in the building supply chain is needed):
If something is more expensive than normal, other actors in the supply chain automatically assume someone is raising their margins, even if the estimated life cycle cost decreases. The solution for this is co-creation / co-making processes. The client, design team, suppliers and builders can help build this trust. This, however, requires time and willingness to adapt the procurement process.

Integrated decision-making (Legislation forms barriers):
Public procurement isn't adapted to accommodate transformable buildings. Often, the cheapest (architectural) solution on paper wins the contract. Although change-supporting and circular designs are not necessarily more expensive than traditional architectural solutions, life cycle gains/costs are rarely taken into account in public (and also private) procurement. Also, potential environmental and social impacts/benefits are rarely taken into account in decision-making. To address this, awareness has to be raised within decision-makers, by providing user-friendly instruments, in which potential life cycle financial costs and externalities are integrated in the assessment of building design solutions.

A fourth challenge has also been identified: Lack of knowledge and information

Many aspects of a circular economy are still unknown in the current building industry. This has been illustrated within the **Circular Retrofit Lab** pilot, in which the involved stakeholders do not apply circular and Reversible Building Design. However, the interest is increasing, and stakeholders are eager to learn how circular buildings may create new business opportunities in the future, and how it can support the transformation of buildings in the long term. For building owners, circular buildings may improve the quality and comfort of their buildings, since they can be adapted and maintained more easily, without the need for destructive transformation works. For investors, the future flexibility of buildings may create new business opportunities, as circular buildings create more spatial and functional opportunities for an unknown future with unknown users of a building.

Many stakeholders are willing to think out of the box and discover new opportunities within the BAMB project. These stakeholders include engineering offices, product manufacturers, general contractors, etc. Their expertise in each building domain enabled the identification of opportunities for circular and change supporting buildings.

Currently, reuse of existing product and materials is difficult to achieve, because there are too few open databases, listing reusable products and materials, available for designers. Designers often have to use their personal contacts to investigate the possibility of reusing construction materials.

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Also, the information of the reusable products is limited. Quality and performance details are often lacking. This can be improved by providing an open platform through which all materials coming from the exhisting buildings will be collected and classified.

The use of reversible construction methods or the reuse of existing materials does not only depend on the availibility of materials, but also on the creativity of designers. It takes a lot of time and a change of design culture to arrive at workable design solutions. Creativity can drastically reverse the waste stream into usable products.

7.2 Materials Passports Platform

The developed structure of the Materials Passports (MP) has been tested on a total of six Pilot Projects. For each of the BAMB Pilot Projects, up to five building materials and systems were selected to be subjects of the passports testing phase. In addition to the BAMB pilots, the NexusHaus - a modular residential green building that demonstrates transformative technologies in Zero Net Energy, is Zero Net Water capable and is carbon neutral in its use of sustainable building materials- was also assessed as a Pilot Project for Materials Passports (http://www.nexushaus.com/). The NexusHaus, developed by the Technical University of Munich and the University of Texas at Austin, was presented at the 2015 Solar Decathlon at Orange County Great Park in Irvine, California. Due to data availability and building documentation, this building was chosen as the first Pilot Project.

An overview of created passports is given in § 3.2.

At the moment of data gathering, the Materials Passports software platform developed within Work Package 2 was not concluded. The collection process was conducted based on the input workbook developed within Work Package 2. Due to the complexity and extensive amount of questions, the implementation of the first Materials Passport was a time consuming process. After becoming familiar with the Materials Passport structure, it was possible to fill out a passport input workbook within 2 to 3 hours, depending on the availability of data and the product's complexity. It is expected that once the prototype of the Materials Passport software platform is available, the time taken for the data collection can be reduced.

There are common questions within the workbook, which could not be answered for multiple products. Data gaps are not an exception as all information could not be obtained for any of the created passports up to this stage. These include an overall lack of information for the following items in the Materials Passport input workbook:

- tax and credit benefits
- cost and value estimations
- detailed information for re- and next use scenarios

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- residue issues
- disassembly
- end of life
- next use potential
- handover agreements
- company registration number
- patent identifier
- BIM objects (However, few manufacturers and databases already provide BIM objects e.g. www.bimobject.com)

Nevertheless, Environmental Product Declarations (EPDs) have shown to be one of the most valuable sources of information for the generation of a Materials Passport data set. Detailed information on demands, impacts and offsets can be taken from an EPD if it exists for the relevant product.

Using the manufacturer's website and the design-stage report of the building (example NexusHaus), 30% - 40% of the Materials Passport information could be obtained. However, manufacturers tend to openly provide information about the product properties that are relevant for consumers, e.g. size, weight, installation instructions or CAD-drawings. Information about production and end-of-life are hardly given. Furthermore, for most products tested within the pilots, there was no detailed information available about the product's composition (i.e. ingredients or chemical composition), their origin and impact on the environment. The comprehensive description of the components' composition (chemical level), could in some cases not even be answered by the manufacturer or suppliers when they were approached directly. An overview of the required information flow for the creation of a Materials Passport is shown in Figure 99.

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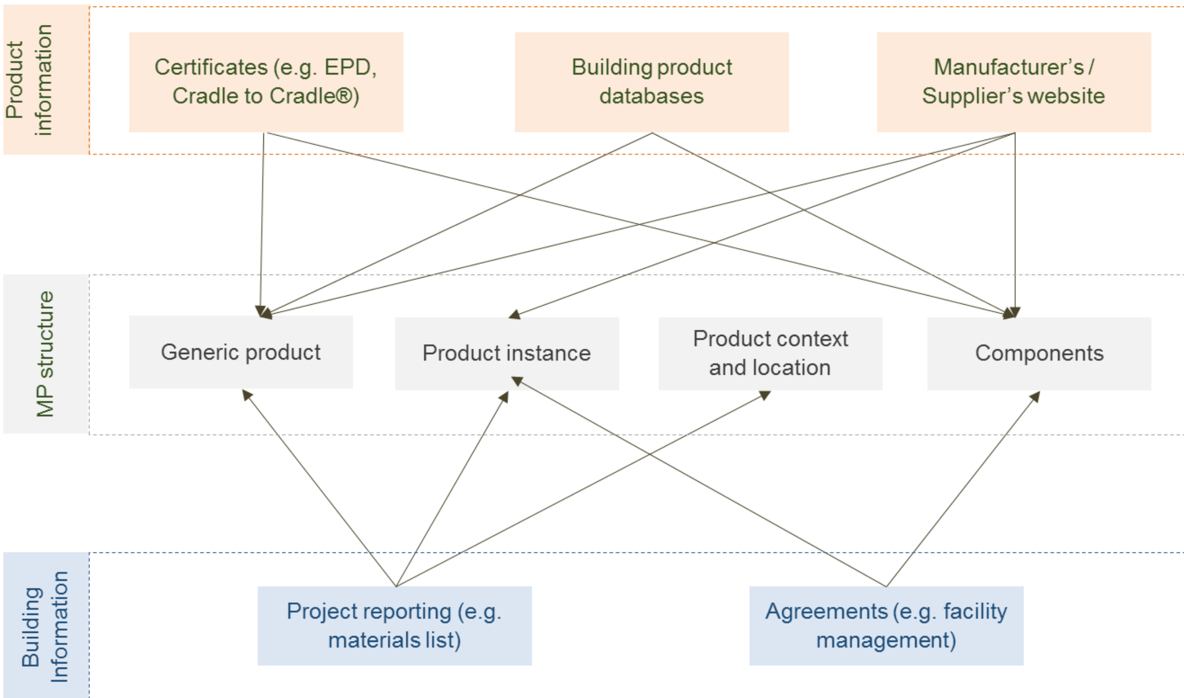

Figure 99: Information flow for stakeholder analysis along the value chain

The creation of Materials Passports is a dynamic process and information can be entered at different stages of the value chain. Some of the required information might not be relevant or is not available at this moment, but a Materials Passport can provide an insight and indication of which information will be needed in the future. Manufacturers, for example can start collecting this information when they introduce new products to the market.

Readily available information on the amount of resources needed for the production process and the types of by-products that are generated during the manufacturing process and use-period could not be found. Another concern was to find relevant information on material health issues. This kind of information needs to be taken directly from the manufacturer, if provided. Some of the questions in the Materials Passports ask for sensitive information (e.g. function of certain components within the product). To protect the intellectual property of some of the companies, this information cannot be shared with the general public. Moreover, some manufacturers may not want to publish information of detailed production processes or potential impacts on the environment, as this could be unfavorable for them.

It is suggested to more strongly involve suppliers and manufacturers in the development process of the MP and account for their individual needs. During the testing phase, certain suppliers were asked specific questions (e.g. chemical composition etc.), which were not readily available, via

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email or telephone, instead of providing them with the complete work book. Once the Materials Passportssoftware platform is ready, manufacturers can gain access to the platform, to ease the data collection process. This aspect will further be pursued during the next stages of the project. Connections to relevant suppliers and manufacturers have already been made up to this stage.

A stakeholder analysis along the value chain (*Figure 100*) can be conducted to provide the following information:

- At what time within the life cycle (e.g. planning, construction stages etc.) can which type of information be provided / is required?
- Which stakeholder can provide the information? (This aspect is also discussed in D5, section 4.1. and will be implemented in the Materials Passports software platform)
- Which stakeholder requires which type of information?

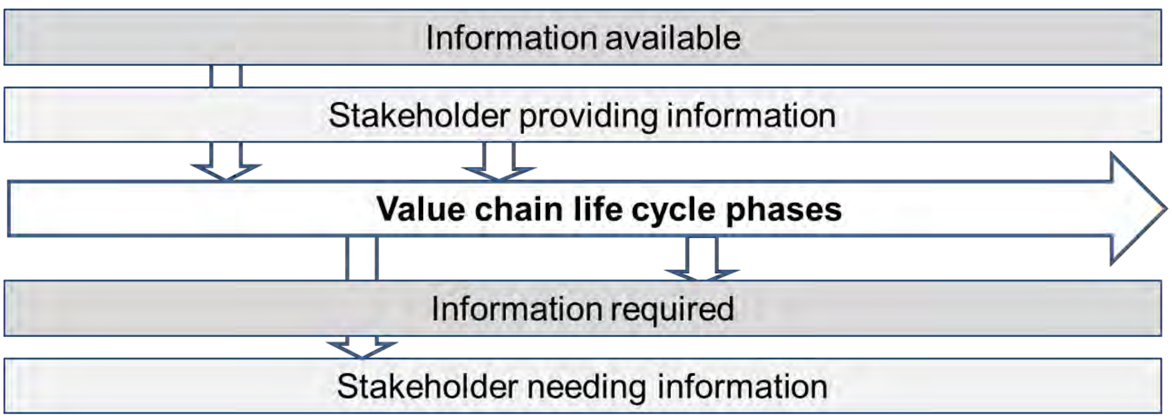

Figure 100: Overview of created Materials Passports for the Pilot Projects

The results of the stakeholder analysis (e.g. planner, demolisher, manufacturer etc.), coupled with a detailed life cycle phase overview (e.g. life cycle phases of buildings, material production, planning phases etc.) could be used as a filter for the Materials Passports to facilitate data gathering. An architect, for example, can provide building related information, but will in most cases not be able to provide detailed information about the chemical composition of a product. Information on instances (a specific component in a building) could be provided by a facility manager for example. Hence, the creation of a Materials Passport is an interdisciplinary task, which requires the input of multiple stakeholders.

Another common issue was the understanding of the hierarchy of different data sets (e.g. building-, product-, component-level etc.). A graphical description within the online system

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could provide clarification. This would also ensure a clearer navigation through the platform for the relevant users.

Not all information required within the Materials Passports is relevant for each product (e.g. reuse of paints). Next to the above mentioned filters, certain information can be hidden or prioritised, based on the product category to ease the implementation process. It was also suggested to provide pre-defined answers in a pulldown menu and information to where the relevant information can be obtained (e.g. EPD, product safety sheet etc.). These aspects will also be further investigated.

To ensure overall data quality, it is necessary to have a common understanding of the used terms and terminology (e.g. recycling, instances). The term recycling, might have a different meaning for different stakeholders (e.g. does it include 'down-cycling' or not?). The terms "instances" and "nutrients" for example, were interpreted differently by each pilot leader. It is recommended to include a glossary, or explanations (e.g. hover menu) at the relevant data entry points to eliminate misunderstandings and provide a common framework. Work Package 2 partners are addressing this issue, by improving the guidance for each input line.

The use of graphical explanation (e.g. term instances) can also aid the implementation process. This would also reduce the complexity of the system and make it more user-friendly. A common understanding will be vital in the further generation of Materials Passports.

The following table (*Figure 101*) shows an extract of comments from the pilot implementation:

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Section in MP	Input description	Comments
VALUE FOR USERS	Eliminating construction and renovation waste.	There are products that are not initially 'designed' for this, but that have the possibility to be relocated, reused, etc. It is not clear whether to fill in 'no' everywhere, since it was not designed for it, but eventually, it 'can' be reused, dismantled, etc.
	Removal for maintenance then re-installation, or for in-place maintenance without removal.	It is not clear how this field can be filled in for a steel profile stud. For the question 'for in-place maintenance without removal' it is also not really clear what is meant by this.
	Traceable history of materials and resource use from sourcing & manufacturing through to use.	What is meant by traceable and by whom (producer)?
	Compliance and standards adherence across the board, locally and internationally.	Field is unclear
	Providing an actively beneficial service that improves the quality of the building environment.	Unclear on what is meant by 'quality of the built environment' ?
	Improving flexibility of the building for diverse uses at diverse times of the day.	It is unclear how this can be answered for a steel profile.
	Recognized frontrunner innovation in the categories described previously.	What is meant with `recognised´? Recognised by who?
	Not considered	Field is unclear
MANUFACTURER AND PRODUCT INFO & BASIC FUNCTION	Product name / Brand name	What is the difference between the two?
	Generic Construction Products database. Specify	Field is unclear
	For how long will spare parts be available?	Field is unclear
	Types of residue, volumes, weights, who takes the materials offsite.	Field is unclear
NEXT USE POTENTIAL	Product is designed for the following biological cascade of uses:	Field is unclear
	Does the product, its components, and/or its components' ingredients have a quantifiable innovation which improves materials re-use potential?	Field is unclear

Figure 101: Extract of comments from pilot leaders

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Some important questions arose related to the provided data quality and will be addressed within the further development. Will the data need to be verified by a third party? What is the procedure for entering undesirable information about a product?

7.3 Reversible Building Design tools

In order to test and use the tool, it was important to have a good view on the structure and the materials used in the building. The following list shows the minimum required information to assess the reuse potential and the transformation capacity:

- Situation plan;
- Transformation scenarios (layout options);
- Characteristic floorplans & two sections;
- Floorplans with the position of the main installation network and marked zone for the installation distribution network;
- Drawings of facades;
- Principle solutions for the key connections;
    - vertical:
        1. load-bearing structure/ facade
        2. facade / roof
        3. floor/ non-load-bearing walls
        4. enclosing of installation ducts
    - horizontal: facade, wall, window, door
- General material specification list.

In the design plans, the materialization should be indicated. A complementary description of the design and the construction methods must be added. If possible, a 3D model should also be added, in order to get a better picture of the building.

The Reuse Potential Tool, which will be developed within Work Package 3 (focusing on the development of the Reversible Building Design tools), was tested for this feasibility study by 2 Pilot Projects: GTB Lab and GDC. The Transformation Capacity Tool, which is still under development will be tested later to assess the transformation of 4 Pilot Projects and will be presented in future reports (Deliverables D13 & D14).

Assessment of the initial design of the GTB Lab extension module

To start, the initial design of the extension module was assessed according to eight criteria based on the assessment framework of Durmisevic (2006). This analysis resulted in a spider diagram (see *Figure 106*) revealing the ease of disassembly and adaptation of the extension module.

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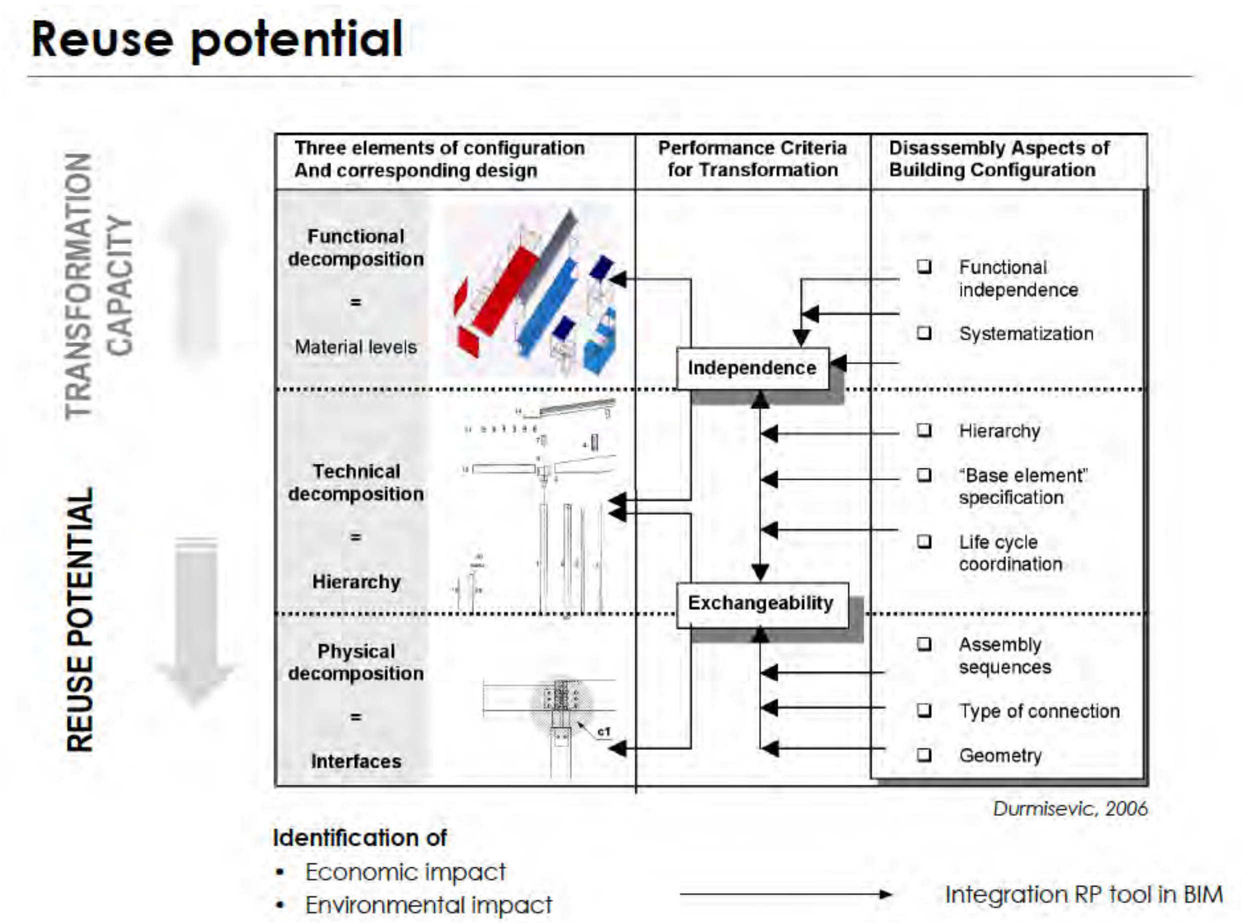

Figure 102: Assessment framework of Durmisevic

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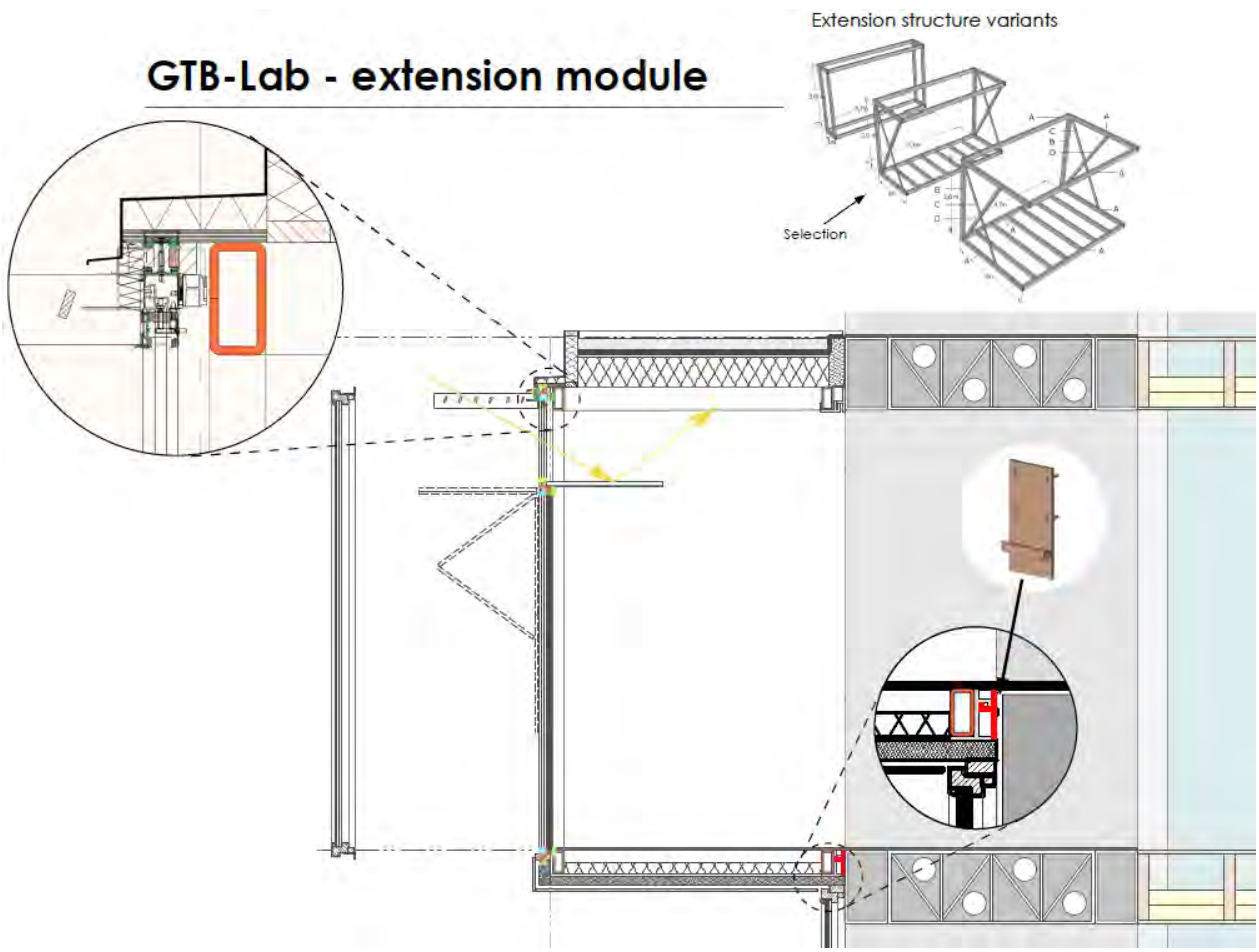

Figure 103: initial design of extension module

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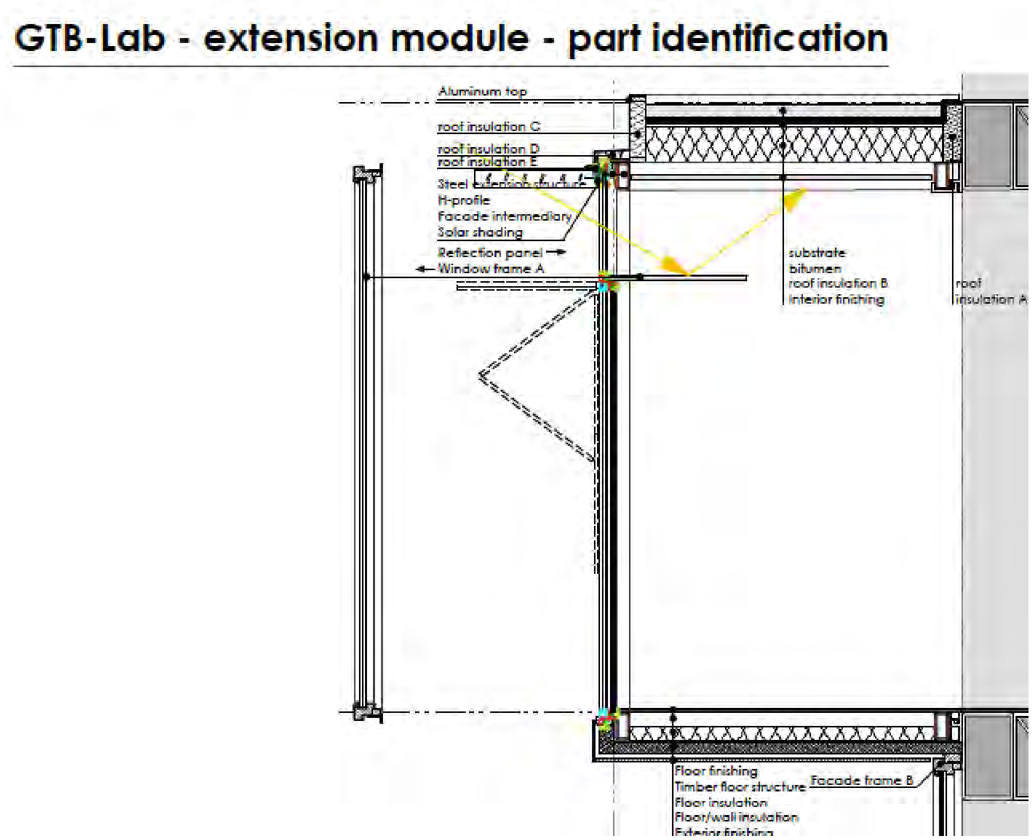

Figure 104: materialization of extension module (initial design)

The spider diagram, *Figure 106*, indicates that for several criteria there is much space for improvement in the design, such as the relational pattern, structure and material levels, and the type of connections. The improvement potential in the design can be traced back to the technical detailing of the module that is mainly based on separate elements rather than components and sub-systems and the various horizontal relations as shown in the relational pattern (*Figure 105*). This complicates the disassembly and will increase the time to perform changes to the module. The improved design of the extension module, described below, was based on the knowledge that was generated during the analysis of the initial design.

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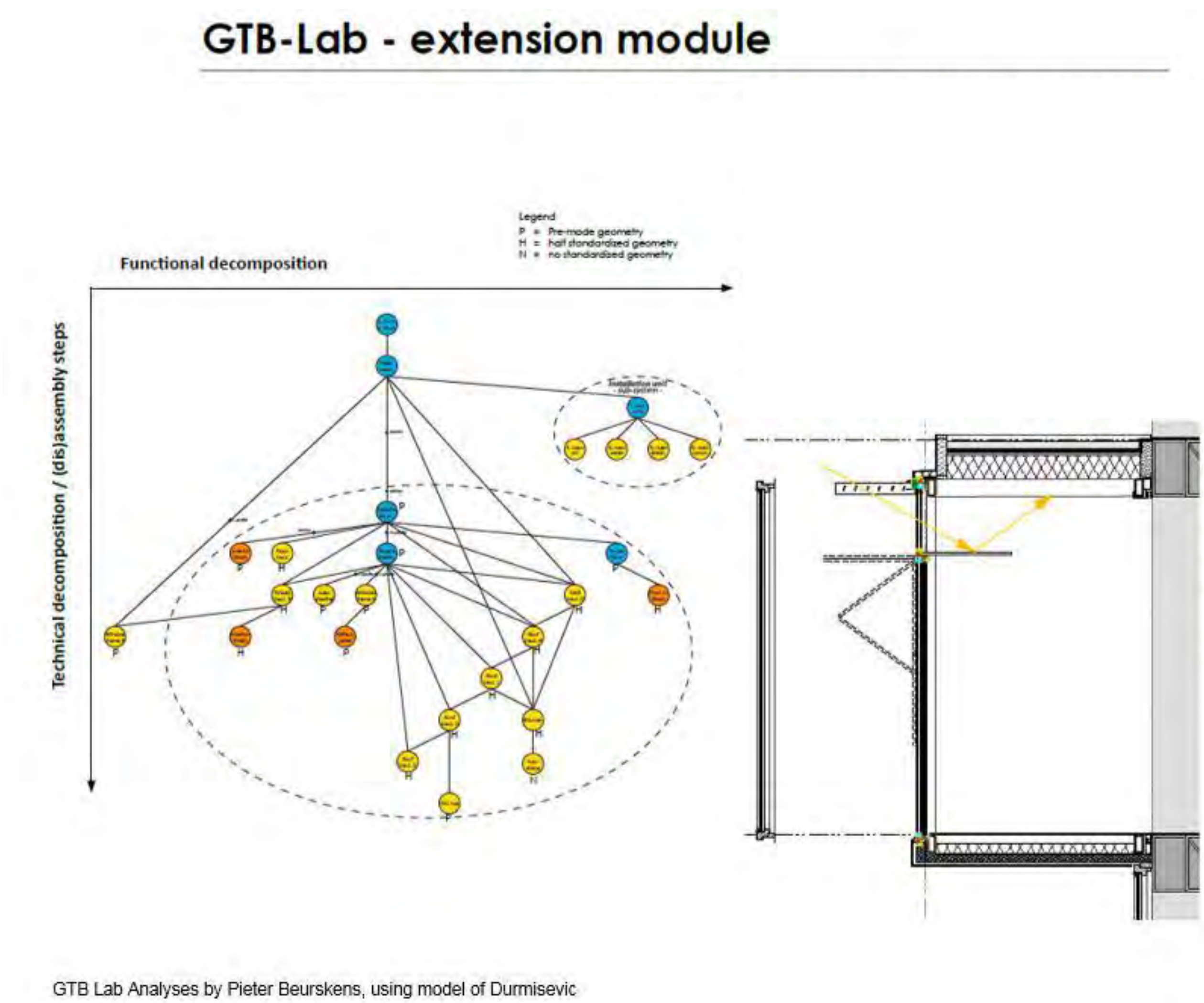

Figure 105: Initial design and its relational pattern diagram

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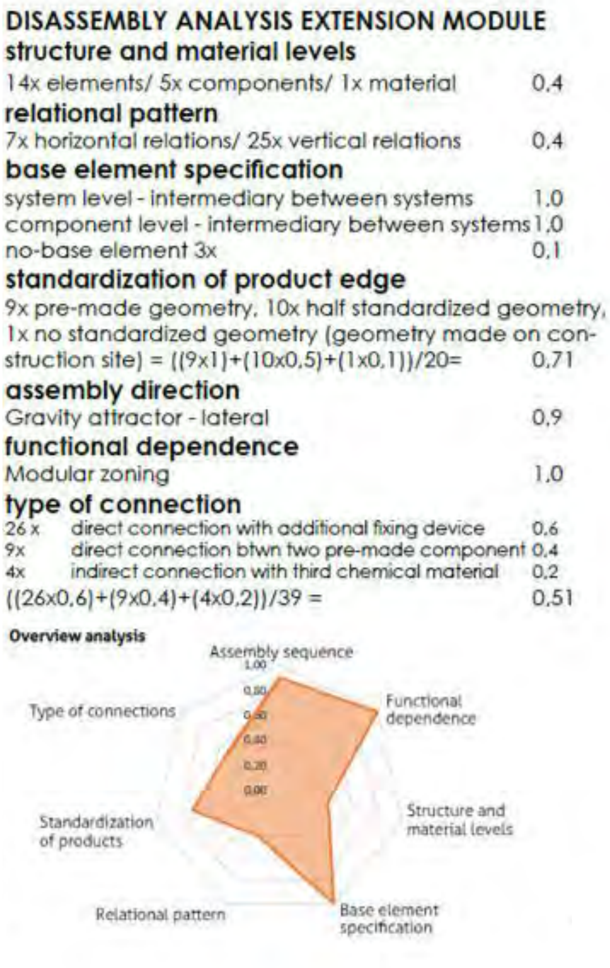

Figure 106: Spider diagram – assessment initial design

Figure 105 and *Figure 106* illustrate the initial design of the extension module and its relational pattern diagram, accompanied by the spider diagram of the assessment of the extension module.

Assessment of the improved design of the GTB Lab extension module

In the improved design, each functionality is separated into independent sub-assemblies that are connected to the base element (steel structure), which functions as an intermediary for the sub-systems (as shown in *Figure 107*). This allows the sub-systems to be easily assembled and disassembled and allows them to be easily reconfigured, repaired, replaced and removed. The

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spider diagram in *Figure 107* reveals that the changes made in the design result in a better score for several criteria, such as the structure and materials levels, the relational pattern, and the type of connections.

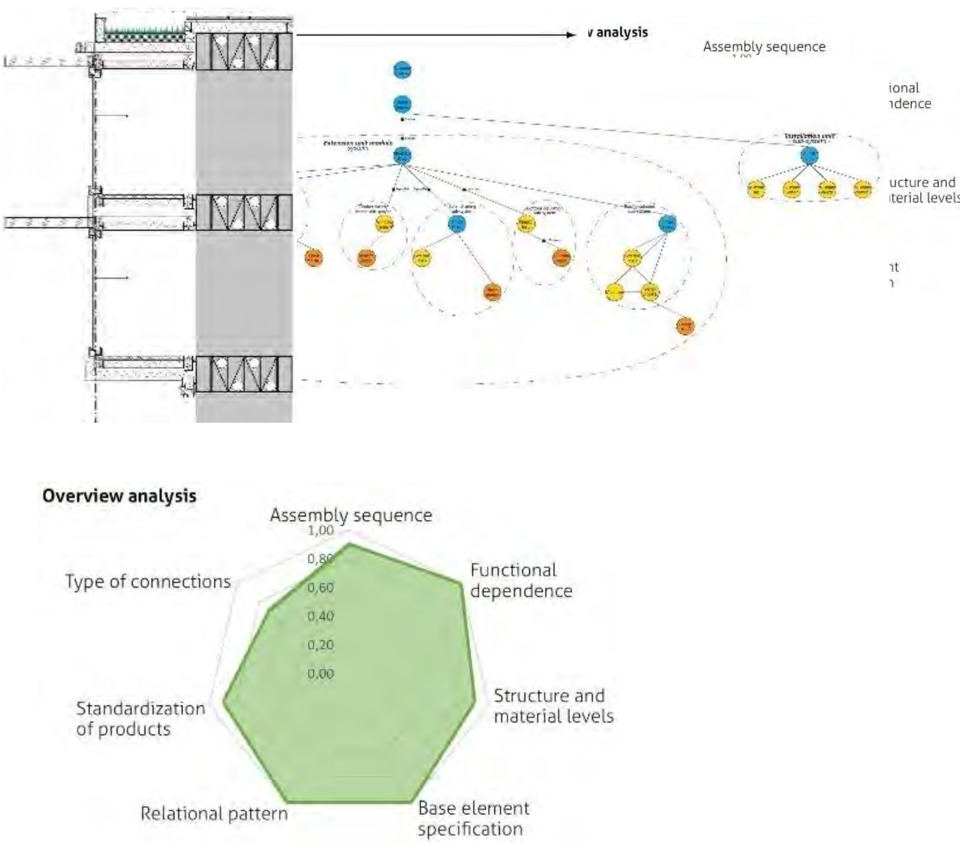

Figure 107: Improved design, its relational pattern diagram and spider diagram

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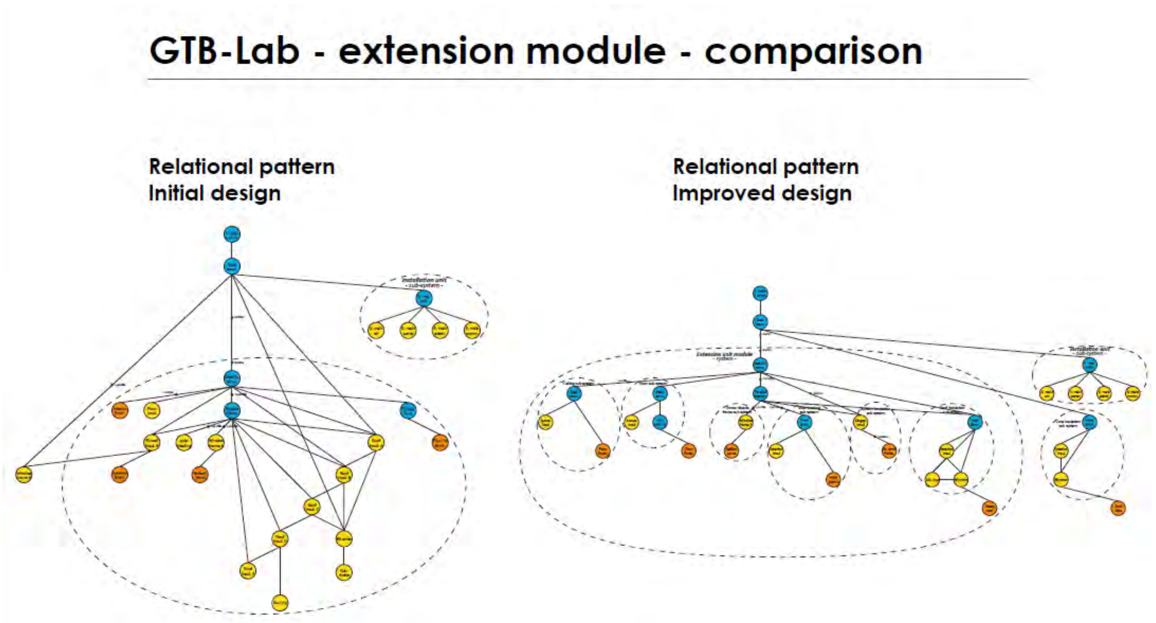

Figure 108: comparison initial and improved design - relational pattern diagram

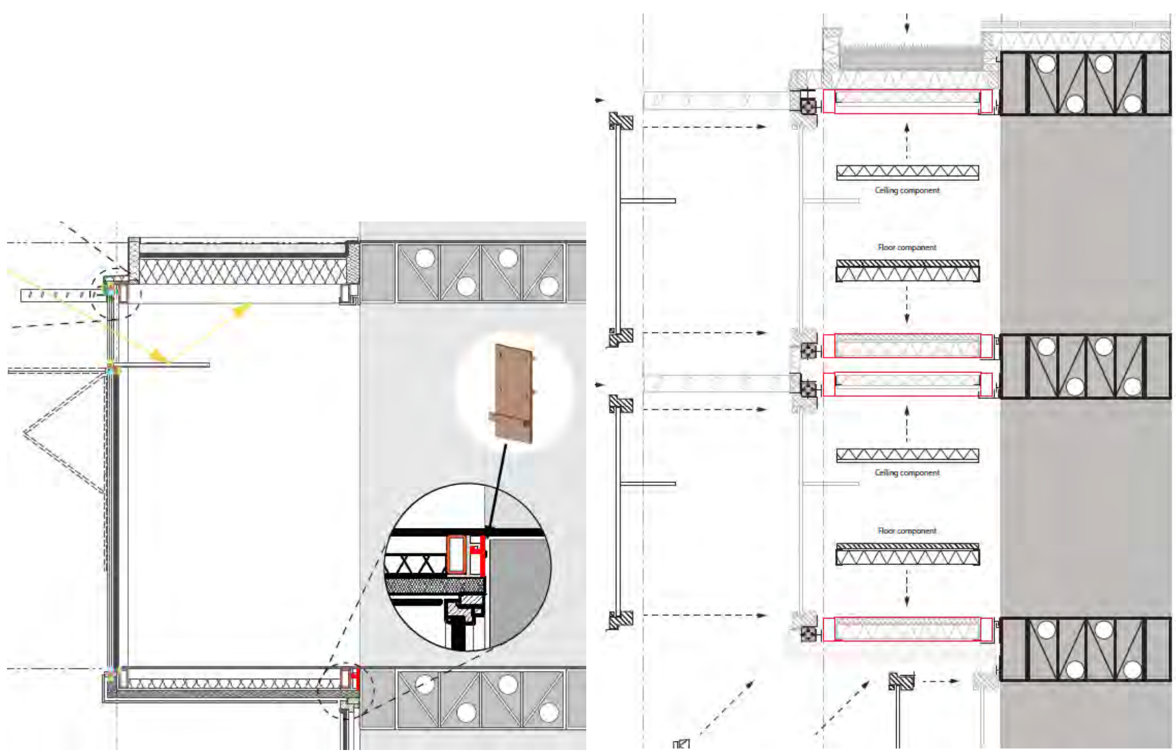

Figure 109: comparison initial and improved design relational pattern diagram

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The initial design of the preassembled extension of the GTB lab module can be disassembled back to the initial elements without damaging them. However, the spider diagram of the initial design does indicate that there are many points of improvement. The points of improvement are primarily related to the systematization of a clustering of elements on the subsystem level of a unit such as a roof, floor and ceiling into modular parts that can be disassembled as one module. In order to support the disassembly of individual subsystems without damaging them, basic elements have been introduced. With this approach, the spider diagram of the alternative design did improve significantly.

However, the fact that additional materials would be added and additional disassembly steps would be required, might increase the financial costs and environmental impacts of the solution. In the next phase of tool development, the financial feasibility and environmental assessment of design solutions will be used as input for the possible calibration of the tool and the optimization of a number of base elements and disassembly steps with economic and environmental impact.

Assessment of the initial design of the Green Design Centre pre-fab module

The initial design of the prefab roof component was assessed according to eight criteria within the assessment framework of Durmisevic (2006). This analysis resulted in a spider diagram revealing the ease of disassembly and adaptation of the extension module, as shown in the *Figure 110* below.

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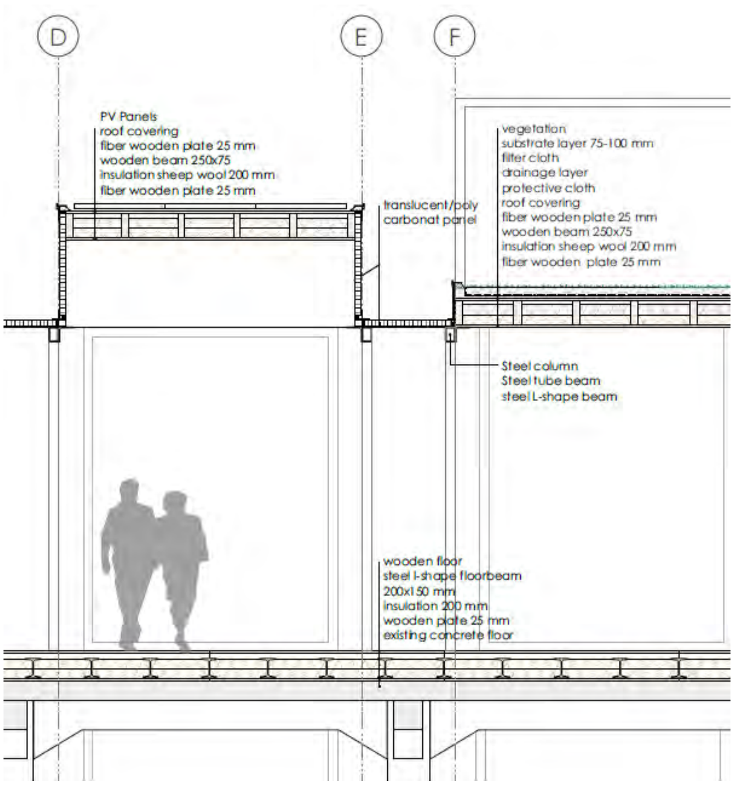

Figure 110: initial design GDC

The spider diagram (*Figure 111*) below indicates that for some criteria there is space for improvement in the design, more specifically on the assembly directions and relational pattern, representing the type of dependencies between different building parts.

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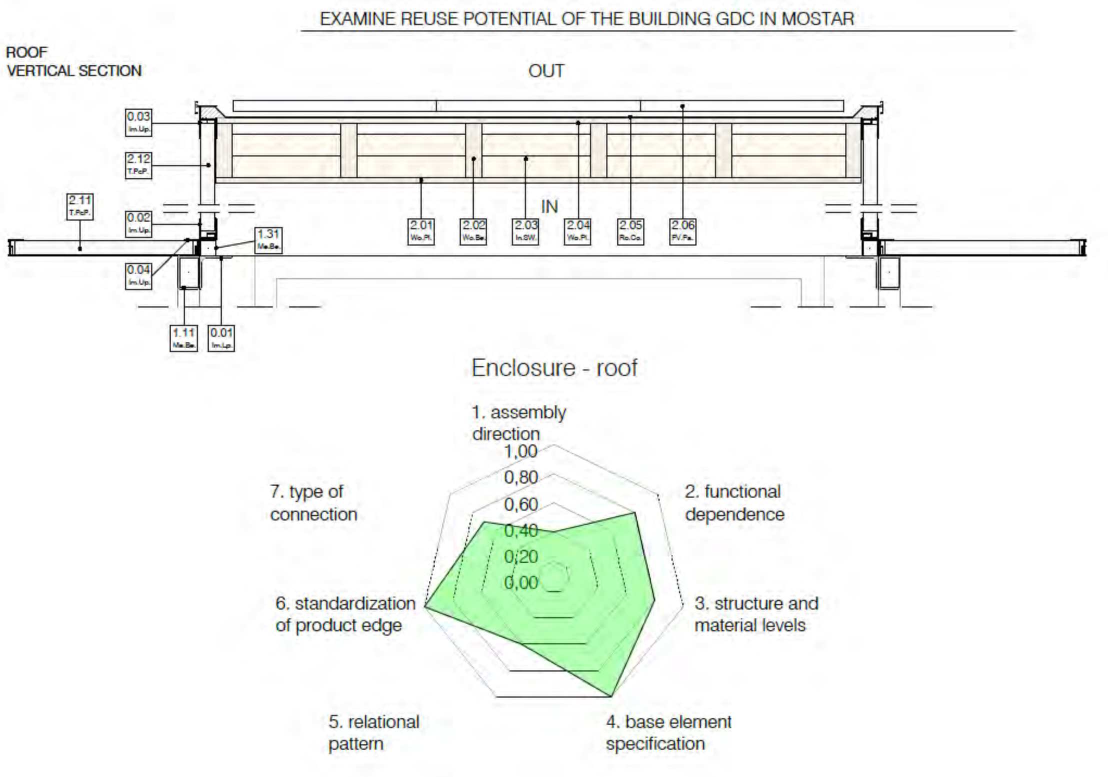

Figure 111: spider diagram GDC initial design

The analysis of the assembly and disassembly sequences indicated detailing could be improved to allow more parallel and independent assembly and disassembly of the facade and the roof. This will also impact the detailing in regard to the type of connections, the basic element and their relational pattern.

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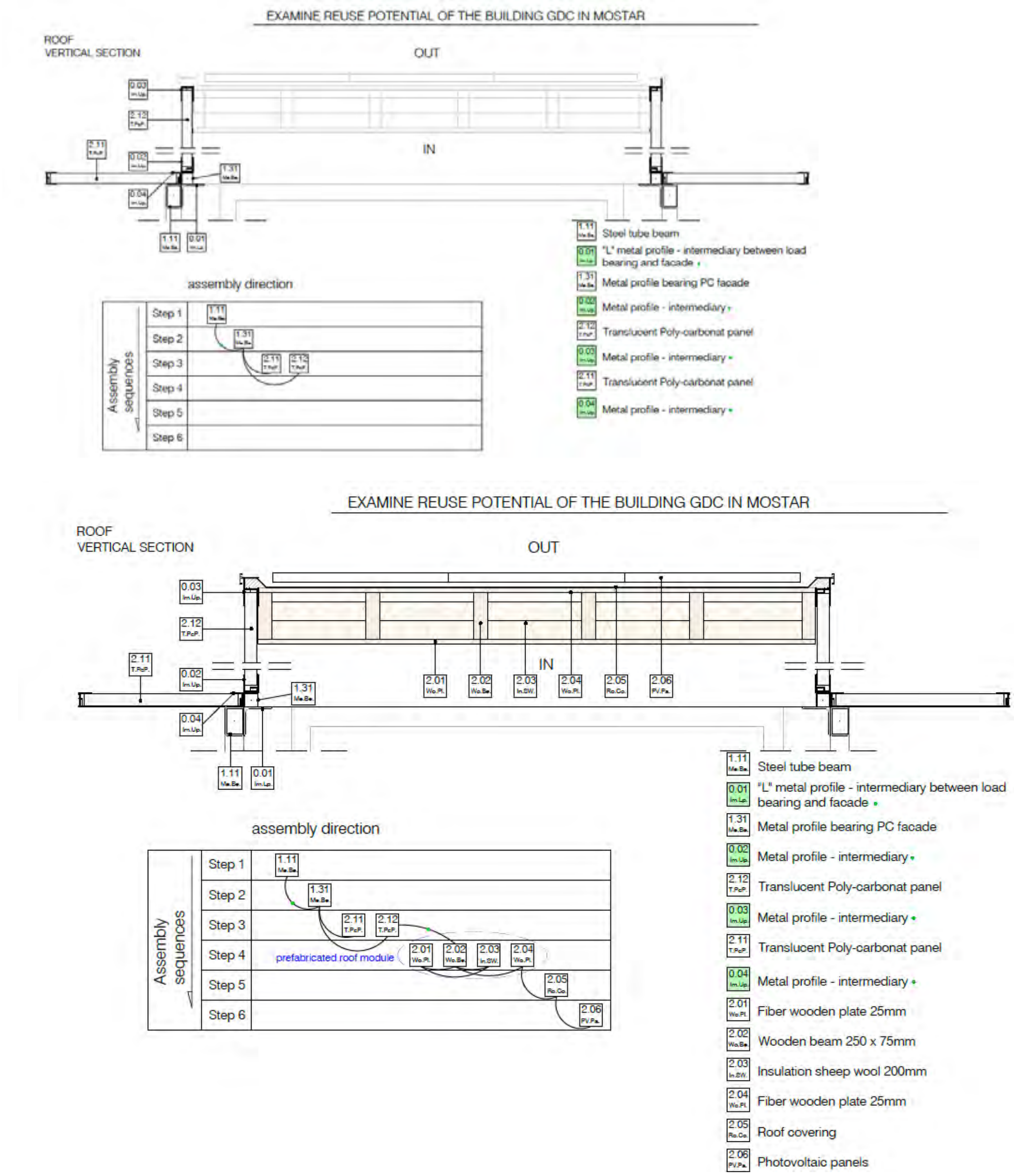

Figure 112: Reuse potential analysis GDC

The assembly and disassembly diagram above illustrates the dependencies between the different elements and the resulting subsequent sequences when assembling the facade and roof components.

Based on the analysis, the design can primarily be improved by reducing the functional dependencies. This can be achieved by designing the facade and roof as two independent functional clusters in the low level of assembly (see diagrams of criteria 4). This has resulted in

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sequential assembly sequences of the roof (criteria 6) and dependency that can be traced back to horizontal relations in earlier assembly steps, as illustrated by the relational diagram (criteria 4).

An improved connection with intermediaries is presented in the figure 113 below. The figure left shows the dependency between the horizontal finishing and isolation of the roof with the profile which is fixing the vertical facade elements to the roof. The fixing profile is accessible only after removing part of the roof insulation and finishing.

The figure right shows the improved connection. The steel profile has been inserted between roof and facade clusters as an intermediary in order to allow disassembly of the facade panels without affecting the roof.

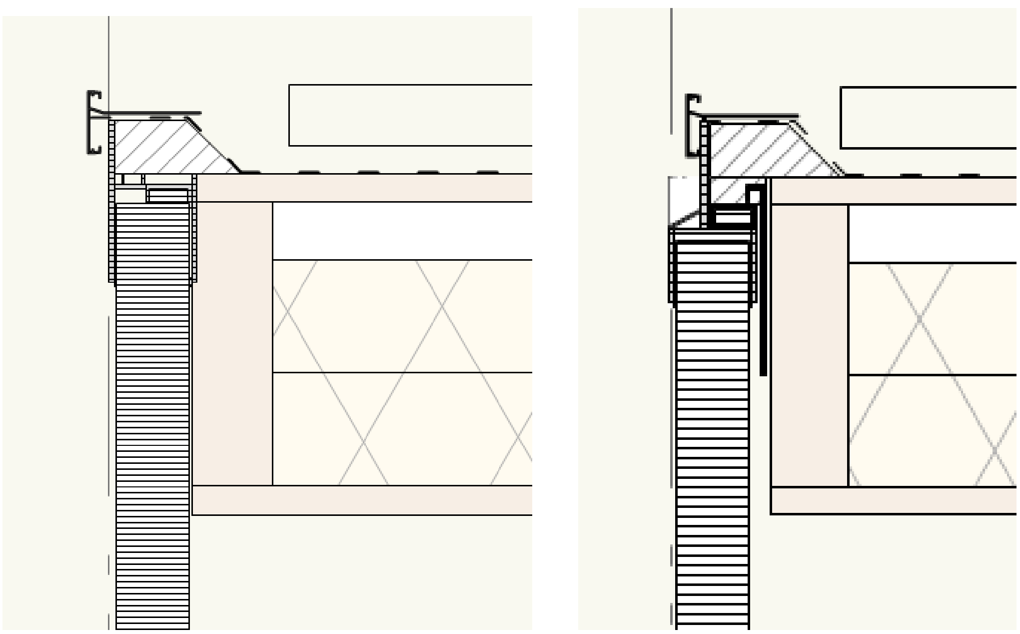

Figure 113: Improved roof connection GDC

7.4 New Business Models

The Pilot Projects have enabled the identification of some important barriers with regard to the implementation of innovative business models supporting the development of circular and change supporting buildings.

Within §7.1, three main barriers have been identified:

1. Competition in the building sector is mainly based on costs
2. Need for transparency and trust in the building supply chain
3. Barriers formed by legislation
4. Lack of knowledge and information

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The lack of insight and knowledge is also acknowledged in regard to the costs and revenue models for several construction products producers and providers. Furthermore, certain constraints related to some service provision businesses are seen as a barrier for certain companies. The requirement, for example, to develop an alliance with a financial institution also seems to hamper the development of leasing models for certain companies. Other companies think that leasing models are not applicable for their products, such as insulation materials or roofing. According to some providers, a take back approach would seem to be more appropriate for those kinds of construction products.

However, most of the stakeholders are eager to implement circularity and circular business models within their business activities.

Together with WP5A2 – which is focusing on business models - the implementation of new circular business models in the Pilot Projects is being investigated. The 2 pilots selected (**GTB Lab** and the **Circular Retrofit Lab**) were contacted by VITO to ask their stakeholders if they were interested in working together on new business models. Both the GTB Lab and the Circular Retrofit Lab found several interested stakeholders.

The results of the two case studies on the Pilot Projects, will be input for the target operating models, to be developed within Work Package 5 Action 2 (Deliverable D18). They will provide insights in the challenges for implementing circular business models and give insight into the financial cases for circular business models. A quantitative analysis of the business case for transformability in a number of cases (schools, offices, facades, ...) will be made, providing an answer to the question: “What would it take to make these business models financially viable?”

7.5 Circular procurement

The implementation of circularity within a building project requires providing special attention to the procurement and contracts. During the development of the New Office Building, it became evident that this specific project would require three levels of business contract relations: The first level describes the contract between the client (user) (RAG) and the project developer (Kölbl Kruse). The second level describes contracts between Kölbl Kruse and the general contractor (Zechbau). The third level describes the contracts between Zechbau and various construction firms which act as subcontractors for specific crafts. All other levels, e.g. with the planning partners, are not described here, as they did not influence the BAMB specific process in any way.

The challenge was to keep the ambitious targets alive through all levels of contract relations. Therefore specific measures were developed for each contract level.

To ensure sustainable construction, all tenders and related materials had to meet the requirements to guarantee a sustainable usage of building materials. Supporting evidence to demonstrate

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compliance was mandatory and was explicitly mentioned in the tender specifications. Preliminaries and section-related specifications include the following subjects:

- Building ecology and pollutants
- Disassembly
- Recyclability
- Obligation to take back and redemption price
- Leasing option or modification in accordance with an adaptation scenario
- Obligatory documentation requirements

The documentation had to be based on material or product declarations in which all the products must be at least listed with the exact manufacturer's designation, material composition, application, the installation location and the amount. Based on the material specific documents, conformity of the proposed materials will be assured.

To ensure this, a process with eight steps was set up:

1. Drafting of the tenders: precise integration of the requirements for materiality and recyclability into the service specifications, and as a preliminary remark. Integration of data delivery requirements for the Materials Passports.
2. Awarding the tenders: examination of tenders for conformity.
3. Initial talks with the executing company to describe the requirements of product selection, documentation, etc.
4. Precise designation of the intended products. Provide documentation as a basis for the detailed inspection and approval.
5. Conformity test of products and clearances proposed for use. Inspection period: 10 working days.
6. Construction
7. Random inspection of the construction management with regard to the materials and designs used.

In order to securely and irrevocably incorporate the requirements into the process, the individual contract levels were taken into account.

By integrating quality gates for circularity within each contract level and especially by making circularity levels a mandatory contract condition, the targets were secured throughout the process.

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However, a basic lesson learned is that for level 2 and 3 contracts, more specific and detailed conditions should be integrated earlier in the process. This would mean, for instance, that for selected materials a specific product is already defined in level 2 contracts.

Another lesson learned appeared with the question about a “take back system,” a “high quality recycling system” that each manufacturer was confronted with respectively. Many companies weren’t able to give a satisfying answer and simply named the official waste key of their product. Nevertheless, a process of “internal questions” could be pushed within the companies just by asking for such information.

The experience of the **New Office Building** has shown that the implementation of reversible products requires new procurem

ent models. It has been shown that a completely product-neutral tender impedes the implementation of reversible materials, ambitious recycling targets and pollutant free material standards. Against this backdrop, it is necessary to involve the potential suppliers much earlier in the project. This requires changes in existing procurement policies, standards and regulations.

7.6 Standards and regulations

The focus of the current standards and regulations in the construction industry is still on energy performance and waste management. Sustainability and circularity are still aspects that the building industry addresses on a voluntary base.

7.6.1 Building regulations & building permits

Building permit regulations are typically focused on the static character of current building practices. As a result, the current building regulations are not supporting the transformable character resulting from a dynamic and Reversible Building Design approach.

In the case of the **GTB Lab**, a meeting with the authorities has been planned in order to agree on a procedure for the building permit. During this meeting, it has been agreed that the building permit will be issued following the phases of the GTB Lab’s development. This means that for each new phase, a new permit will be issued. During the meeting, it has been concluded that it would be interesting for the committee to rethink a procedure for issuing urban and building permits for transformable buildings. It has been agreed to organise a brainstorming session with the committee that is issuing urban permits based on the GTB lab case.

The **BRIC** module is considered a temporary construction. According to Belgian law, no building permit is required for an installation that remains for a maximum of 3 months. Since the module is constructed and deconstructed each year, and each constructed configuration will remain for less than 3 months, the building regulations are flexible.

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Because the **Circular Retrofit Lab** also wanted to proceed with the exterior transformations, a building permit was compulsory. The student units of the Circular Retrofit Lab are listed as heritage of which the value should be maintained. The building regulations are less rigid than for listed monuments, however, maintaining the exterior aspects as close as possible to the original design has an important impact on the design and detailing of the energy performant facade.

Furthermore, according to Belgian law, except for internal partitioning changes, all adaptations in a building require a new building permit. In other words, it is not possible to introduce a single building permit for buildings that aim to adapt their function and shape depending on the context's requirements during their life span. In the case of the Circular Retrofit Lab, a building permit is needed for the initial refurbishment as well as for every future transformation related to the envelope of the building (e.g. enlargement of the daylight openings for new functions).

The main requirement for the redevelopment and construction of the **GDC** was to keep the existing groundfloor footprint of the building. In order to construct the building, two permits are needed: an urban permit and a building permit. In order to facilitate the process, the municipality has agreed that one urban permit will be issued, based on the maximum volume that SGDF will propose. SGDF was asked to deliver volumetric design for minimum and maximum volume of the GDC, which will be used to set the parameters for the urban permit. While the first transformation stage is pending, only a building permit for the extended volumes will be needed.

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8 CONCLUSIONS

The development of the Pilot Projects and related feasibility studies have shown that different dynamic and circular building solutions can be created for new constructions as well as refurbishment projects. The design approaches aren't rigid, but compatible and complimentary. Depending on the requirements and the local conditions, the implementation of the design approach can differ. Design requirements that are essential for dynamic and circular buildings are however recurrent: standardization, reversible connections, systematisation, relational patterns, separability of functions and elements.

The qualitative assessment in regards to the resource productivity of the different pilots (§ 4) has confirmed that the applied BAMB concepts and results that have been implemented and investigated in the Pilot Projects have a positive impact on resource efficiency. This qualitative results will have to be confirmed by a quantitative analysis later on in the project. The analysis has pointed out that in the further development of the Pilot Projects, specific attention needs to be given to resource efficient procurement. The importance of well defined procurement and contracts, to achieve the objectives of resource efficiency has also been identified as key within the New Office Building Pilot Project.

The feasibility studies have also shown that, although challenging, the technical aspects of Reversible Building Design are not the biggest issue in regard to the transition towards a circular and dynamic built environment. A shift in mentality and design culture seems to be an important barrier to circular economy in the built environment.

To create change supporting and reversible buildings, it is important to involve the stakeholders from the beginning of the project onwards. Cooperation and transparency are essential to achieve the aspired circularity. Stakeholders give essential input and have specialized knowledge. Many stakeholders are willing to think out of the box and discover new opportunities. Their expertise in each building sector domain enabled the identification of opportunities for circular buildings. Furthermore, the different pilots have demonstrated that by being confronted with certain issues and questions, knowledge and expertise is developed that will be implemented in future projects, even if it was not possible to do so in the Pilot Project.

The shift in design culture also relates to the different timeframe required for the development of circular and dynamic buildings. The design and detailing of the whole project must be done before the start of the construction. The different use scenarios require all detailing to be developed and calculated in advance. This can also improve the functioning and efficiency of the building firms, so that they don't have delays.

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In some Pilot Projects, although experienced designers and engineers have been involved in the preparation and engineering phase (structural and energy detailing) of the project, it took lots of effort to change their focus form delivering classic building permit documentation into delivering systems that set up boundaries for future transformation potential. It is estimated that design and engineering teams have spent two times more time on project preparation than for linear projects. This is not only because of the different time frame and need for detailing, but also because of the need for training to change the design approach.

The lack of knowledge of the different stakeholders in regard to innovative business models supporting circularity also seems to be one of the major barriers.

Therefore, raising awareness and providing information and training are seen as key to solve the above mentioned issues.

However, in regards to innovative and circular business models, different stakeholders also mention practical issues to be tackled: lack of warantee in regards to reused products, lack of reversed logistics and stockpiling after disassembly, lack of policy support to apply certain models, increased financial costs to repair/recuperate materials, a lot of small companies with no guarantee of staying in business for eg. 20 years, some materials aren't suited to apply certain models...

Many aspects of a circular economy are still unknown in the current building industry and its position in the new world of reversible construction. Although the industry does not have a direct answer for circularity, the awareness that businesses are going to change is fully present. Many stakeholders are eager to learn about this and if profitable, be part of the change. They recognize also the possible positive influence on their businesses, i.e. increase of differentiation of its complete solution from the competition; support revenue growth beyond the limitations of pure-product market; establish stronger customer loyalty; create continued service revenue streams; and manage the whole product life cycle, …[13]. It is important to support this change by providing the information and guidance so that the right service, take-back or circular business models can be developed for each stakeholder.

For the development of a circular and dynamic building, the project organisation should be structured around discussions with the different stakeholders. This will facilitate getting their perspective on daily business opportunities and involve them in the process of understanding the nature and objectives of the building. This process needs to be connected with a real development and design, as they can more easily assess what the new approaches could mean for their business. This implies a very intense and time consuming preparation period. However, design

[13] de Senzi Zancul et al. 2012

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sessions, one-to-one and group discussions that involve companies in the search for reversible solutions, are essential to bring companies together and form a platform for innovation.

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