Application of circular technical services in a living lab in Ghent

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Abstract. The construction industry in the EU possesses great potential for mitigating environmental impacts because of its large share in resource use and waste production. The Circular Economy Action Plan of the EU stimulates the sector to adopt more circular principles and bio-based material use. The European Interreg 2 Seas project "Circular Bio-Based Construction Industry" (CBCI) is in line with these European ambitions researching technical, economical, legal and, social aspects. In the course of the project, a prototype for a terraced single-family house called the living lab (LL) Ghent is developed and constructed in close collaboration with multiple stakeholders of the construction sector. The building implements and tests the research outputs in a real-life setting. During the development of LL, the circularity of building components was taken into account by utilizing the layers of Brand approach. Among those layers are structure, skin, technical services and, space plan. On the one hand, each layer has its specificity (e.g. life duration). For example, for technical services and space plan, components are subject to upgrades and/or replacement more often than those in other layers. The retention and reuse of valuable materials and components need to be anticipated. This calls for circular strategies and solutions corresponding to each layer. On the other hand, the layers are interdependent and integrated in terms of energy performance and spatiality. This interconnectedness compromises the efficacy of the applied circular strategies. Despite the need for such circular strategies, existing assessment tools seldom focus on technical services due to a lack of appropriate design methods and increased investment costs of components suitable for reuse. This paper documents the translation of existing European assessment tools as method and related design strategies for layers of structure, skin and space plan to the layer of technical services. The selected design strategy was an iterative process ensured by a design & build procurement and the solution for the integration of technical services was determined as a plug-in unit which is part of a modular CLT technical core. It is expected that the technical unit will continue its lifetime beyond the lifetime of LL Ghent.

Keywords. Circular and integrated building design, Design for Disassembly, Product Life-Cycle Strategies, Component Reuse and Remanufacturing, decision-support.
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1. Introduction

Improving methods of construction and the use of buildings in the EU would decrease the European energy consumption by 42%, greenhouse gas emissions by about 35%, water consumption by 30% and, only 50% of the current extraction of materials would take place [1]. Existing policies for promoting energy and resource efficiency in buildings need to be further strengthened and should consider the environmental impacts across the life-cycle of buildings and infrastructure. Life-time costs of buildings should be taken into account rather than just the initial costs, including waste production (both during construction and at end-of-life (EoL) and residual value. Enabling this accounting, calls for elaborate approaches for evaluation of circular construction materials and methods.

The development of 'ISO 59020, Measuring circularity framework' is currently in progress [2]. This paper aims to address the gap in applicability for technical services in buildings in mentioned standard by sharing the user experience of circular assessment tools. It is estimated that the share of the embodied impact of technical services in buildings, on average, is around 10 to 12% [3, 4]. In case of industrial buildings, it accounts for an even higher number. Despite the importance of this characteristic, there is a lack of environmental evaluation methods to assess and mitigate the impact of the embodied energy of technical services. In the next sections, relevant indicators from an inventory of circular assessment tools are retrieved for an analogous assessment of the technical services. In Living Lab Ghent, which was developed in the scope of the Interreg CBCI Project, a stand-alone HVAC system in a housing project is described to demonstrate the circular application of technical services. The concept was developed with a special focus on circular principles, which was purchased using a Product-as-a-service business model, will be monitored during the use phase and at end-of-life when the HVAC system is demounted and retrieved from the building.

2. Literature Review

In preparation for deriving a list of indicators for assessing the circularity of the 'service layer' [5], an inventory and categorisation of characteristics of existing assessment tools regarding circularity and flexibility is compiled. A systematic market and literature research is carried out focusing on micro and meso scale (see Figure 1) to give a complete overview of such assessment tools. Subsequently, the review framework of Lindgreen et al. [6] will be applied.

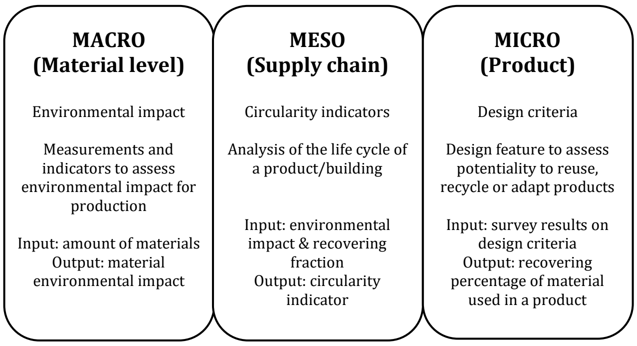

Fig. 1 - Methodology for circular assessment tools [7].

The methodology used can be divided into the following steps:
- Defining concepts for the inventory
- Carrying out literature and market analysis resulting in an inventory
- Application of the review framework

2.1 Defining concepts for the inventory

Compiling suitable assessment tools requires a definition of circular construction. According to 'Vlaanderen Circulair' [8] circular construction strives for an efficient and effective use of resources. The aim is to create or at least maintain economic, social and ecological (added) value. During the construction process, the existing legacy and future opportunities specific to the built environment is taken into account. Flexible or future-oriented construction [9] also aims to reduce the environmental impact of the construction sector by, at the start of projects, anticipating future changes in expectations and use of the building.

Assessment tools are set up to gain insight into the performance of a particular subject (company, product, process, etc.). This research is specifically concerned with circularity and helping to increase the implementation of circularity into the technical services by making the performance transparent, communicable and comparable, making improvement possible in the long term. A multitude of such tools are available in the absence of a legislative framework and standardisation for measuring circularity. The development of ISO 59020 is expected to address this gap.

Furthermore, it is important to note the methodological difference between measuring and assessing circularity. As far as circularity is concerned, it is considered impossible to carry out a purely quantitative valuation, as circularity is a very broad and abstract concept and thus not a measurable quantity. Tools that work on a numerical basis cannot be called purely quantitative in their principle, as qualitative characteristics are often translated numerically. Van Oppen et al. [10] makes a division according to Table 1.

Tab. 1 - Breakdown measuring vs. assessment according to Van Oppen et al [10].

Measuring	Assessing
Quantitative	Qualitative
Objective	Objectified by methodology

The assessment level should be considered. Given the CBCI Living Lab context, both the micro level (component level) and the meso level (supply chain) seem to be important. Cottafava et al. [7] address the need and make a proposal for an interaction between macro, meso and micro level assessment data (see Figure 1).

2.2 Carrying out literature and market analysis resulting in an inventory

Existing literature reviews on academic papers on assessment methodologies for circularity indicate that there is an oversupply of tools and more specifically developed methodologies documented in academic publications [6]. In addition, according to a recent study by Lovrenčić Butković et al. [11], the number of available methodologies increases in an exponential line through time (see Figure 2).

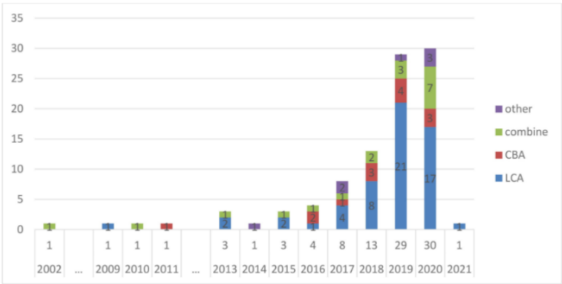

Fig. 2 - Annual distribution of available circular assessment tools [11]

Sources used are databases for academic papers, conference papers, grey literature and web-based assessment tools of the last 5 years (2016-2021). Search terms can be divided into several themes; circularity and assessment. More specifically, they are respectively circularity, circular economy, change-oriented, flexible and assessment tool, assessment tool, methodology, measurement, valuation. A set of inclusion and exclusion criteria was used to oversee the multiplicity of tools as presented below in Table 2.

Tab. 2 – Criteria for inclusion and exclusion

Inclusion criteria
Micro (and meso) scale
Building and component level
New methodologies regarding CE
Assessment methodology transparent
Published and working version
Exclusion Criteria
Macro level
Product or company
Conventional methodologies like LCA
Unpublished underlying methodology
Beta version

This resulted in the following tools; De Material Circularity Indicator (MCI) by the Ellen McArthur Foundation, The BCI & demountability index by Alba Concepts, Cb'23 by Platform CB'23, Calc-C by Cenergie, Circulariteitsindicator by Madaster, CBA by BAMB, Flex 4.0 by Geraedts TUDelft, Circularity tool by One-Click, GRO by OVAM, Circulair gebouw by WTCB/VCB, Circulaire peiler by Circularie bouweconomie NL, CPG GPR gebouw by W/E adviseurs, KIEM.CIE by Saxion, Levels by the EU commision, Circulaire handtekening by Upcyclea and Veranderingsgericht bouwen by OVAM.

2.3 Review framework

The selected tools were characterised and categorised according to the revised review framework developed by Lindegreen et al. [5].

Tab. 3 – Revised review framework

Perspective	Goal	Characteristic	Clarification
General	Description of characteristics	Name	Reflection on the general characteristics of the tool
		Age	
		Source/ Country	
Descriptive	Inventory of underlying methodologies	Scale	Micro or meso scale [6]
		Sector specific	Construction sector specific or otherwise
		Indicators	Assessment tools are often based on more fundamental methodologies such as LCA/MFA/input-output/... An understanding of this basis allows to appreciate the tool more.
		Case study	In case practical examples are available in the methodology, it is easier for the users to apply the tool correctly.
Normative	Pillars of sustainability	Three pillars integrated	In the context of CE assessment, the question is: "What should be the ideal outcome of the application of CE for the concept to be of value?" The concept of CE is interpreted here as only being valuable if it achieves greater sustainability (three pillars).
		CE specific	
Prescriptive	Suggestions and	Insights in results	How can better decisions be made? Are lessons learned or points of improvement provided?
	Lessons learned	End score	How is the overall performance communicated?

The framework consists of four perspectives; a) general, b) descriptive, c) normative and d) prescriptive, further described in Table 3. The inventory and analysis of existing tools results in a shortlist of underlying methodologies and subsequent indicators (descriptive perspective). A summary of the indicators, according to their main overarching objective, is given in Figure 3.

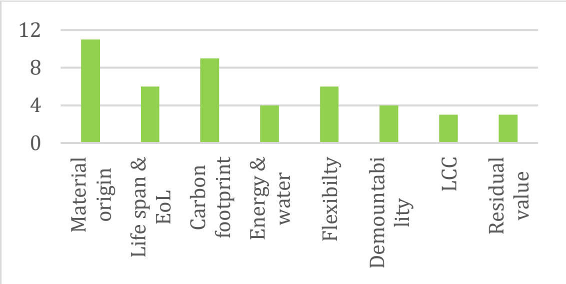

Fig. 3 – Summary of indicators

The first four indicators all relate to Life Cycle Assessment (LCA) calculations. Literature shows that efforts have already been made to develop methodologies for LCA, specifically applied to technical services [12]. However, the underlying indicator types relating to LCA are influenced by other aspects; among which the reusability of components and the end of life (EoL) scenarios, which in turn, are influenced by the manner of integration of the components in the building (Flexibility) and the methods for design-for-disassembly (Demountability). Demountability is defined as the degree to which objects can be dismantled within buildings so that the object can retain its function and high-quality reuse can be realized [13]. These two concepts form the basis of research in this paper, resulting in a component-level demountability and building level integration and flexibility of the technical services.

3. Methodology

3.1 Design for Disassembly

The inventory shows many tools assessing the potential for reuse, yet those seldomly take into account the preconditional aspect of demountability and if so, adhere to a limited and qualitative or quantitative approach. OVAM, One-Click and Flex4.0 only qualify whether demountability is considered. CBA quantifies the share of the total building that is demountable. Only C-calc and BCI (demountability index) apply a more in-depth assessment, with BCI using the most advanced approach with the so-called Demountability Index.

The Demountability index is based on four factors which are defined as follows; (i) type of connections, (ii) accessibility to the connections, (iii) crossings (level of integration), (iv) form enclosure (composition of objects). These factors are assessed for each object between 1,00 being the best score and 0,10 being the worst. A distinction is made between the Demountability Index of the connection (Dlc) and the Index of the composition (Dls) of the element, respectively influenced by the connection between objects and influenced by the composition of objects. As shown in Figure 4, the demountability index is a combination of both indexes.

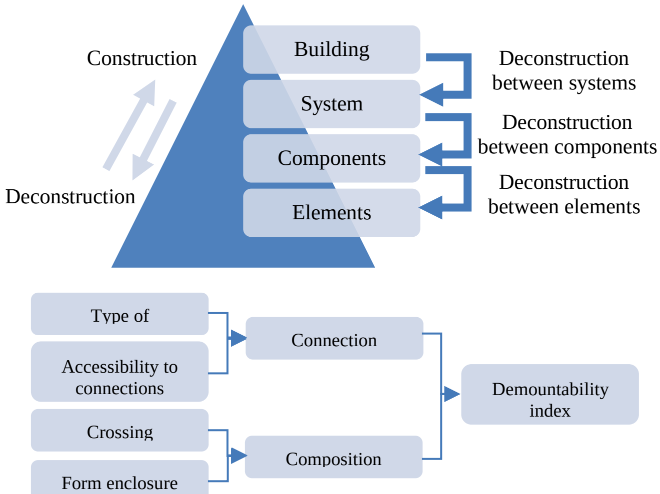

Fig. 4 – Demountability index calculation and levels of material composition [13]

To determine to what level of detail the calculations should be done, Van Vliet [14] refers to the diagram in Figure 4 of the 'Transformable Building Structures' by Durmisevic [15] showing the different levels. The described assessment methodology is applied for all types of components with the same pre-set values, regardless of the layer of Brand the component belongs to. However, it is considered that these values are not specific enough to be applied efficiently to technical services. A converted list of pre-set values and supplementary factors is given in Table 4. In addition, supplementary factors are listed in Table 5 based on the early work of Van Vliet [16] and Durmisevic [15] which formed the basis for the Demountability Index development.

Tab. 5 – Supplementary factors for demountability assessment of technical services.

Supplementary factor	Clarification	Pre-set values
Assembly direction	The assembly sequence sets a mirror image for the disassembly sequence. [14]	Direct disassembly possibility Multiple actions needed before disassembly
Tolerance between components	The provision of space with adjacent components to allow for separation	Tolerance included in connection, outside connection No tolerance foreseen
Required tools	The required tools to disassemble products, range in complexity	Standard tools required Specialize tools required

3.2 Integration

The method of BCI manages to qualitatively asses the demountability of components, while going as far as, yet not exceeding, the boundaries of the layers of Brand. Additionally, the spatial interdependency and integration of the layer of technical services in the Brand model should be assessed, in other words, how the whole layer is integrated in the building and not only its individual components. This aspect is almost entirely missing in available tools apart from FLEX4.0, which considers the location of the facilities, disconnection of facility components, independence of user units and anticipation for future adjustments to the system. In order to assess demountability and circularity, the following concepts can be assessed additionally:

Accessibility of all the components in relation to the other layers Brand. The demountability Index considers accessibility only while demounting, that is the whole building, not accessibility during use for maintenance of replacement. This can be further nuanced by considering the four main segments separately; production, distribution, delivery and storage. Integration, layout and compactness of the overall concept. While the individual components could be easily accessible, the entire system can be integrated into the building to a varying extent, ranging from widely spread to very lean and centralised. Further divisions could be made, again based on the four segments. For instance, considering centralisation of vertical distribution in a technical shaft.

Tab. 4 – Converted list of factors and pre-set score for demountability assessment of technical services.

Factor original	**Pre-set value original**	**Factor converted/ supplementary**	**Factor converted/supplementary**
Type of onnection		**Type of Connection**	
Dry connection	Dry connection Click connection	Dry connection	Reversible dry connection Reversible click connection
	Velcro connection		Magnetic connection
	Magnetic connection		Tapered fitting
Connection with added elements	Bolt-and-nut-connection	Connection with added elements	Bolt-and-nut-connection
	Spring connection		Spring connection
	Angle connection		Angle connection
	Screw connection		Screw connection
	Connection with added elements		Connection with added elements (clamps)
Direct integral connection	Pin connection	Direct integral connection	Pin connection
	Nail connection		Nail connection
			Press fitting connection
Soft chemical connection	Kit connection	Soft chemical connection	Kit connection
	Foam connection		/
Hard chemical connection	Glue connection	Hard chemical connection	Glued connection
	Connecting pour		Soldered connection
	Welded connection		Welded connection
	Cement connection		Hard chemical connection
	Chemical anchor		/
	Hard chemical connection		/
Accessibility of the connections		**Accessibility of the connections**	
	Freely accessible		Freely accessible
	Extra operation resulting in no damage		Extra operation resulting in no damage
	Extra operation resulting in damage		Extra operation resulting in partial damage of components
	Non-accessible		Extra operation resulting damage of all components Non-accessible
Crossings		**Crossings**	
	Modular zoning of objects		Modular zoning of objects
	Intersection of objects		Intersection of objects
	Full integration of objects		Full integration of objects
Form enclosure		**Form enclosure**	
	Open		Open
	Overlap single sided		Enclosed single sided
	Closed single sided		Enclosed double sided
	Fully closed		Fully Enclosed

4. The application for LL Ghent

The CBCI LL Ghent is a prototype for a terraced single-family house. Several scenarios for structure and technical services have been generated and evaluated in a multi-criteria assessment. In this section, the definitive design case is explained in parallel with circularity concepts that were provided in the previous sections.

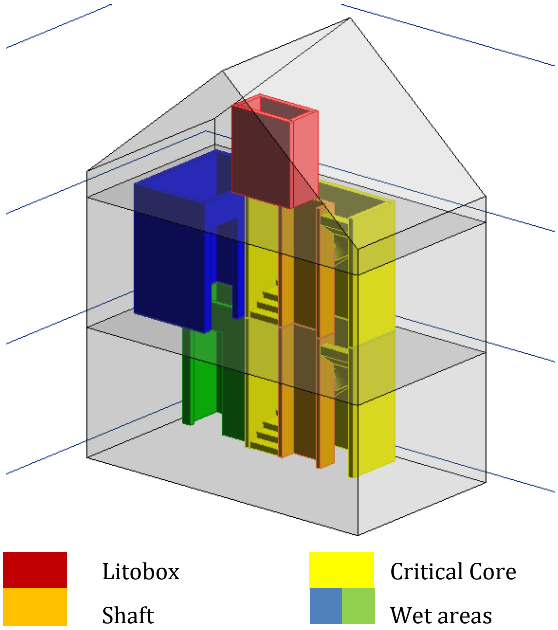

Fig. 5 – Location of technical services in LL Gent

Both structure and technical services in LL Ghent are designed in a modular fashion around a 'critical core'. The critical core is a CLT structured staircase which wraps around the technical shaft in the centre of the building. Technical services are based on the top level above the critical core, in the form of a pre-fabricated technical room, the Litobox (see Fig 5). The previously listed indicators for demountability assessment are converted to the building concept in the sub-sections below;

Demountability assessment

The connections of messing fittings and clamping fixings are highly reversible dry connections that are freely accessible. The simple and organized layout of both the Litobox, the technical shaft, and floor integration make all components individually and freely accessible.

Concerning integration, layout, and compactness, the Litobox centralizes all production in a prefab box, whereas the technical shaft (vertical) and subfloor (horizontal) make up for an orderly integration. Any crossings in vertical or horizontal direction are avoided as such; (i) Litobox with a direct access to production and storage components, (ii) the technical shaft that is open on one side for maintenance and (iii) the integration of the piping in the subfloor combined with a demountable floor finish, make the whole system easily accessible (see Figure 6). In this configuration, the system is considered as having an open enclosure which enables removal of a certain component without intervening with another one.

As a result, the technical system becomes a 'plug-in-system which has a practical sequence for the mounting and demounting of the main components. In the application for LL Gent, the Litobox is the main component that was mounted only before the roof was enclosed. In its location, it would be considered as accessible for regular maintenance at a 'material level'. In case of a major revision, it would also be possible to remove the whole 'component' with minimum amount of intervention on the structure. That would also imply that at higher scales of built environment, one can demount the mechanical system as a whole easily (just after the roof is demounted) and reuse it at another building.

For educational and demonstrative purposes, the system was accessible for stakeholders during the construction phase and will be monitored during the use phase in the KU Leuven Technology Campus in Gent for learning purpose.

Fig. 6 – Integration of the technical services

5. Conclusions

The literature review shows there is a lack of circular assessment methods specifically for technical services, both on micro and meso scale. This study reviews the existing assessment tools that can also be utilized on technical services. A list of converted indicators based mainly on the demountability index and partially on additional tools is presented. Supplementary indicators considering several levels of a building and integration are provided as well.

The CBCI LL Gent demonstrated the real-life implication of the collected indicators. Not only can integration be considered in the end result, but also in the process to come to said result. It was seen that the vertical piping in the critical core can be pre-mounted off site. This would also increase the demountability of the critical core together with installation system.

Realising high accessibility to the technical system may result in a decrease in performance on other criteria, for instance the acoustic barriers will be less effe. This aspect will be monitored during the use phase of the LL Gent. It was also noted that the Litobox had to be placed just before the roof was enclosed. Then, this requires a different mounting order and additional attention to protect the system during the remaining exterior and interior works.

Further analysis of the demounting phase is necessary to validate the first insights gained in this study. Such a future study would contribute to close the gap in case studies and examples on demounting of structural and technical components.

6. Acknowledgement

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