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THE ROLE OF BIM IN THE PROGRESS OF SUSTAINABILITY IN THE AEC SECTOR

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Graduated in Architecture from ISCTE-IUL in 2016, Rita has worked as an intern in a banking institution and in architecture offices. In September 2019, she joined the Research Project Evolving Modular Housing at CITAD as a research assistant, a position she held until December 2021. Along this path Rita developed a particular interest in sustainable construction and deepened her knowledge in BIM methodology.

Abstract: The implementation of the ambitious environmental targets set by the Paris Agreement of 2015 will demand an enormous transformation in the Architecture, Engineering and Construction (AEC) industry. In order to the participating countries to become carbon-neutral by 2050, new sustainable strategies have to be promoted in the building sector, since “buildings and construction in the EU account for 50% of all extracted materials, 30% of water consumption and 33% of total generated waste”, according to MORAN et al. (2020). To address the problems in the building sector, the EU is promoting new sustainable policies and it developed the Waste Framework Directive (WFD) in 2008 and enacted the Energy Performance of Buildings Directive (EPBD) in 2010, with supportive measures for the ‘decarbonisation’ of the building stock. The EPBD triggered the development of new concepts such as Nearly Zero-Energy Building (NZEB), technical solutions, more efficient materials and assessment tools, namely Life Cycle Assessment (LCA). With buildings becoming more energy-efficient, and with the effort from the governments to invest in cleaner energy sources, new obstacles have emerged in the building sector. With buildings becoming more energy-efficient and producing surplus energy, the idea of turning them as sources connected to the neighbourhood area is quite challenging. With the growing emphasis in the planning phase, there is an opportunity for technologies such as Building Information Modelling (BIM) to excel with their performance. This paper will focus on how BIM could help AEC stakeholders in the assessment of the sustainability performance of the proposal, at the production and end-of-life phases, since it has shown reliable results to the achievement of more sustainable practices.

Keywords: BIM; Sustainability performance; Embodied energy; Building’s end-of-life.

Introduction

The exploitation of natural resources and the emission of greenhouse gases from human activities is unbalancing the planet to a no-turning-back point. Nowadays, the consequences of climate change are already being felt all over the world, leading to a severe social impact, such as severe drought periods leading to food scarcity in impoverished regions or cities' highly polluted environments deteriorating public health (e.g. rise in respiratory diseases and allergies). With the future generations in check, governments and institutions are making an effort to avoid the worst-case scenarios. Even if carbon emissions were kept at the same level as today, the planet would still experience a significant increase in the global average temperature (Figure 1.).

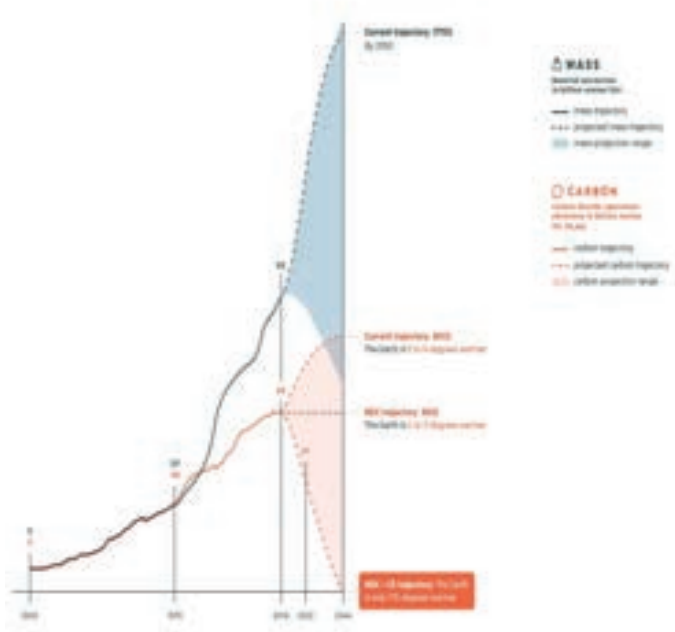


Figure 1 - Material Extraction and GHG Trajectory graphic. Source: The circularity GAP report 2021.

Through the Paris Agreement of 2015, several countries have established the ambitious target of becoming climate-neutral by 2050 and avoiding the current emissions trajectory. However, more needs to be done regarding raw materials resources as the understanding of energy consumption is deepened through the circular economy's paradigm.

The construction sector in the European Union (EU) is estimated to consume 50% of all extracted materials and 30% of the water consumption (MORAN

et al. 2020), causing approximately 30% of all generated waste (EUROPEAN COMMISSION). Another perspective of the severity of this exploitation is that only 12% of materials extracted are transformed and reintroduced into the European economy (THE CIRCULARITY GAP REPORT 2021).

As result, the EU is promoting a change in the Architecture, Engineering and Construction (AEC) sector, through supportive measures for the 'decarbonisation' of the building stock. In 2008, the Waste Framework Directive (WFD) established the goal to recycle up to 70% of the construction and demolition waste by 2020, setting the transition to the cradle-to-cradle philosophy of circular economy in the sector. In 2010, the Energy Performance of Buildings Directive (EPBD) promoted the development of the Nearly Zero-Energy Buildings (NZEB), where operational energy (OE) in buildings is optimised.

While new materials were designed concerning their energy efficiency performance in buildings, further questions were raised by the research community when taking the production phase and the end-of-life of these materials into the equation.

NZEB is a well-established concept in the current practice regarding the OE in buildings, with tested solutions for cooling and heating demands according to different climate regions. However, statistical information reveals that the new construction rate in European countries was only 3% in 2018 (HONIC, et al. 2021), whereas the EU Building Stock Observatory showed a scenario of aged building stock in which, 75% of the buildings are more than 30 years old (Magrini, et al. 2020).

With buildings becoming more energy-efficient and producing more energy than needed, some researchers are developing the concept of Positive Energy Buildings (PEB), where new buildings should have a greater role in the community. The idea of turning them into sources connected to the neighbourhood area is quite stimulating. The concept is still in an embryonic stage and has a few challenges. It is well known that one of the biggest problems in highly efficient buildings today is the use of materials or components that have a significant carbon embodied energy, contain rare minerals, or are costly. Besides, the PEB concept also conflicts with the transition of energy suppliers to renewable energy sources and their grid management system.

Since Operational Energy in buildings is a well-documented subject in the research community, this paper focuses on Embodied Energy (EE) in buildings and recent approaches to assess it in the early design stage and the end-of-life of buildings' life cycle.

To this end, a literature review was made on the implementation of tools to assess the EE through Building Information Modelling (BIM), considering its relevance in current AEC practice. This versatile methodology is also helping find new solutions to minimize the construction and demolition waste (C&DW) in buildings, which will be presented briefly.

The role of bim in current practice

Besides the environmental challenge, the AEC sector is already in transformation through the implementation of a new practice – Building Information Modelling (BIM). Since cost and savings play a key role in buildings design, information and forecast scenarios during the design process are becoming more crucial than ever (Figure 2).



Figure 2 - Opportunities for Change and The Design Process. Source: Kibert, Charles J. Sustainable construction: green building design and delivery. John Wiley & Sons, Inc. 3rd Ed. 2013. p.200. ISBN 978-1-118-38458-9 (ebk).

BIM can be understood as a new methodology boosted by technological developments where the combination of a collaborative environment and digital representation allows closer communication between stakeholders. Another relevant factor in this switch is the introduction of programming language in design models, for example, Express language. This led to the parametric models' concept where objects become more dynamic and adaptable while incorporating the information.

In the methodological domain, the common data environment helps the connection and supervision of the teams involved. And this cooperation helps to foresee and avoid construction errors in the design process. It can also guide the maintenance and repairs of the building.

Standards and guidelines are being published to help stakeholders process data, despite language, expertise area and time. The most relevant standard for implementation of BIM is ISO EN 19650, published in 2018, where the definition of concepts and frameworks for information management in the construction sector are well described. This document has the particularity of considering the entire life cycle of buildings, which promotes a better understanding of the information produced and needed by different teams in different stages of a built asset.

Several documents were designed to establish and organize the information required in a building project between stakeholders and how information should be exchanged. The information requirements of building projects can be translated into BIM execution plans (BEPs), Information Delivery Manuals (IDMs) and Model View Definition (MVD). The IDM and MVD have gained relevance when handling sustainable information in the project. Some studies note that it helps predict what information will be needed for sustainable assessments (SANTOS, et. al. 2019) and how models should be developed in the Design, Operations and End-of-Life stage (CHAREF, R. 2022).

Level of Information Needed (LoI) or Level of Development (LoD) is also fundamental to the development of the BIM model because it defines information requirements even if some data is not useful in the design phase. This information is relevant when the construction stage ends, and a Digital As-Built Record is delivered to the parties involved. According to the interviews conducted by CHAREF. R (2022) it is in the exchange of information between these two phases, that owners and Operations and Maintenance teams usually struggle with the lack of information in the model.

As a result, the need for rich-data objects for the models is leading to an emergence of BIM libraries, where objects contain descriptions and features of the product provided directly by the manufacturer. The advantage of these imported data-rich objects is that they already include parameters for data exchange and follow a classification system. Sustainable information is still not incorporated in these objects but could be added afterwards through Environmental Product Declarations or sustainable databases.

The Industrial Foundation Classes (IFC), developed and promoted by BuildingSmart, are fundamental for the interoperability between software and teams. This open format efficiently allows data exchange however it is in constant improvement due to the stakeholders' needs and issues between different software tools.

It is known that technologies can excel with their performance towards a sustainable future. BIM plays a significant role when studying new sustainable solutions, distinctly if applied in the early stages of the building. As SANTOS, et al. (2019) concluded *"literature on the integration of sustainable performance and BIM has grown considerably in recent years, which indicates that BIM is increasingly being used as a reliable method for sustainable construction practices"*.

BIM in the design phase of buildings life cycle

The most recent research on sustainability led to a new path of economics, one that approaches current consuming patterns from a holistic view. The circular economy focuses on every stage of a product, from the extraction of the materials to its end-of-life. Since products and buildings have already reached an upstanding efficient performance in energy demands, relevance is being given to embodied energy.

The most reliable method identified to study embodied energy and other environmental indicators is the Life Cycle Analysis/Assessment. The LCA is described as an evaluation method of “the potential environmental impacts of products and services and their resource consumption” (DANISH TRANSPORT AND CONSTRUCTION AGENCY, 2016). According to ISO 14040: 2006, this assessment tool has four steps: the first step is the definition of the goal and scope of the assessment; secondly, the creation of the Life Cycle Inventory (LCI); followed by the Life Cycle Impact Assessment (LCIA), the analysis itself; and finally, interpretation of results (ALWAN, et al. 2021).

With buildings becoming energy-efficient, and with the effort of governments in investing in clean sources of energy, this assessment tool allows to foresee new obstacles in the building sector. Some studies refer that the production phase, i.e. the embodied carbon or energy in the materials or building components, should be the next focus for a sustainable building environment (GOGGINS, et al. 2016). Researchers are exploring the application of LCA in the building sector from the point of view that a building could be seen as a complex product on a larger human scale. LCA is an appropriate tool for the environmental impact due to its accuracy when analysing all the stages of a building’s lifespan.

The only disadvantage pointed out is its lack of economic measurements (HOOGMARTENS, 2014). Therefore, Life Cycle Cost Analysis (LCC) is the proper tool to study the economic feasibility, in order to understand the economic impact of the project. The LCC can comprise all stages of a building (construction, maintenance, demolition, recycling or other end-of-life solutions) and should also be employed in the designing phase since it could be truly relevant in the decision-making.

Therefore, researchers undertake BIM as it is becoming adopted worldwide in the AEC sector and it is showing flexibility in its uses. Attending to the quantity and range of materials employed and buildings’ long lifespan, BIM is recognised to have the potential to achieve more automatic assessments in the early design stages.

Through the review of several studies conducted exploring the BIM use for LCA, three approaches can be identified (Figure 3):

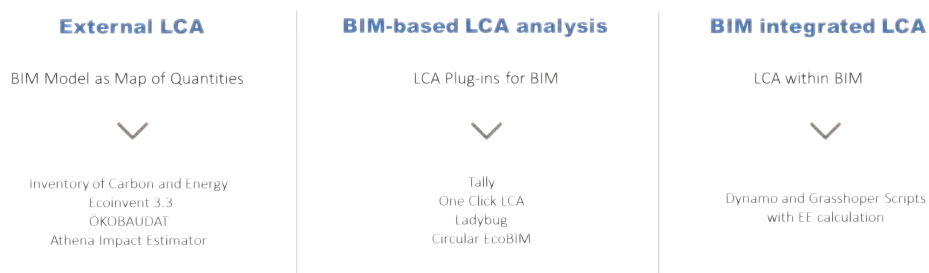


Figure 3 – The three approaches identified when using BIM for sustainable assessment.

- External LCA, where the BIM model is used for material take off for the LCI;
- BIM based LCA, uses plug-ins of LCA databases.
- BIM integrated LCA, that include scripts with embodied energy calculations and LCC.

The most common approach in the LCA research case studies is the second mentioned above (ABBASI and NOORZAI. 2020), while the third is quite recent and still under development (RÖCK, et al. 2018; SANTOS, et al. 2019; ALWAN, et al. 2021).

Performing an LCA can be time-consuming, as it requires a detailed LCI, which in the building context means an extensive list of materials and components used according to the building system adopted. One of the main difficulties is the lack of materials' information which is commonly circumvented with LCA databases. It can also be complex to perform and lead to inconclusive results if the sustainable data is inappropriate for the asset. These databases contain information from a specific construction market that may differ from country to country and usually do not allow inputs or data edition.

Consequently, the first approach is in disuse, as it is more prone to errors, and any design change leads to the restart of the assessment. Also, it can not be performed until a certain maturity level of the project is achieved, which does not promote improvements for a better solution in the early design phases.

BIM based LCA does not have this issue, as it can perform several types of LCA according to the user's needs. This approach is semi-automatic and requires some software which is understood as a disadvantage for small and medium-sized companies, due to the increases in costs associated with software licenses and software skills requirements. There is also the risk of interoperability issues between software which may cause data loss.

Ultimately, the BIM integrated LCA is more flexible to the user's knowledge and can also include LCC calculations as demonstrated in SANTOS, et al. (2019). As LCA is inside the BIM model, it is possible to perform new assessments anytime during the building life cycle. BIM objects need to be enriched with more information, particularly, related to sustainability measurements. Information requirements documents could include this additional information to guide stakeholders during the design process. To avoid incomplete models, it is necessary to consider what information will be needed for the later life cycle phases, as previously referred. It could mean more information than traditional design models require. Nevertheless, the model will be used as a data repository.

This additional information demands more from manufacturers, as Environmental Product Declarations (EPDs) are necessary for accurate results. One of the barriers of performing a comprehensive sustainability assessment based on EPDS is highlighted by SILVESTRE, et al. (2014). When analysing EPDs from different insulation products and ceramic tiles, the authors found that EPDs data was progressive less between Module A1 - A3 to Module C of building materials classification modules (Figure 4). According to the European standards,

only Module A1 – A3 is mandatory, whereas the following information depends on the manufacturer. This lack of data undermines the LCA results when the end-of-life is considered. In the example of SILVESTRE, et al. (2014), manufacturers were only considering incineration and waste disposal into a landfill in Module C even when claiming that the product or material was recyclable.

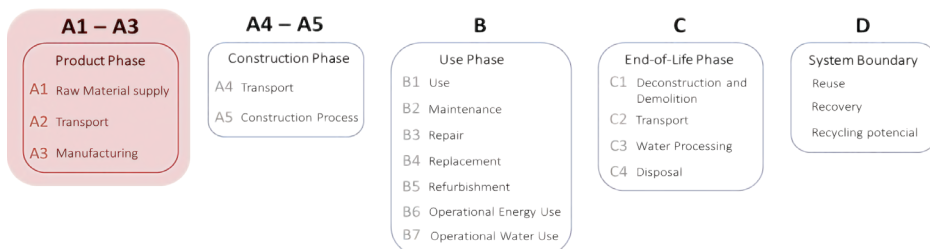


Figure 4 - Life cycle stages modules of a building asset. Based on EN 15978: 2011 and EN 15804: 2012. Adapted from SANTOS, et al. (2019).

Another challenge within the BIM environment while performing an LCA and LCC study was addressed by SANTOS et al. (2020), where the IFC 4 schema was analysed. The authors concluded that 137 other IFC parameters should be added to perform a complete LCA. It does not include some environmental and economic indicators, especially in materials and project related properties. To sum up, mechanical aspects of the materials, transportation impacts, estimated lifespan of the asset, utilities' impacts, etc., needed to be manually added. Beyond this barrier, the measurement units for environmental impacts were not suitable for the existing properties with the "kg" unit value. In conclusion, the IFC 4 schema was updated with sustainability-related data, which allows performing basic LCA studies, while a complete assessment requires more information that needs to be manually added.

Case-study experiments of LCA through BIM have shown interesting results that may differ from the general idea about embodied energy according to building typologies. For instance, RÖCK, et al. (2018) developed a study where BIM integrated LCA was applied to a case study of a residential building in its early design phases. The BIM model only contained schematic elements equivalent to LOG 200, so only a simplified LCA could be performed. The authors decided to use the library Swiss SIA MB 2032 for the LCI, a datasheet where information could be extracted through a script. This research also focuses on the visualisation of results in the 3D model, permitting a more intuitive interpretation for practitioners. In this specific case study revealing conclusions were made, as partitional walls take over a bigger role in embodied impacts of the proposal when Global Warming Potential (GWP) is calculated by ground floor area (m^2_{GFA}) (Figure 5).

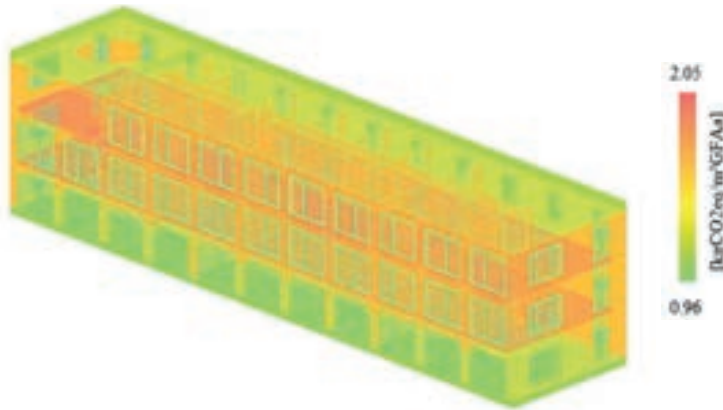


Figure 5 - Visualization of the Average GWP of each building element expressed per m^2_{GFA} .
Source: RÖCK, et al. (2018).

While in the efficient operational energy performance the focus is on the building envelope, other building elements can be relevant when it comes to embodied energy. In this specific case, the solution chosen for floors and partition walls should be modified to achieve better GWP outputs. However, as the authors warn, these results “*should not be generalized as they depend on the quality of input data from both BIM model (e.g. model completeness and accuracy) and LCA data.*”

BIM in the end-of-life phase of buildings life cycle

The aged built environment is far from energy-efficient and burdensome to deconstruct due to makeshift refurbishments or lack of information in the design projects. The end-of-life of a building is based on assumptions, and recycling data is missing, which restrains sustainability assessment.

The Deconstruction process could bring a new market opportunity since buildings could be used as materials stocks, boosting the industrial and construction sector. There are some challenges in this practice as pointed out by RIOS et al. (2015), associated with the disassembly's time and costs. Besides, most of the obstacles to the disassembly have origin in the design phase due to the unawareness of the designer. The theory of Design for Disassembly already established measures to reinforce the deconstruction and dismantling of buildings. Still, the building could not be exactly built as in the design project and usually suffers changes during its use.

BIM technologies can be aligned with laser scanning, 3D video cameras and others technologies to obtain geometric models of the existing building. As ESFAHANI et al. (2021) observed, laser scanning allows the capturing of long-distance objects while keeping the millimetric information. The authors also stated that it is the most reliable automated technology for as-built models. It

makes it easier to perform a survey of an existing building accurately and in a shorter period than traditional methods.

A literature review could help understand how this technique is being applied in practice, as in SANHUDO, Luís et al. (2020), where laser scanning has been used to develop a geometric model of a bus station in Oporto, Portugal (Figure 6). In this research project, researchers wanted *“to provide a complete framework for the acquisition of point clouds to be applied in BIM”*.



Figure 6 - As-built model of the Campo 24 de Agosto Bus Station, Oporto.

Source: SANHUDO, Luís; et al. (2020).

The problem with geometric models obtained through point clouds is that point clouds data cannot be converted into BIM objects directly (TANG et al. 2010). Especially secondary objects that are more difficult to be identified, which means that manual modelling may be required to obtain more precision (ESFAHANI et al. 2021).

The use of BIM models as data repositories can also be helpful to the development of Materials Passport (MP). The European Research project BAMB: Buildings as Material Banks defines MP as *“a digital report containing circular economy relevant data that entered into and then extracted from a centralised database in the form of reports customised to the needs of diverse users (Luscuere and Muhlhall 2017)”*. This tool aims to address the gap in the EPDs, which are static documents and only present traditional end-of-life scenarios of the current market practices. Researchers believe that it can transform the way we see the built environment.

According to HONIC, et al. (2021), materials passports could be used as an evaluation method of *“the recycling potential and environmental impact of materials embedded in buildings”*. Their research studied a scenario of the demolition of a lab and office building at TU Wien, where several techniques were used to create a Digital Twin Record of the building and its respective material passports.

Laser scanning was used to capture the building's geometry, while the material composition was calculated through Demolition Acquisition (mainly non-invasive methods) and Urban Mining Assessment (invasive methods). The authors advise that this last technique should only be used in the building during the demolition phase. In this case study, the disposal of demolition waste had not been possible to ascertain, so the results obtained in the Material Passports could not be compared.

Researchers from diverse fields are developing new technologies to improve materials survey in existing buildings, like ground-penetrating radar and others that align scanning tools with robotics (HONIC, et al. 2021; INCON.AI).

In addition to the need for technological developments, more information could be added to MP (e.g. economic data about the end-of-life products) so that a comparison with new materials could be done. A clearer definition of the information needed for MPs and a public database to exchange it between stakeholders could encourage a new market of secondary raw materials and other building elements in new construction. As HONIC, et al. (2021) deliberate *"Concepts such as a "digital urban mining platform" would enable a direct use of the demolished materials within new construction projects."*

As CHAREF, et al. 2019 stated "BIM has been widely used in the design phase but significantly less in the construction and 'in use' phases, with the first publications about deconstruction arising in 2013. As-built models are advantageous in providing detailed information for decision-making, such as calculating materials quantities, materials location, and the cost and environmental impact of the possible deconstruction or demolition scenarios.

Theoretical frameworks for the definition of BIM models are being proposed considering the difference between uses and information needed for each life phase (CHAREF R. 2022). Although, the Refurbishment and the End-of-Life in buildings are beyond other building phases concerning standards and guidelines for sustainable assessments in BIM. That discourages the implementation of the environmental assessments by practitioners as there is no guidance or views about the process (CHONG, et al. 2017).

Conclusions

With the application of BIM from the concept stage (to evaluate the sustainability of the proposal), designers and engineers could minimize errors and anticipate solutions for the construction phase. In the meantime, the same logic could be applied for the deconstruction phase, as a deconstruction plan could be designed containing all the information about the materials and components used in the building. The challenge is to create a solid database or platform that could be used for all the AEC sector, where second raw materials could be marketed.

BIM is already showing great potential for connecting knowledge, preserving information, and narrowing collaboration between stakeholders.

Regarding the sustainability assessment in the early design stages, BIM

integrated LCA seems to be the best approach to assess the environmental impacts of a building, as it can be easily performed anytime during the asset lifespan. Through simplified LCA, designers and stakeholders can have supportive data for their decision-making.

Even with the need for improvements in the information exchange format, IFC, BIM is becoming relevant for LCA and LCC studies, not only for processing results but also for visually presenting them. The visualisation of these results by element or building's gross area in the model facilitates the interpretation of the results as it is more interactive for practitioners.

Many of the authors identified the lack of criteria specification and guidance to provide orientation when assessing sustainability. The existing LCA databases are specific market-orientated which leads to unreliable results in some case studies based on similar contexts.

The lack of information is noticeable in the End-of-Life phase, where accurate recycling rates are yet to be determined. The most adequate document, EPDs, usually presents traditional scenarios even when claims about the recyclability potential of products.

There is no doubt that the potential of BIM for coordination tasks could lead to better management of materials resources. The current technology is already opening the possibility to develop a Digital As-Built Model that allows the study of the best scenario for buildings' End-of-Life. Even with some manual inputs, these models allow practitioners to identify which materials were used and in what quantities. The development of a plan for deconstruction could decrease its costs and time of labour. The end-of-life in buildings is still an explorative area since the circular economy was introduced recently and there is not much expertise in this field (CHAREF, R 2022).

The decreasing rate of new buildings in Europe and the urge to recycle or reuse C&DW could lead existing buildings to be future material stocks (HONIC, et al. 2021; BAMB). Furthermore, the combination of BIM with Geographic Information Systems could lead to a new market around secondary raw materials and components. Further legislative measures and guides should be provided to encourage practices such as Design for Disassembly, the deconstruction of aged buildings and the increase of recyclability by manufacturers.

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