02-025

CIRCULAR ECONOMY AND DIGITAL TWINS IN THE CONSTRUCTION SECTOR

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Progress in digital and industrial technologies, shape all sectors of the economy and society. In the construction sector, digital building logbooks allow circularity by tracking the CO2 emissions and waste in construction projects, and enhance the durability, reparability and re-cycling of products and components. The integration of digital building logbooks into digital twins (green twin) also ensures better and more efficient use of construction-generated data to sustain competitiveness and greening of the sector. Grupo Construcía is a group of companies that offer circularity services, from strategic consulting to the construction of circular assets by implementing Cradle to Cradle circular principles and integrating them into digital and BIM (Building Information Modelling) technologies. This paper presents the current practices on circular economy in the construction sector and the benefits of integrating digital building logbooks into digital twins. It also presents a business case to highlight the drawbacks and complexities of data integration and to demonstrate the expected impact of this integration.

Keywords: Circular economy; digital logbooks; digital twin; green twin.

ECONOMÍA CIRCULAR Y GEMELOS DIGITALES EN EL SECTOR DE LA CONSTRUCCIÓN

Los avances en las tecnologías digitales e industriales son básicos en todos los sectores de la economía y la sociedad. En el sector de la construcción, el pasaporte de materiales de edificios permite la circularidad de éstos mediante el seguimiento de las emisiones de CO2 y los residuos en los proyectos de construcción, y mejoran la durabilidad, la reparabilidad y el reciclaje de productos y componentes. La integración del pasaporte de materiales en gemelos digitales (gemelo verde) también garantiza un uso mejor y más eficiente de los datos generados para mantener la competitividad y la sostenibilidad del sector. Grupo Construcía es un grupo de empresas que ofrece servicios de circularidad, desde la consultoría estratégica hasta la construcción de activos circulares mediante la implementación de los principios circulares Cradle to Cradle e integra estos principios en tecnologías digitales y BIM (Building Information Modelling). Este documento presenta las prácticas actuales sobre economía circular en el sector de la construcción y los beneficios de integrar los pasaportes de materiales de edificios en los gemelos digitales. También presenta un caso de estudio para resaltar los inconvenientes y las complejidades de la integración de datos de circularidad en modelos digitales y para demostrar el impacto esperado de esta integración.

Palabras clave: Economía circular; pasaporte de materiales; gemelo digital; gemelo verde.

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1. Introduction

Over the past few decades, global climate change has become increasingly problematic. Despite this, the construction industry has contributed 40 percent of total greenhouse gas emissions in the past few decades, and it is the largest contributor to global waste generation (European Commission, 2019). Considering these issues and the high demand for materials in the construction industry, Circular Economy (CE), a model of production and consumption, which involves sharing, leasing, reusing, repairing, refurbishing and recycling existing materials and products is considered to be beneficial for keeping materials in the loop and extending their useful lives (Meža et al., 2021). Despite the focus on the environment in CE, there is a strong connection between CE and economics and society, thus bringing CE into a vital sustainability context (Helander et al., 2019). Several measures such as waste prevention, eco-design, recycling, and reuse could generate a net savings of 600 billion euros or 8% of annual turnover for European companies, in addition reducing total greenhouse gas emissions by 2 to 4% per year (European Commission, 2014), which demonstrate the importance of CE implementation.

The European Union is promoting a shift to a more resilient, green, and digital recovery. The green transition and digital transformation are just at their beginning. In order to transition to the CE, Digital Technologies are recognized as an enabling factor (Antikainen & Uusitalo & Kivikytö-Reponen, 2018). Building Information Modelling (BIM) and Digital Twins (DT) are examples of these technologies used in construction. BIM plays a significant role in the Architecture, Engineering, and Construction (AEC) industry. Creating a digital model of a building makes it possible to gather and store information about all assets in a centralized location beforehand, which facilitates upcycling and reuse (de Tudela & Rose & Stegemann, 2020). As a result, buildings can be treated as a continuous source of materials, a concept known as Buildings as Material Banks (BAMB). BAMB is instrumental in designing for a CE (Gepts et al., 2019). BAMB defines a Material Passport (MP) as an electronic set of data that describes characteristics of materials in products that make them valuable for recovery or reuse. MP is being explored as a potential tool (BAMB, 2020). Compared to BIM, DT provides a more comprehensive and complex data management system; since DTs are data-driven and can integrate multiple data sources. Through the integration of artificial intelligence, machine learning, and data analytics, the DT platform develops dynamic digital models capable of learning and updating the status of the physical counterpart by combining multiple information sources (Lu et al., 2020). Therefore, DT can help tracking, recycling, and managing construction waste (Chen & Huang, 2020).

It will be difficult to provide sufficient land, material, and natural resources in the near future, and it will also be challenging to address upcoming waste problems. However, CE can aid in solving these problems, although it is still not widely implemented in construction. BIM can be used to understand building stock composition and construction waste, which is crucial for achieving higher recycling rates. However, Integrating digital models into CE, such as using BIM for managing the end-of-life of a building, is still an infrequent activity (Charef & Emmitt, 2021). Construcía is a company that offers circularity services, from strategic consulting to the construction of circular assets, is leading the implementation of CE in the construction sector and is implementing a set of technologies to enable circularity into their projects. This paper describes the current practices of circular economy in the construction sector, including Lean principles, Cradle to Cradle circular principles, Material Passport, DT and BIM technologies. It also presents a business case to highlight the drawbacks and complexities of data integration and to demonstrate the expected impact of this integration.

2. Literature Review

2.1 Circular Construction

"The circular economy is an economic system that represents a change of paradigm in the way that human society is interrelated with nature and aims to prevent the depletion of resources, close energy and materials loops, and facilitate sustainable development through its implementation at the micro (enterprises and consumers), meso (economic agents integrated in symbiosis) and macro (city, regions, and governments) levels. Attaining this circular model requires cyclical and regenerative environmental innovations in the way society legislates, produces, and consumes" (Prieto-Sandoval et al., 2018). Many different frameworks conceptualize the CE; the 3Rs (Reduce, Reuse, Recycle) model has focused most. The original model, however, quickly evolved into the 6Rs model (Redesign, Reduce, Reuse, Remanufacture, Recycle, Recover) and then into the 9(10) Rs model (Refuse, Redesign, Reduce, Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle, Recover) (Okorie et al., 2018).

Ellen Macarthur Foundation coined the term circular economy, represented in the butterfly diagram, as the most used definition. In this diagram, the circular economy is divided into biological (organic nutrients) and industrial (technical nutrients) cycles. While biological loops are more aligned with environmental and biology perspectives, technical loops are more aligned with economic and industrial perspectives. This diagram accompanies three circular economy principles. The first is preserving and enhancing natural capital, the second is allowing materials and products to circulate for more extended periods of time within both cycles, and the third is restricting waste (MacArthur, 2013). Recently, the fields of management and strategy have begun to discuss CE more in their literature on circular business models (Linder and Williander, 2017).

Circular construction is the result of applying circular economy principles in the construction sector. CE allows to mitigate waste generation and material toxicity. To properly design a circular building, it must be traceable, designed for disassembly and healthy in terms of material configuration. Furthermore, the whole lifecycle of the building must be assessed and all the stakeholders since its inception should be involved in collaboration spirit and transparency. Some authors have explored how the CE approach may be adapted to the construction industry, but most of the current research is based on case studies of specific types of construction waste. For example, Hertwich et al. (2019) proposed a life cycle analysis for recovering steel, aluminium, and copper from construction waste. The study by Cobut, Blanchet and Beauregard, (2016) suggested remanufacturing hardwood waste in buildings based on case studies and evaluation models.

2.2 Lean Management

Following World War two, Toyota faced fierce competition from its US rivals, leading Taiichi Ohno to develop the Lean concept (Ohno & Bodek, 2019). Lean management aims to meet customers' quality and speed demands while reducing waste (Dey et al., 2020). This management concept has been adopted across various industries with positive results. Lean management can also encourage businesses to achieve sustainability goals. There is substantial synergy between Lean and CE, despite their differing priorities. CE offers an ideal solution for the current global problems of resource scarcity, environmental damages, and the need to establish a closed loop economy. Meanwhile, Lean offers a method to eliminate waste, become more efficient, and maximize the economic benefits. They both aim to reduce waste and create value. Using Lean's value stream mapping principle and creating flow within the closed-loop system, CE can preserve and enhance natural capital and seek perfection through continuous improvement (Nadeem, 2019).

Additionally, Integrated Project Delivery (IPD) approach based on Lean Construction has been adopted in the AEC sector to respond to fragmentation by integrating information, processes, and organizations (Fischer et al., 2014). According to the American Institute of Architects, IPD is "a project delivery method that integrates people, systems, business structures, and practices into a process that collaboratively harnesses the talents and insights of all participants to reduce waste and optimize efficiency through all phases of design, fabrication, and construction" (AIA, 2014). Several features distinguish the IPD approach from traditional project delivery. It includes a multi-party contract, early participation by key participants, collaborative decision making, shared risks and rewards, liability waivers among key participants, and jointly developed goals (Ghassemi & Becerik-Gerber, 2011). In IPD, BIM plays a crucial role, as it introduces BIM as a powerful tool that can boost sustainability and circular economy (Chang & Hsieh, 2019).

2.3 Cradle to Cradle (C2C)

William McDonough and Michael Braungart developed C2C to combine chemistry and design in industrial products (McDonough & Braungart, 2002). CE and C2C promote the reuse of materials in the new biological cycle (organic nutrients) or industrial cycle (technical nutrients). The organic cycle can be used to fertilize the soil. In contrast, technical nutrients cannot return to nature but circulate through industrial cycles (Brennan & Tennant & Blomsma, 2015). As a result of its product circularity indicators, C2C has become an increasingly practitioner-oriented concept. As a result, C2C served as a proxy for circular economy implementation and ultimately transformed into an operationalized version of circular economy unlike other predecessors (MacArthur & Zumwinkel & Stuchtey, 2015). Although C2C has been widely embraced by industry, a number of other circularity indicators have also been proposed at the product level, such as Remanufacturing Product Profiles (REPRO) (Gehin & Zwolinski & Brissaud, 2008), material circularity indicator (MacArthur, 2015), and the circular economy index (Maio, & Rem, 2015), the eco-efficient value ratio (Scheepens & Vogtländer & Brezet, 2016). Despite their differences in application, each of these indicators has the same goal.

2.4 Building as Materials Banks (BAMB)

In a rapidly changing society, mono-functional buildings become outdated sooner than expected and as a consequence, its demolition becomes waste. In contrast and to-rethink the whole supply chain value, BAMB is a new trend in circular construction that envisions buildings as repositories of materials (BAMB, 2020). With the aim of preventing construction and demolition waste, reducing virgin resource consumption and promoting the development towards a CE, BAMB framework develops and integrates the implementation of Reversible Building Design (RBD) and Material Passports (MP).

RBD is the design of buildings in which its components and systems can be easily disassembled without harming the building or the products (Durmisevic, 2016). In order to do so, RBD subdivides the building in different layers such as structure, facade, partition, systems and furniture. Each layer has a life cycle and RBD focuses on their future scenario, therefore, material recovery allows adaptability of spaces and re-use of the materials inside the building. Consequently, materials prevail in a use loop maintaining their value instead of turning into waste.

To effectively recover the materials inside a building a comprehensive data set is required to identify, keep track and reuse materials in a continuous flow. This has led to the development of the MP (Luscuere & Mulhall, 2018). These material passports contain information about quantities, qualities, and dimensions of all materials used in buildings. Standardization and central registration on materials passport platforms are prerequisites for circular resource management in the built environment (Rau & Oberhuber, 2017). In the transition from a linear to a circular economy, documentation is one of the essential elements because this allows an assessment of the transition by measuring progress and evaluating indicators. As well as lowering the barriers to implementation, this data is essential for the management of stocks and flows in the system. Numerous European research consortiums are currently developing appropriate methodologies and circularity indicators, e.g., the EU's Level(s) or BAMB (European Commission, 2019). In addition, several companies, such as Construcía, Madaster, and EPEA, have developed a variety of product solutions for MP that are either in the process of being implemented on the market or have just been launched.

2.5 Building Information Modelling, and Digital Twins

In the current remanufacturing of construction waste, the main challenge is the lack of data and the difficulty of exchanging information between parties involved. This issue can be solved by implementing BIM and DT for waste minimization related to the CE approach. In general, Digital Twins can be divided into four categories: BIM, GIS, reality capture tools (such as 3D laser scanning, point clouds, and photogrammetry), and IoT (such as RFID and sensor networks) (Wong & Ge & He, 2018). Although BIM and DT are becoming more popular, they are not widely used for end-of-life management. Their application in the construction industry is mainly at the design and maintenance stages (Chen & Huang, 2020, Charef & Emmitt, 2021). Following are some studies on DT that relate to CE. Popa et al. (2018) designed recycling logistics for glass panels using the DT in a Romanian case study. Wang, X. & Wang, L. (2019), proposed a system framework for component-level remanufacturing based on Digital Twins for waste electrical and electronic equipment (WEEE). Using a DT, Scott-Emuakporl et al. (2014) proposed technology and process for component remanufacturing of old gas turbines. Mandolla et al. (2019) developed a Digital Twin application framework for additive manufacturing of aircraft components. Gordon et al. (2019) and Sun et al. (2018) examined the performance of stainless steel additively made based on the DT process.

3. Business case: Construcía

3.1 Description of Construcía

Construcía Group is composed of 4 main companies that offer circularity services, from strategic consulting to the construction of circular assets. Currently, the Group has presence in Spain, Portugal and France, with headquarters in Madrid, Barcelona and Lisbon, employing over 300 people and forming an interdisciplinary team. In 2021, the company generated a turnover of more than 150 million euros, which represented a growth of 40% compared to 2020 turnover (Construcía,2022a).

Construcía is a service-oriented construction management firm from Construcía Group. Born in 2002, it has executed more than 160,000 m2 of constructed area. Among its projects, it highlights its expertise on residential, office and industrial buildings (Construcía,2022b). In 2012, Construcía partnered up with Eco Intelligent Growth (EIG), a firm specialized in circular economy consultancy and also in the transition from business, regions and organisation into C2C principles. EIG advise on the transformation to circular economy, allowing Construcía to be a pioneer implementing Circular construction in Spain. Currently, Construcía is committed to innovation, continuous learning and to generate abundance in its field through circular construction.

Construcía's mission is to transform and promote a shift in the construction sector towards a circular model with positive impact on people, society, and the ecosystem, while generating economic value. Construcía group has developed its own methodology to properly design, plan, execute and manage Circular Buildings (EIG, 2020): Lean to Cradle (L2C).

3.2 Lean to Cradle (L2C) Methodology

3.2.1 L2C principles

L2C is based on Lean Construction (LC) methodology and C2C design principles. L2C's objective is to create spaces and buildings that enhance the well-being of its occupants, generate economic, ecologic, and social benefits and promote a shift in the construction towards a more sustainable model.

L2C faces the current challenges of the industry by changing the traditional project management methods. In L2C, while LC aims to reduce waste in the execution process -such as waits, transport, overproduction, and defects- the C2C paradigm promotes the use of products and processes that are safe and constantly cycled. When combining these two approaches in the built environment it leads to efficient processes and regenerative design. Nevertheless, according to Construcía, EIG and KPMG (2019), the key part of the methodology is to share and enhance the following principles among each actor of every project:

Industrial transformation

Inspired on LC methodology to maximise value for the client. By implementing key Lean tools such as Pull planning, just in time, prefabrication, and daily control, savings in time, cost and quality are ensured. Another key factor is the use of Building information modelling (BIM) along the design and execution of the project. BIM models allow to detect incompatibilities between specialties and missing information is detected early in the process, moreover, the transition and visualisation of information to the construction site is carried out easily (Construcía, 2022c). In consequence, this principle embraces innovation in the way of design and build.

Comfort and wellbeing

To ensure the indoor comfort and health of the building occupants, the incorporation in the design stage of key factors such as active design, promote natural light, view from the exterior/outsides, acoustic improvements, and strategies to enhance better indoor water management is recommended. McDonough (2002) stated, “design is the first signal of human intention”, therefore, L2C incorporated the C2C approach and aims to design healthy and comfortable spaces, therefore creating “more good”.

Circular and healthy design

To achieve a healthy design, it is important to include low toxicity C2C Certified construction materials where possible in the project. Additionally, it is required to include circular tools such as MP, design for transformation and disassembly and deconstruction plan (Construcía, 2022d). In the construction stage, it is suggested to employ suppliers that provide take back policies and implement on each project a plan on Waste prevention and management. By doing so, most of the materials incorporated in the building will be cycled continuously at their highest value.

Maximise the use of renewable energy

Buildings that are energy optimised are fit for the future by reducing carbon footprint and generate savings for the client through lifecycle of the project (KPMG, Construcía and Eco

Intelligent Growth, 2019). This goal is achieved by using renewable energies such as solar energies and reducing energy demand on the building from simulations at the design stage.

3.2.2 L2C workflow

To implement L2C principles and generate positive impact for people, business, and the planet, Construcía has developed several strategies and tools (Construcía, 2021). During the design stage of a new project, the circularity of materials should be assessed by evaluating the selected materials and products. Consequently, a preliminary diagnose on residual value of the building and which components can be reused is obtained. Then, circular design proposals should be added to the current project. In other words, this means selecting suppliers that provide "take back" possibilities as well as picking healthy materials to be included in the building. Furthermore, the design should consider not only the first life of the building layers but also the following ones. According to EIG (2020), the success indicator of circular design is measured by the number of materials that can be disassembled from the building and reused in a perpetual cycle.

During the planning phase, pull sessions take place enhancing the collaboration between the main actors in the construction value chain. Encouraged by Lean methodology, last planner system is implemented during the execution phase to minimize risks of delay or waste in the process. In addition, prefabrication offsite is carried where it's possible and a just in time logistic plan is implemented. By doing so, savings on budgets are 10%-25% and reduction in delivery time is 10-30% (Construcía,2021). It is important to highlight that L2C as well as LC encourages continuous learning and improvement during this phase to reuse and spread the knowledge gained on each project.

When applying L2C, each component has an identity and its location inside the building is specified on a MP. Additionally, information about its deconstruction and recuperation is included (Construcía,2022d). While in most of the projects, the delivery of the building is the end of the information; on the contrary, L2C considers it the start of the circular loops. During the use and maintenance phase, the information allocated in the MP will be updated according to the maintenance works and the changes made on each component.

At the end of service, the detailed deconstruction process must be executed according to the specifications stated in the material passport (Construcía,2022d). From this point on, new business opportunities are created as the materials come back to the supply chain value at its highest value. The main purpose is to re-use materials on perpetual loops and therefore stop generating waste and gradually stop relying on virgin materials from natural resources.

3.3 L2C digital tools

Construcía has taken one step forward by digitalizing tools implemented in L2C methodology. Consequently, better transparency in the processes and spreading of knowledge is obtained. The following tools were presented by Construcía (2021) in the "First report about circular construction in Europe" to properly apply L2C framework:

BIM

Construcia has implemented BIM methodology in several projects. One of the key benefits has been the integration of a significant amount of information in one single model that can be updated along the life of the building. Another highlight is that the model can simulate energy performance of the building and assess energy efficiency within (Construcía, 2021). As a result, Construcia avoids mistakes early on the design stage, assures savings on the project budget and provides sustainable solutions (Construcía, 2022d). In addition, at the end of the execution phase, the information contained by the model is transferred to be used in the elaboration of the MP.

BEDEC products database

The BEDEC products databased is a compilation of databases for the construction sector which was developed in collaboration with "Instituto de Tecnología de la Construcción de Cataluña". It includes valuable information such as price of materials, embodied energy and carbon footprint, legislation and even BIM objects library (IteC,2022). This database is built as a cloud database that is nourished by the expertise of the construction industry, and provides valuable information that allows transparency in decision making and properly justification of any proposal that enhances the circularity of the project. Therefore, Construcía implements this database to achieve the principles stated in L2C methodology.

MYUPCYCLEA software

MYUPCYCLEA is the first software powered by artificial intelligence (AI) that enables circular assets management. Based on input-information from each product, this platform helps to compute residual value, manage carbon cycles, and allows to keep cycling valuable and healthy materials (Construcía, 2021). Subsequently, the traceability, management, and commercialization of the products along time become feasible. This platform is fed by the knowledge from each project. Therefore, it suggests different options for products that may add value to new projects.

Material Passport

From the information acquired by BEDEC, BIM, UPCYCLEA a MP of the building is developed. From a life cycle analysis approach, information about toxicity and cyclability of material can be assessed early in the process and taken into consideration for proposals of material selection or changes. Afterwards, traceability of the materials is achieved by classifying each component as a technical or biological nutrient and defining the best deconstruction strategy. Among the applied strategies the reuse of materials, recycle and take-back from the original supplier are highlighted. During the use and maintenance stage, the MP is conceived as a consulting database to manage the building and is updated to maintain traceability. At the end of the service life, the MP help properly deconstruct the building (Construcía,2020d). By doing so, the building becomes a material bank, remains at its highest residual value and is managed as a circular asset.

3.4 L2C key performance indicators

Apart from the workflows and the tools for achieving L2C principles, Construcía also developed key performance indicators to keep track of the circularity of the project, in which L2C methodology is being implemented (Construcía, 2021).

Circular Signature

The result of the product passports of the project and their financial information is a Circular Diagnose which is based on 4 key indicators: Carbon footprint, circularity rate, materials health, and residual value. Carbon footprint measures the amount of greenhouse emissions associated with the fabrication of the building materials (tons CO2 eq). Likewise, circularity rate stands for previous life of materials and next possible uses. It highlights the importance of deconstruction of the incorporated materials. Material health is based on the toxicity analysis under C2C Certified parameters. And residual values accounts for the financial value that could be obtained by re-incorporating a product after fulfilling one life service (Construcía,2021).

L2C True Value & L2C Value to Business

To properly share the value of implementing L2C methodology, Construcía has created two indicators that account the financial and social value. L2C Value to Business reflects the value gained to the client's business. Accounting savings obtained in water and energy operative costs, higher residual value of the selected materials and the reduced risk of new environmental policies, better performance in KPI such as Internal Rate of Return and Net present value are obtained (Construcía,2021). On the other hand, L2C True Value reflects the value created to society and the environment. It reveals all the positive impacts generated by L2C project. Metrics such as the reduction of carbon emissions, reduction of material toxicity, elimination of waste and the increase on occupants' productivity are characterized to monetize the true value to people and the planet (KPMG, Construcía and Eco Intelligent Growth, 2019). By adding these two KPI, Construcía offers the "Shared Value" created to people, business, and environment.

3.5 First implementation results

Gonsi Sócrates Building is the first circular building designed and constructed in Spain using L2C methodology. It is located in Viladecans (Barcelona), has more than 6000 m^2 distributed in 4 floors and is constructed with materials free of harmful substances and highly cyclable (Construcia,2022). The development of the project under IPD methodology was a key factor to address the L2C approach and successfully execute the project. The collaboration among all actors, allowed assessing and considering different design options. The information gathered from the BEDEC database, allowed analysing environmental indicators such as Carbon footprint and toxicity of materials early in the design process. A BIM of the building was developed to facilitate the transfer of information, improve the communication, detect interferences and better visualization of the project. The quantities of building materials obtained from the BIM were used to evaluate the circular asset management using UPCYCLEA. Finally, the building MP was created and used to avoid turning materials into waste, therefore increasing the building´s residual value.

According to Gonsi Socrates MP (Construcía,2022e) from the 9000 tons of materials that has been incorporated, almost 89 % has a cyclability defined path. Furthermore, 99% of installed materials are C2C certified and promote health among users. According to L2C True Value (Construcía,2021), the impact of health in productivity will be 36.7 million euro along 30 years of lifespan. Selection of materials, natural lighting, indoor vegetation, noise control and high air quality are key strategies to increase performance of indoor employees. From an environmental point of view, the utilisation of C2C certified materials accounts for a reduction of 320 tons of CO_2 which shows the benefits of C2C to the world. Nevertheless, according to the L2C Value to Business the profit for this building rounds 8.7% and will return in less than 12 years of operation; in addition, residual value in the next 30 years will increase from 84 thousand euros to 354 thousand euros. In consequence, early advantages have been recognised from implementing L2C Methodology.

4. Discussion and future trends

The implementation of LC&IPD methodology and BIM as a tool for project management has proven that major changes can be adopted by the industry (Elghaish et al.,2019). These initiatives have been generating a proper scenario to adopt a circular economy and boost the digitalization of the sector by promoting transversal integration of people. However, all kinds of corporate, process and technology innovation are needed to start thinking of a new circular era (Muñoz-La Rivera et al.,2021). When predicting BAMB as the main model for the circular built environment, relying on technology that connects actors, facilitates the identification and reaction to possibilities and prioritises the flow of materials throughout the future lifecycles of the building´s layer becomes a must (Adisorn et al., 2021).

To properly select the materials and systems that can be used, reused and managed in a circular economy, it is important to rely on available MP information from cloud platforms such as UPCYCLEA (Construcía, 2021). It is also important to grant Data Sharing (DS) among users, suppliers, builders, policy makers and clients to enrich the exchange of data, feedback from experiences, results, good practices for better decision making, learning and further developments from a waste and resource perspective (Farinella et al.,2014). Currently, there is no connection between MP and digital models due to interoperability problems. However, this would be a requirement in the near future implementation. BIM-based MP will facilitate the storage of CE data per building as well as its resource management. Additionally, BIM-based MP can predict different building scenarios in terms of carbon footprint, toxicity, circularity or energy performance. and thus, acquire knowledge of the expected behaviour of the building. It would also be a key tool to ensure that the MP remains a dynamic up-to-date document (Adisorn et al., 2021). Moreover, during the Maintenance and Operation stage, the integration of the BIM model into a DT will be able to optimise and monitor the building systems. In consequence, DT will become the most complete tool for preventive and predictive maintenance and will enrich the update of the MP during this stage (Tao et al., 2019).

In the future circular-built environment, cities shall be understood as interconnected living systems. In order to integrate the digital models of the buildings (BIM or DT) considering its location on the map, Geographic Information Systems (GIS) should be implemented (Zhu et al.,2019). After one life cycle ends, another one begins. Connecting the information of BAMB across the globe by GIS will allow management and geolocation of material. From this point on, the possibilities are endless. The rise of new circular material markets will allow continuous circular loops of materials and the construction industry may gradually stop relying on raw virgin materials. By doing so, properly imitation of the nature, in which there is no waste, will be implemented.

5. Conclusions

This paper presented the current circular construction trends, reviewed existing digital tools and presented Construcía as a business case that promotes circularity within the sector. To properly face the environmental and waste problems that face the industry, a shift to circular construction must be undertaken. C2C incorporates CE principles in the development of projects by rethinking the linear design, use, and disposal to circular endless loop of materials. As a consequence, buildings become material banks that allow the deconstruction and reused of its components. However, the information related to environmental indicators, toxicity of materials and deconstruction of products is still scarce and when available it´s presented in endless amounts of documents. While Upcyclea provides a cloud platform that stores MP of different construction products and promotes resource management, BIM models allow visualisation, integration and collaboration of the project in one digital model. Combining the MP and BIM models will represent a first intersection point between two existing trends: the digitalisation of the sector and the need for a circular future. In addition to this challenge and as important is to adopt a holistic approach that implements methodologies that enhances collaboration and active participation between actors such as IPD or Lean, training at all levels and the willingness to face the complexities involved in this transition. Construcia is facing these challenges and being a pioneer by developing its own L2C methodology. Additionally, the implementation of digital tools has boosted the innovation across the partners and suppliers involved as well as shown some clear benefits in the execution and development of projects. It is the aim of Construcía to develop a hub of circular construction companies in which the exchange of knowledge will ensure a faster, feasible and long lasting transformation to circular construction.

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11 CIUDADES Y COMUNIDADES SOSTENIBLES

OBJETIVOS DE DESARROLLO SOSTENIBLE

Communication aligned with Sustainable Development Goals