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ENABLING CIRCULAR CONSTRUCTION INFORMATION FLOWS USING DATA TEMPLATES – CONCEPTUAL FRAMEWORKS BASED ON WASTE AUDIT ACTION

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ABSTRACT

The Construction Industry faces challenges to achieve the key goals of Digital transformation, Sustainability, and Waste. The problem is that these have been strategically detailed mostly in separated documents. Despite common elements, the defined roadmaps use different headings, terminology and are over-focused. This leads to gaps at several levels. Connected information flows can foster alignment and bridge the gaps.

This research provides awareness and demonstrates how Circular Construction can be built on Digital Transformation, Sustainability, and Waste, using information flow conceptualizations. The approach is made from the "digital challenge" and through Data Templates as enablers for circular information in construction.

INTRODUCTION

The Architecture, Engineering, Construction, Operators and Owners sector (AECOO) strongly affects the economy, the society, and the environment as a whole (Forum, 2016) (Hjelseth, 2017). The industry transformation framework sets many challenges and this research focus on "Digital Transformation" and "Sustainability and Waste" (Forum, 2016).

There is a real problem related to the dimension of the industry environmental impacts, as in recent years the waste production and low recycling rates have been raising more and more concerns (Forum, 2016). The waste reduction challenge cut crosses the entire life-cycle and relies on efforts at product manufacturing and construction levels. Yet, the ability to re-use, in this or other industries, or recycle products and elements that are already part of the built environment is what impacts the most. Given this, even the smallest improvement, if scalable, will provide significant outcomes. For all these purposes it is key to distinguish what is real waste and what it is not. Waste audit actions are pointed as the tool to perform this assessment, through the identification and quantification of the amounts of different waste types on an existing built object (European Commission, 2018). This identification and inherent data are key to change from a linear value-chain to a more circular one.

Most of the construction strategic documents are focused on or depart from one of the abovementioned challenges. This leads to a "siloed" approach that often lacks on the identification of common outcomes and on how a specific challenge can be supported by or benefit from the other.

The research motivation arises from this awareness and from the perception of the potential negative impacts that this might induct on the industry stakeholders, namely confusion and inaction. Digital Transformation and Sustainability and Waste are complex challenges that the industry must accomplish. Despite their differences and the over-focused strategies, there are connection points that can bridge the existing gaps and foster broader and more assertive innovation actions.

This study sets way from the Digital transformation challenge side and how specific initiatives, namely Data Templates, can work together and improve Sustainability and Waste goals.

The novelty is associated with the awareness of the potential role of the Waste Audits. The process of delivering waste audits follows specific guidelines that nowadays are not sufficiently embedded with the digitalization trends but they can be easily be corrected to work together.

The assumption is that if a product or an element can be reused or recycled, so its information can also be. Data Templates are key elements fostering streamlined information flows and working as enablers/facilitators for waste audits fostering a circular information flow across the construction life-cycle.

CONTRIBUTIONS TO THE BODY OF KNOWLEDGE

The research aims to contribute to the body of knowledge by providing insights and conceptual frameworks at two different levels. At the strategic level (EU/Governments) by raising awareness on the imperative need to combine/harmonize construction digitalization strategies and construction sustainability and waste strategies. The research reveals the misalignments/communication gaps and identifies a connection point.

Considering the already existing strategies and the identified connection point, develops and discloses conceptual frameworks to provide common outcomes,

first by delivering a conceptual approach for the development of waste audits based on Data Templates and further, a conceptual framework for Circular Construction Life Cycle Information Flow.

RESEARCH METHODS

This study progresses from a brief literature review based on strategic documents addressing dimensions of the AECOO transformation framework and the few research works ranging the topics "Digital Transformation" and "Sustainability and Waste". Conceptual proposals are developed and discussed considering the headings defined for the challenges, focusing on how the communication requirements must be aligned and on how the processes and elements must be implemented to boost circularity and data-centric sustainable built environment visions.

Data is vital for any process and construction is not an exception. Due to its fragmented value chain in terms of stages and stakeholders, it becomes even more relevant to find ways of collect data to structure and provide information at the right time, with streamlined flows, with associated ownership and responsibility, as well as updates and traceability mechanisms (Watson, et al., 2019). This is key for the strategy to bridge the identified gaps.

From a whole life-cycle perspective, a built object at the end of its life will be refurbished or deconstructed and its systems and elements will become waste, recyclable products, or products with the ability to be re-used (European Commission, 2018). This identification should be made prior to each one of those actions through a waste audit.

As a product can be suited for re-use, so its information must be. Therefore, the waste audit was selected to conceptualize a proposal aimed to close the information circle through the construction life-cycle and to be used as an example to bridge essential aspects between the digital transformation strategies and the sustainability and waste goals applied to construction. EN 15978:2011 (CEN, 2011) is used to support the construction life-cycle stages, from A1 (Raw material supply) to D (Recovery/Reuse/Recycling-potential), and system boundary covering to cradle to grave.

The new standards ISO 19650-1:2018 (ISO, 2018) and ISO 23387:2020 (ISO, 2020) should be regarded as strategic facilitators for the accomplishment of the challenges

KEY ELEMENTS FOR INFORMATION FLOW AND MANAGEMENT

In 2012, the publication of the European Union (EU) "Strategy for the Sustainable Competitiveness of the Construction Sector and its Enterprises" set the global challenges for the industry (even surpassing the EU boundaries) and opened the way for the development of strategies to raise the industry bar.

Due to the AECOO vast scope and number of challenges, different headings were assumed by leading organizations, namely EU DG's - Directorate-General. During this time, many strategic documents, research projects and guidelines were developed.

Many of them, due to the nature of the organizations have focused on specific issues, topics and priorities to be solved. Given this and looking from a broad perspective, their approaches followed different assumptions and became "fuzzy" when there is the need to perform a combination or harmonization between them. As mentioned, two challenging dimensions are found to be key for the construction transformation framework and where it was possible to find misalignments and communication gaps. These are the "Digital Transformation" and the "Sustainability and Waste".

Following the strategic approaches and placing them as a layer framed with the construction life-cycle, Digital Transformation tends to look forward to the construction value-chain and its processes, to the implementation of Industry 4.0 technologies, raising the sector to an analogue 4.0 paradigm. The Sustainability and Waste look behind, to the already existing Built Environment and to the industry installed capacity (understood as production capacity and potential of the built stock), seeking ways to become more eco-efficient both through the production of more environmentally friendly products, waste reduction and re-use and recycling of products/elements. Figure 1 aims to evidence, from a conceptual point of view, the somehow seeming "opposite" heading of these dimensions/strategies, as well as the vacuum/gap that exists, due to the over-focused approach, making a joint understanding less feasible.

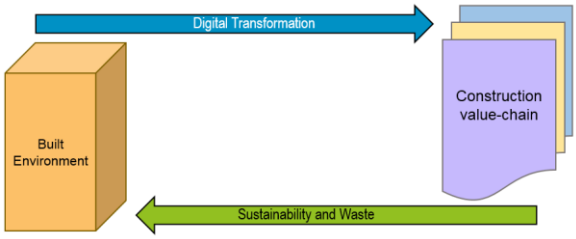

Figure 1: Dimensions to raise the bar of construction. "Theoretical" headings and gaps.

The next sub-sections aim to support these visions as well as briefly introduce relevant concepts for the research development.

Digital Transformation

The sector has significant opportunities to exploit digital innovation (Forum, 2016). Some examples of digital technologies are Building Information Modelling (BIM), Common Data Environment (CDE), unmanned aerial systems, cloud-based project management, Augmented Reality/Virtual Reality (AR/VR), Artificial Intelligence (AI), cybersecurity, big data and analytics, blockchain, and laser scanner (Desruelle et al., 2019).

The "Digital Twin" concept as a model for data-driven management and control of physical systems has emerged over the last decade in the domains of manufacturing, production and operations, quickly spreading to the construction industry (Sacks, et al., 2020).

The key difference between Digital Twin Construction (DTC) and current construction management practice is that DTC is data-centric (Sacks, et al., 2020).

Recent studies seek to identify the "heat" of these technologies and their contributions to the ambitioned transformation. Despite some quick wins, namely around BIM, many are still in their infancy and the abovementioned data-centric challenge is yet, in most part, to accomplish.

Sustainability and Waste

The AECOO is identified as a priority domain on the action plan for Circular Economy in Europe because, in volume terms, is among the biggest sources of waste (European Parliament and European Union Council, 2015).

The promotion of the efficient use of resources to reduce overall environmental impacts throughout the full life-cycle is a major goal (European Commission, 2014).

To accomplish it, reliable indicators must be developed seeking to evaluate total energy use, including operational energy, material use, carbon footprint, the durability of construction products, recyclability and reusability as well as recycled content used in construction products (European Commission, 2014).

These indicators rely on comparable and affordable data, methods and tools on which the operators in the supply chain can analyse and benchmark the environmental performance of different solutions. Yet this is still lacking (European Commission, 2014).

The ability to perform improved assessments and quality reliable data is essential to develop the environmental analysis and achieve the abovementioned indicators (ECSO, 2019).

As well, despite some quick wins on the recycling and re-use of products, there are still several data challenges at this level.

DATA FLOW CONCEPTS DEVELOPMENT

The strategic level documents explored in the previous section globally define some of the ACEOO main challenges, focusing both on global and specific aspects.

Yet and despite some converging endeavours, the underlying message still lacks common approaches and terminology, causing confusion and inaction at sector, companies and personal levels. As evidenced, BIM methodology and circular economy in construction based on sustainability and waste efficiency arise as main topics.

Ganiyu, S. et al. developed a study ranging the two dimensions seeking to identify the required competencies to deliver projects fulfilling both types of requirements. One of the aspects that are highlighted in the introduction is that "BIM usage for delivering waste-efficient projects is not commonplace" (Ganiyu et al., 2020), meaning that there is still a lot to explore.

In accordance with ISO 19650 series, the Asset Information Model (AIM) is composed of Documentation, Alphanumerical information and Geometrical information (ISO, 2018). This must be a fundamental understanding around all BIM uses becoming increasingly indispensable when dealing with life-cycle approaches. At this level, all the added value is on the data and its interpretation, compilation and organization into useful information.

From the literature review, it highlights that Data is a common point between both challenges and strategies meaning that it constitutes a connection point to start bridging the existing gap.

The following sub-sections introduce key elements for the development of the Circular Building Life Cycle Information Flow Conceptual Framework.

Waste Audit

A waste audit is a specific action before the demolition (C1 with other terminology) or renovation (B5, likewise) of buildings and infrastructures that must be foreseen within a project planning in order to understand and quantify the types and amounts of elements and materials that will be deconstructed and/or demolished, and to issue recommendations on their future handling (European Commission, 2018) (CEN, 2011).

A specific document with guidelines on this task was produced by the EU and despite all processes and benefits it confirms, as mentioned, a "siloed" approach to the construction challenges as there is no single reference to "digitalization" nor "BIM". Despite that, there are some key aspects (that may, however, go unnoticed) that on one hand confirm the existing gap, namely in terms of communication, and on the other hand, are used as starting point to bridge that gap (in terms of processes). Both support the need and contributions of this research. These aspects are the "Data to achieve the materials inventory" and the "Data Traceability concerns".

In terms of "Data Traceability," it is stated that "Waste audits should be considered as living documents that are revised periodically" (European Commission, 2018). In this, there are considered 3 stages that run from a situation prior to the deconstruction/refurbishment until the end of the process (disposal or reuse). This is found to be a short term traceability requirement but one that is not so different and can glue to wider traceability requirements running through different construction process phases as evidenced.

Regarding the "Data in Materials Inventory", it is stated that "The inventory of waste fractions and elements is the core part of the waste audit report" (European Commission, 2018) "The assessment of materials aims to present reliable data about the type and amount of the demolition waste" (European Commission, 2018).

The material inventory must include the materials quantification in relevant units of measurement and type of material under several classifications as the European Waste Catalog (EWC), EURAL waste list and data related to hazard ability, recycling and re-use.

None of this required data has an origin in this process. It is data that comes from prior stages but is identified and organized in this action for a specific/different purpose.

Digital Building LogBook

The study action for the development of an EU framework for digital building logbooks has recently published a report where through this tool, the building logbook, aims to bridge the gap between construction digitalization and environment initiatives.

In accordance with it: "A digital building logbook is a common repository for all relevant building data"."… is a dynamic tool that allows a variety of data…". "As such, it can include administrative documents, …, technical systems, traceability and characteristics of construction materials, performance data such as operational energy use, indoor environmental quality, smart building potential and lifecycle emissions." (Sophie Dourlens-Q. et al., 2021).

Given this, and for the purpose of the present research, the Building Logbook is found to be the "place" where all the DS of a specific build object are stored and updated, mainly from handover until refurbishment/deconstruction. As so, this closes the data and information cycle required to implement a circular economy in construction.

The EU Renovation Wave strategic document to foster refurbishment actions across the European Building stock highlights that all these processes should seek for the:

- use of Building Logbooks
- development of waste audits
- implementation of BIM

Data Templates

Data Templates are data structures used to describe the characteristics of construction objects (ISO, 2020). They are also information exchange enablers across the construction life-cycle. The standard is aligned with the digital processes and assumptions. Yet, this is still not the understanding among the majority of the stakeholders across the sector. Many don't know the term and others point to information structures that despite their value do not highlight the real value of the Data Templates. To contribute to the full realization of the potential role of these structures and despite the standard, it worth's highlighting that we are addressing data templates as Digital Data Templates (DDT).

Focusing on construction products, understood as manufactured products (tiles as an example) and raw materials (sand), and on systems (wall composed by several products) it becomes more clear the role that these structures can have in each stage, both for the compliance of more "traditional" requirements, as well as requirements related with sustainability.

DDT have their properties defined following products types, applicable standards and requirements.

The Manufacturing (A3) phase is where a specific product, understood as a brand with an associated model, specific designation and performance values borns. This means the specific values for the properties are addressed to the DDT, transforming this structure into the Digital Data Sheet (DDS) of that specific product. Depending on the type of product and manufacturer characterization process, the DDS might have more or fewer properties with filled values.

The DDS are used during the design and become part of the specifications. They are a substantial part of the AIM alphanumerical information, supporting also some geometrical information. During construction, the DDS's gain more values, namely the ones that depend on the construction process, as asset code, date of placement, warranty start date and so forth (Mêda, P. et al., 2020).

During construction, changes might occur in construction products, either by changing the product type maintaining the manufacturer, changing the manufacturer or even changing the design specified solution. All these changes need to be safeguarded to assure data traceability. Given this, it can be easily understood the relevance and the role of these structures for the digitalization strategies of Manufacturing 4.0, Construction Process 4.0 and Site 4.0. (Sousa, H.; Mêda, 2017).

The Use (B) stage, in accordance with EN 15978:2011, has 7 sub-categories where similar changes to the ones abovementioned can occur on the Data Sheets. Prior to the B5 "Refurbishment" or C1 "Deconstruction" there is a key task that must be made following the strategies focused on environment and sustainability; the Waste Audit.

Bridging the Gap

From this results that the Digital Transformation and Environment and Sustainability challenges identify Data within their concerns to provide common or specific information and that there are common data structures with the ability to support both requirements, from the processes perspective.

Therefore, the information communication strategies to the AECOO and their stakeholders addressing both dimensions should use data and digital data structures to bridge the gap and foster a more favourable environment to promote a circular economy. Figure 2 evolves from the schema presented in Figure 1. The developments are used to bridge the gaps at process and communication levels and set a movement to promote the digital circular construction based on information. Figure 2(a) presents the existing gap between strategies, and Figure 2(b) sets the Circular Economy built on Digital Transformation and Environment and Sustainability goals.

DIGITAL LIFE CYCLE INFORMATION FLOW FOR CIRCULARITY

Given the elements and concepts above described the conceptualization of their potential uses and relationships to make a proof of concept on how both challenges can work combined through the use of Data constitutes the other contribution.

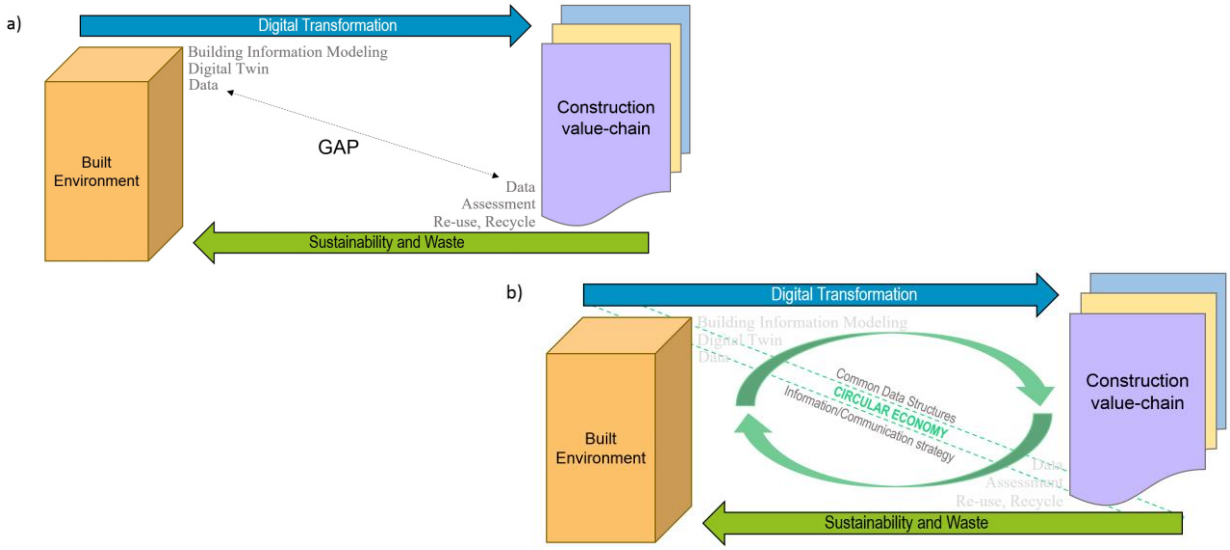

Figure 2: Circular Economy built on Digital Transformation and Environment and Sustainability goals.

The first conceptualization is focused on the combination of the waste audit action and the digital data templates use for the situation of two different Built Environment scenarios. The Digital Building Logbook concept is used as the "information vault" through the construction life-cycle and is used here to introduce the overall conceptual framework.

Considering a new project/construction process, the DDT's are called to support specific construction products/elements data becoming DDS and following a part of the AIM alphanumerical information. During the handover phase, the Logbook assumes the role of information vault/container with several layers supporting all kinds of information. On the edge, it can become part of the DTC system or eco-system with traceability and update routines, contributing to the update of the Material Inventory that will, in a certain moment of the life-cycle, be called either in the case of a refurbishment or for the deconstruction process.

A similar situation, and the one that is expected to happen the most, is the case of an "old"/existing built object facing a refurbishment or a deconstruction process.

The digital data relating to these cases is often none and most times the paper/other formats available information is not sufficient. Facing a waste audit, the material inventory will be developed from scratch. In these cases, if the waste audit guideline could point to the use of DDT, even without all the values, these structures would suit for the purpose of the waste audit itself and also for the case of products/elements to be re-used or recycled.

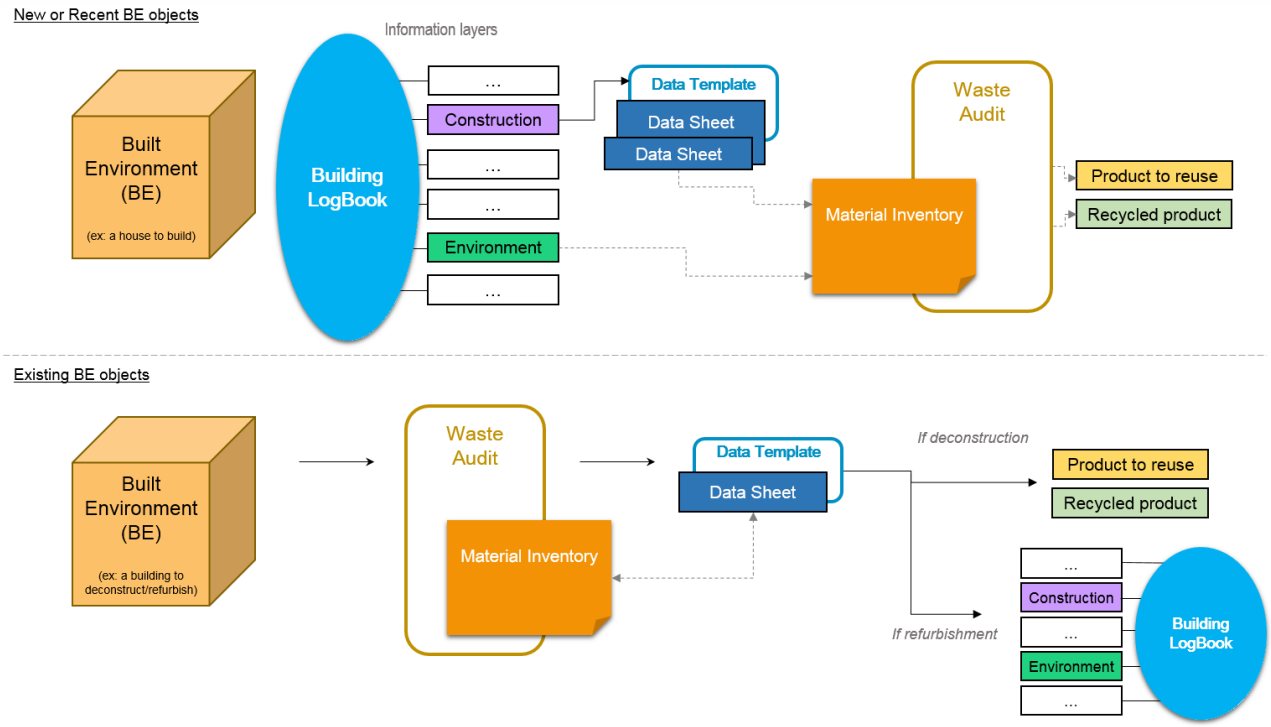

Figure 3: Waste Audit action based on Data Templates for New BE objects and Existing BE objects (V1.0)

At this point, it is important to distinguish also if the built object is going to be deconstructed or refurbished. If it is the second case, the use of DDT will support the development of the Building Logbook. Figure 3 provides a conceptualization of how the processes can run for both types of situations; new projects and existing built objects.

It is also important to highlight that the adoption of Digital Data Templates can introduce benefits in many other processes besides waste audits. Through the organization of the data in a standardized way, it is possible to streamline other processes in other phases as sustainability assessments during design, simulations, and so forth.

Following a data-centric perspective applied to a circular construction life-cycle, it becomes clear the essential role that DDT must play. The conceptual framework presented in Figure 4 evolves from all the elements and concepts presented. The Environmental Product Data (EPD) and the CE mark values constitute layers or groups of properties of the Data Templates, as well as some of the waste audit information requirements, do. LEVEL(s) is a sustainability assessment as LEED or BREEAM that uses products/elements values, meaning values from different DDS under DDT's.

SUMMARY

The AECOO is being called to build smarter and more efficient built objects. Underlying, there are challenging requirements to be accomplished as the Digital Transformation of the construction value-chain and Sustainability and Waste goals, both for new or existing built objects construction processes.

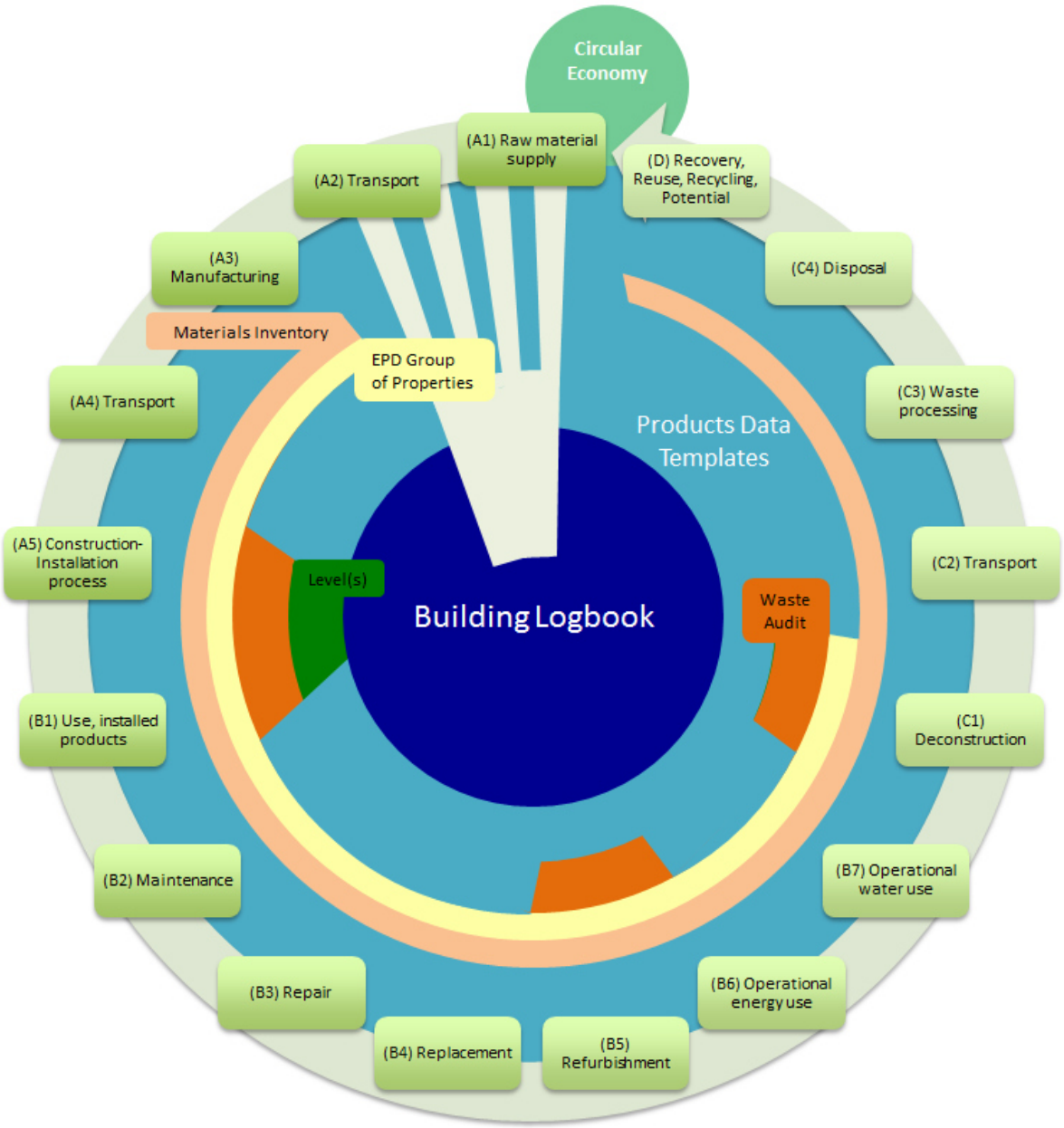

Figure 4: Circular Construction Life Cycle Information Flow Conceptual Framework (V1.0)

As evidence, it is important to align the communication to highlight how digitalization and environment strategies can work, evolve together and support each other, promoting more circular and efficient practices.

The waste audit action was used to deliver a conceptual approach of a relevant improvement that can be achieved if both challenges are approached from a combined point of view. The novelty was to perform this kind of approach using Data Templates (understood as DDT's) across the value-chain and the Digital Twin Construction and Digital Building Logbooks concepts to assure the production, storage and traceability of the construction-related information to be available at the moment of deconstruction or refurbishment, feeding and fulfilling most of the waste audit requirements, as they are now established in the guidelines.

Considering the outcome, a similar approach was introduced for the situation of existing built objects where before refurbishment/deconstruction and through the use of DDT's the data that is possible to collect will be ready and in the right format to support the characterization of a product/element/systems that will be reused, recycled or disposed in the landfill.

In addition, a conceptual framework based on the construction life-cycle was developed evidencing the different phases, the processes, groups of properties and strategic actions such as LEVEL(s).

These frameworks constitute the basis for future studies to prove how several elements working together can provide interesting outcomes, both in recent or future construction processes as well as on processes working with existing built objects. Specific case studies involving data sheets exploring further the data flows and the information exchanges through the life-cycle are a goal. In regards to building logbooks, the research will address the requirements to foster and streamline the relationship between these tools and Data Templates.

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REFERENCES

Akbarieh, A., Jayasinghe, L. B., Waldmann, D., & Teferle, F. N. (2020) 'BIM-based end-of-lifecycle decision making and digital deconstruction: Literature review', *Sustainability*, 12(7). https://doi.org/10.3390/su12072670

Desruelle, P., Baldini, G., Barboni, M., Bono, F., Delipetrev, B., Duch Brown, N., Urzi Brancati, M. C. (2019) *Digital Transformation in Transport, Construction, Energy, Government and Public Admin*, Seville. https://doi.org/10.2760/689200

Dourlens-Q, S.. & Giulia, C. (R2M Solution), De Groote, M.; Borragán, G. De Regel, S. (VITO), Zsolt Toth, J. V. & J. G. (Buildings P. I. E. (2021) *Study on the Development of a European Union Framework for Digital Building Logbook - Final Report*. Brussels. https://doi.org/10.2826/659006

European Commission (2014) 'Resource Efficiency Opportunities in the Building Sector', *COM(2014) 445 final*. Brussels.

European Commission (2018) 'Guidelines for the waste audits before demolition and renovation works of buildings. UE Construction and Demolition Waste Management' *Ref. Ares(2018)2360227 - 03/05/2018*. Brussels.

European Committee for Standardization (2011) *EN 15978 - Sustainability of construction works - Assessment of environmental performance of buildings - Calculation method*. Switzerland.

European Construction Sector Observatory (2019) *EU construction sector: in transition towards circular economy*. Brussels.

European Parliament and European Union Council. (2015) 'Closing the loop - An EU action plan for the Circular Economy' *COM(2015) 614 final*. Brussels.

Forum, W. E. (2016) *Shaping the Future of Construction - A Breakthrough in Mindset and Technology*, Geneva.

Ganiyu, S. A., Oyedele, L. O., Akinade, O., Owolabi, H., Akanbi, L., & Gbadamosi, A. (2020) 'BIM competencies for delivering waste-efficient building projects in a circular economy' *Developments in the Built Environment*, 4(June), 100036. https://doi.org/10.1016/j.dibe.2020.100036

Hjelseth, E. (2017). BIM understanding and activities. *WIT Transactions on The Built Environment*, 169, 3–14. https://doi.org/10.2495/BIM170011

International Standards Organization (2018) *ISO EN 19650-1 - Organization and digitization of information about buildings and civil engineering works , including*

building information modelling (BIM) - Information management using building information modelling. Switzerland.

International Standards Organization (2020) *EN ISO 23387 - Data templates for construction works entities of data templates , and how to link the data templates to Industry Foundation Classes (IFC)*. Switzerland.

Mêda, P.; Sousa, H.; Hjelseth, E. (2020) 'Data Templates - Product Information Management Across Project Life-Cycle', *Sustainable Materials in Building Construction, Building Pathology and Rehabilitation 11* (Springer, p. 168). https://doi.org/10.1007/978-3-030-46800-2

Ribeirinho, M. J., Blanco, J. L., Mischke, J., Rockhill, D., Sjödin, E., Strube, G., Andersson, T. (2020) *The next normal in construction*. Mckinsey & Company.

Sacks, R., Brilakis, I., Pikas, E., Xie, H. S., & Girolami, M. (2020) 'Construction with digital twin information systems' *Data-Centric Engineering, 1*. https://doi.org/10.1017/dce.2020.16

Sousa, H.; Mêda, P. (2017). Desafios Da Transformação Digital Da Fileira Da Construção. "In Proceedings of *XXI Congresso Da Ordem Dos Engenheiros - Engenharia e Transformação Digital*, Coimbra, pp.13-19" (in portuguese).

Watson, R., Kassem, M., & Li, J. (2019) 'Traceability for Built Assets: Proposed Framework for a Digital Record' "In Proceedings of *Creative Construction Conference 2019*, July, Budapest, pp. 496–501". https://doi.org/10.3311/ccc2019-06