Data Templates – Traceability and Digital Record Through Project Life-Cycle

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Buildings and infrastructures result from construction processes that use construction products. Built environment logbooks and digital records rely on products data. Likewise, the same data is essential in previous phases; design and construction. Among the sector inefficiencies is the inability to properly disclosure, capture, manage, store and trace built objects information.

This paper updates and expands a research on product information management. Highlights how data is managed by different stakeholders and the role of Data Templates as game changer. These are found to be the standard structures to enable and foster the life-cycle digital supply chain at built environment level.

Keywords: information management, construction products, construction 4.0, efficiency

INTRODUCTION

In narrow sense, the construction industry transforms construction products into built objects with the aid of human labor and equipment/tools (Calvetti, Magalhães, Sujan, Gonçalves, & Campos de Sousa, 2020). To achieve the built object there is a multi-phase process; the construction process (Figure 1), where a design is established supporting all the main ideas related with what is to be built (RIBA, 2020). Through the years, increasing requirements and constrains have been placed due to the number of aspects to be considered as investment value, performance (fire, acoustic, thermal), quality, safety, environment, durability/maintainability, among others (PMI, 2016). All fall down on the design phase, understood as the core of the construction process, where most of the ideas are discussed, as well as the solutions and their testing/contribution to the intended outcomes (Figure 1). The above mentioned requirements and constrains deal with a lot of disciplines. Nowadays, a team with a significant number of members is required to build a building or infrastructure (Mêda, 2014) (Ashworth, 2015). All have to deal and validate the solutions, meaning that the construction products to be placed must comply with different requirements and the different disciplines have to agree and adopt the same solution. Construction products data traceability becomes therefore an essential aspect to assure during the design and following phases (Katenbayeva, Glass, Anvuur, & Ghumra, 2016).

In the construction phase other stakeholders come in leading to the built object. In the case of zero changes, the object is built in accordance with the design. Detailed data must always be added to the design documents. Often, there are changes on the designed solution, meaning that the built object results different than what it was initially designed (Hackitt, 2018). Given the relevance of this aspect we will come back to this later on this section.

In broad sense, the construction industry is not restricted to the construction process, as it ranges all the built environment life-cycle (with Handover and Use phases other stakeholders take their role on the process) and starts early before the project idea. In fact, one of the most relevant findings is that for the purpose of Construction 4.0 it is crucial to bear in mind that the design and production (manufacturing) of construction products is part of the industry value chain (Sousa, H.; Mêda, 2017) (DSCiBE, 2020). Assuming this, the construction sector becomes even more relevant for societies, gains more economic relevance, but also contributes more in terms of world impacts (energy, environment, resources). Likewise, it becomes more comprehensive and complex, involving a larger number of stakeholders, big amounts of documents/information, increased set of requirements and a wide range of processes (Wolstenholme, 2009).

The Industry 4.0 visions applied to the construction sector gain strength in the term Construction 4.0. The Construction 4.0 paradigm identifies digitalization and BIM – Building Information Modeling as megatrends (Mckinsey Global Institute, 2017) (Turk, 2019). BIM has been an acronym in the industry for some years now and many countries are already quite ahead in terms of its adoption (Kassem & Succar, 2017). Yet, there are still a lot of misunderstandings regarding BIM in terms of its essence, technology VS methodology, potential uses, true dimensions of the "I" in BIM, among others. According to Borrmann et al., BIM "represents the consistent and continuous use of digital information across the entire life-cycle of a built facility" (Borrmann, A.; König, M.; Koch & Beetz, 2018). The requirements to achieve the "consistent and continuous" and the scope interpretation of "digital information" constitutes essential aspects to overcome some of those misunderstandings. For the purpose of this paper by "consistent and continuous" it is assumed the term "traceability" and for "digital information" it will be used the standardized metadata structures with the ability to capture and manage objects data; the "Data Templates" (ISO, 2020a).

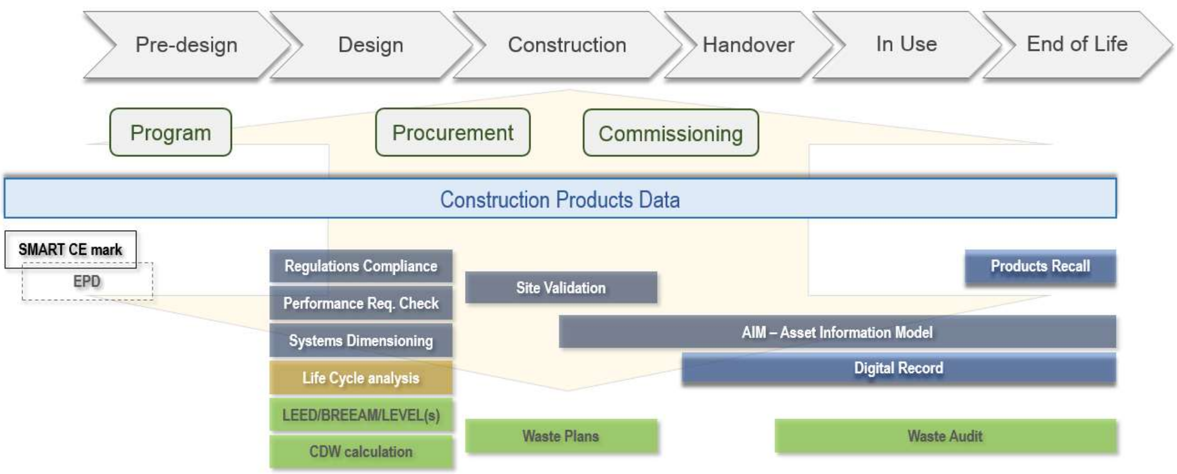
As BIM is entering a stage where global standards are being published with the goal of promoting common approaches and contribute to this methodology scalability (ISO, 2018). The term Digital Twin in entering in the construction industry as a much more ambitious outcome (buildingSMART, 2020). The potential for misunderstandings is also very big, but the Digital Twin of a built object tends to translate better the amount of information/data behind than BIM, where the 3D models can foster fuzzy approaches (Hartmann, Gao, & Fischer, 2008). The selected contractual framework (procurement route) is a subject that impacts a lot on the tasks and on the relations between stakeholders. An IPD – Integrated Project Delivery agreement is totally different from a design-bid-build agreement (Martin Fischer, Howard W. Ashcraft, Dean Reed, 2017) (Alves & Lichtig, 2020). Despite that, there are always requirements to be fulfilled, different stakeholders working in parallel or in sequence, phases/deliverables to be accomplished and an object that is idealized and then built.

Given this "environment", the industry has been adopting "siloed" approaches to protect the different contributions and contributors, many times leading to a result with less quality at the commissioning and with several fails during use. In addition and associated to these siloes, is the loss of information, loss of knowledge, incomplete outcomes, wasted effort in non-productive tasks and low profit margins.

The tragic fire of the Grenfell Tower in London is one of the most impressive examples of how the industry is capable of failing during use. Bringing back the topic of design changes during construction, added to what was mentioned, the Hackitt Review (Hackitt, 2018) identified the need for construction traceability; a "golden thread" of information with the ability to preserve critical data about design intent and the as-constructed built object, this is a Digital Record.

A substantial part of this "Record" is data related with performance characteristics and behavior of construction products that starts being built during design. The same and other data, part of it construction products data, is used and must be kept during construction life-cycle for the purpose of maintenance/renovation/recall (Watson, Kassem, & Li, 2019). AIM – Asset Information Model is the term that ISO standards set out for it (ISO, 2018). Similarly, the European Green Deal strategy identifies several actions aligned with circularity, efficiency and environmental sustainability that in essence rely on the use, analysis and traceability of construction products data (European Commission, 2019). In brief, and as Figure 1 summarizes, construction products range all the construction process and go beyond cut crossing the all industry value chain. This Figure aims to translate how the construction products impact the industry and sets out the way for the objectives and contributions of this research.

FIGURE 1
CONSTRUCTION PRODUCTS RANGE THROUGH THE LIFE-CYCLE



RESEARCH OBJECTIVES AND CONTRIBUTIONS

This study has several objectives. First, and based on the range and impacts of construction products, it aims to provide awareness for the construction sector of the construction products manufacturers' role for the overall value chain.

Following and facing the digitalization trends, it investigates and disclosures the potential added value derived from the use of standardized metadata structures for construction products data; Data Templates. It presents the different stakeholder's goals and processes requirements during the construction process, evidencing the potential disturbances on the information flows.

To end and through the use of a specific case study, the research presents the data challenges related with a defined construction product during a construction process, highlighting the benefits that the use of Data Templates can bring towards an improved information traceability, the establishment of an AIM for post construction phases, Digital Record of the built object and inherent benefits for the efficiency and sustainability of the industry contributing to the materialization of a construction data digital supply chain.

METHODOLOGY

The selected methodological approach comprises a systematic review based on Construction 4.0 trends, data templates, information traceability and digital record. This was conducted to frame the construction sector main challenges and narrow down the topics focusing on the added value of setting a "golden thread" of information for the built object life-cycle. Based on authors previous works, this research updates and expands the matrix related with stakeholders goals and processes requirements, as well as it details the information traceability challenges based on the use of data template standard structures in accordance with ISO 23386 and ISO 23387, for the specific case of a construction product; an external paint.

REVIEW

This section draws a literature review with the goal of summarizing some of the most relevant publications and research works related with the challenges and trends of the construction sector. The adopted structure and its objective is to frame and narrow down the topics to focus on the specific aspect that constitutes the scope of the present research. By doing this, the intention is also to highlight the main terminology and definitions as well as the context in terms of requirements that will be explored in further sections. Due to the adopted strategy the documents do not follow a chronological order.

Digitalization, the Only Way Forward

Many authors have state that construction lost its place on industrial leadership. Others advocate that the industry singularities did not allow direct comparison with other activities (S. T. P. L. on behalf of the B. T. Group, 2016) (Rezgui, 2001) (Dubois & Gadde, 2002). In both visions truth can be found. On one hand, it is correct that this industry is unique as it is always providing different outputs/built objects. On the other hand, many parts of these objects are the same and when compared with other industries/activities, low or fewer effort has been placed on the development of new solutions, innovative processes or actions in order to streamline the productive chain and its performance. Most of the introduced innovations derive from legal requirements add thus, the actions become mandatory to all stakeholders and in all processes; scalability. Yet, each one individually develop actions to comply with the more direct requirements. The already mentioned "siloed" or fragmented approach of the industry justifies these actions. As stated, in order to overcome many of the industry inefficiencies, the trends point to digitalization as one of the drivers for construction modernization and innovation. In this respect, it is interesting to highlight some quotes from different documents that address the construction trends/visions/strategies:

Digital Twin (buildingSMART, 2020) (Franchek, 2018)

"A Digital Twin – also referred to as digital shadow is a digital representation of a physical asset. Linked to each other the physical and digital twin regularly exchange data throughout the PBOD - plan-build-operate-decommission lifecycle and use phase" (buildingSMART, 2020).

A digital twin relies on data that starts being gathered and integrated on the early phases of the construction process and continues being produced during the In Use phase. Digital Twins are composed by static or semi-static data and dynamic data. Examples of the first type is the data of built objects as the performance characteristics of a wall, a floor or a HVAC chiller. These might suffer changes when maintenance or replacement operations occur. The dynamic information is the one that results mainly from the sensors that are part of the built object; indoor temperature, number of people in the building, energy consumption, functionality of an equipment, among others.

Data is the essence of digital twins. Yet, to make it meaningful for digital twins there must be standards for data models, standards for data management and integration, as well as protocols for data security and privacy.

From this results that the limit of digital twins concept in the construction industry is at this point limited by our thinking and limited by the ability to standardize, systematize, gather, integrate and trace construction related data.

Integrated Design and Delivery Solutions (Owen, 2013)

The CIB goal in assuming IDDS as a priority research theme was to pursuit a vision of a revitalized sector through the rapid adoption of new processes, developing a workforce with enhanced skills and supported by information and knowledge technologies. "The goal is a sector where people with traditional and new skills practice more collaborative and communicative processes, supported by pervasive, but nearly transparent, knowledge and information based technology".

Without setting the terminology that nowadays is being used the CIB IDDS Research Roadmap assumed big data and the requirements of its integration and management during the construction life-cycle.

Emphasis is placed on the people, processes and technology dimensions as a way to identify the positioning's and stakeholders starting points towards the adoption of innovations.

Developments made from this strategy and focused on stakeholders relations led to the definition of some concepts as Life cycle Information Model (LIM), and Role Information Model (RIM) (Hjelseth, 2017).

In brief, this research roadmap presents and explores the short to long term goals and focus on the processes that can best lead to the outcomes.

Industrial Agenda – World Economic Forum (Forum, 2016)

This World Economic Forum Industrial Agenda is relevant because not only presents a strategic vision for the industry as a hole but it makes comparisons with other industrial areas. It is the result of a set of documents on the topic during time. Most of these strategic documents identifies BIM as a major step towards the sector digitalization. In the "Introduction" section some awareness was already provided regarding the danger of "BIM understandings". At global level, it worth's to highlight the following aspects touched by this publication:

"While most other industries have undergone tremendous changes over the last few decades, the Engineering & Construction sector has been hesitant about fully embracing the latest technological opportunities, and its labor productivity has stagnated accordingly. The industry has vast potential, thanks to digitalization, innovative technologies and new construction techniques. To capture all this potential will require a committed and concerted effort".

This document, besides the behavior comparison that delivers, it highlights the effort and commitment that must be made by the industry and its shareholder's to embrace innovative actions.

European Green Deal (European Commission, 2019)

The European Green Deal is one of the most recent communications from the European Commission. It was developed as a response with strategic actions to tackle the climate and environmental-related challenges. As mentioned previously and assuming the industry broad vision, construction is responsible for huge impacts and therefore many of the Green Deal actions are devoted to the sector. Carbon neutrality, energy efficiency, waste reduction, circular processes, the use of sustainable products, improved collaboration and digital technologies for sustainability are general topics from this strategy that impact a lot in the construction industry.

Among the different strategic actions that compose the European Green Deal are the initiatives towards smart CE marking, development of constructions logbooks, development of tools to perform sustainability analysis at built objects level, as well as fostering the disclosure of environmental impacts of construction products and recycling and reuse of waste as raw materials for new constructions.

From this it highlights the knowledge requirements regarding construction products and the tools to standardize and allow the traceability and exchange of this knowledge/data throughout the construction life-cycle.

DSCiBE - Digital Supply Chain in Built Environment (DSCiBE, 2020)

The Digital Supply Chain in Built Environment Whitepaper is the first outcome of an industry targeted task group with the scope of:

- setting a solid foundation to deliver successful BIM according to ISO 19650;
- jointly develop processes for the digital exchange of all kinds of data and information based on existing global standards.

These foundations work as an enabler for built environment digital twins. The document identifies 3 major challenges; the definition what structured product data is, the exchange of structured data and products identification.

With a clear vision of the added value and benefits that can arise from construction products data, this work focus on the challenges to overcome in order to achieve streamlined processes for data structures production and information exchange.

Product DNA (S. T. P. L. on Behalf of the B. T. Group, 2016)

"Product data is essential for the delivery, maintenance and operation of any physical built asset. It is important to share consistent, accurate information to enable specification, assembly and ongoing maintenance and replacement through an asset's life cycle." The change to digital environments leads to a change in the information required and exchanged between actors in the construction and operation of an asset, but also a change in the timing, actors and format of information."

The term Product DNA is, from a holistic point of view, an interesting term to be used to foster the awareness, stakeholders understanding as well as evidence the requirements and the relevance of construction products data for the built object's management.

All product data to be defined during the life cycle must be characterized. The data fields can be found on the standards, or in other documents such as Environmental Product Declarations. Others are inherent characteristics related with geometry or related with the production/application/use of the product/asset, as serial number, or tag number. All this data is assumed as product properties and each property is characterized by a group of attributes that are now defined in ISO standards such as ISO 23386 (ISO, 2020b).

This document was published before many others, namely the Digital Twin ones as well as Hackitt Review or DSCiBE. Therefore, the terminology is somewhat outdated but comprehensive on the intentions. In fact, this document set many of the assumptions that were later on explored of some of the abovementioned documents as well as on the ISO standards.

ISO Standards (ISO, 2020b) (ISO, 2020a)

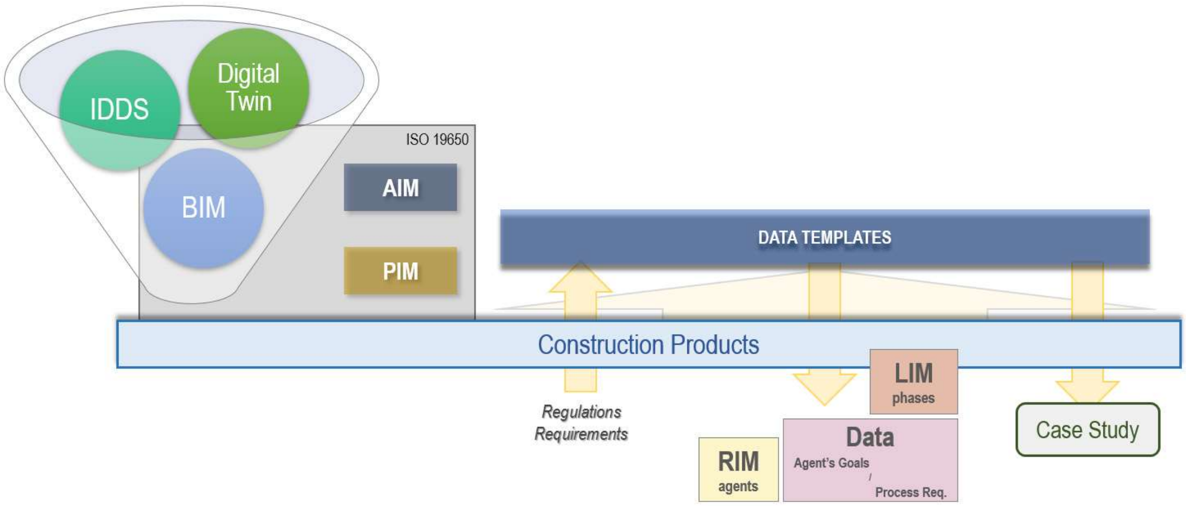
ISO 23386 and 23387 are essential documents for the BIM interoperability and scalability strategy and to the definition of Data Templates. The first standard is focused on the definition of rules to streamline the communication between data dictionaries. At the same time, it defines all the attributes that are required to set a property, as well as the processes and roles for the governance of a single data dictionary in a network of coordinated data dictionaries. The second is devoted to data templates, assuming that data templates will enable project stakeholders to exchange information about construction objects through an asset life-cycle, using the same data structure, terminology and globally unique identifiers to enable machine-readability.
These documents are enablers for the industry to start the development of interoperable data templates. DT's are assumed to be the predefined way of stating the properties of a construction product (Chapman, 2016) ((CIBSE), 2017) (Tune, 2016).

FRAMEWORK

The previous section drawn a review on several topics that are relevant for the future of the construction sector, namely in terms of it sustainability, competitiveness and efficiency. Built objects either the most recent or the oldest ones are made of construction products. The properties of these products are essential not only during the construction process but also during the In Use phase. A digital record of what was built, with the ability to feed and be used as the base data for the digital twins. Prior to decommissioning, the same record can be used to better evaluate the amount of waste or potential recycle/reuse of products/raw materials.

Digitalization is a driver towards most of these goals and BIM in accordance with ISO 19650 is the methodology that supports it. Given the broad scope of issues that were mentioned and without neglecting the stockholders roles during the construction life-cycle, Figure 2 aims to provide a global picture or "the ingredients" of all the elements involved on the study, as well as contributions for the construction information life-cycle.

FIGURE 2
ELEMENTS INVOLVED ON THE STUDY AND CONTRIBUTIONS FOR THE CONSTRUCTION INFORMATION LIFE CYCLE



PROCESS REQUIREMENTS AND STAKEHOLDER'S GOALS

Construction products, as stated, are present throughout the construction life cycle and they come early on. The following section describes the process requirements and the stakeholders' roles during the different construction process phases. This description sets the base for the identification and presentation of the different visions, providing at the same time awareness for the importance of construction products data information management/traceability. The following description uses the phases presented in Figure 1.

During "Pre-design", the Owner must identify the main characteristics of the object to be built, in terms of function, general spaces and also some technical solutions/performance. A broad range of construction products can be "called" for discussion. "Circular and Sustainable Construction" practices are gaining relevance. These focus on construction products reuse or environmental friendly products selection, implying and fostering the development of EPD - Environmental Product Declarations.

During "Pre-design" and "Design", the Design Team explores and details different technical solutions for the construction elements. Individually or combined, during the different steps of the design, more and more characteristics are called in order to perform verifications as the U parameter for Thermal Comfort assessment, properties related with resistance for structural dimensioning, resistance to fire or the level of soil and water acidification for the development of environmental analysis. Traditional procurement procedures as "Design-Bid-Build" set a tender process for awarding a Contractor. The Design Team finishes the design with all the detailed specifications and the Contractor is called to develop the designed object. At this point there is a significant amount of information that constitutes the Design Digital Record. As it will be further detailed, it is relevant to store and add traceability features to assure all the data evolutions and changes.

During "Construction", the Contractor must propose specific construction products and it is very usual to present more than one alternative. These alternatives must comply with the requirements and the design, but at this phase they are mostly related with economy, once Contractors establish agreements with different manufacturers, becoming more competitive on certain products. Supervision teams or the Owners, combined with the Design Team must select and formally accept the construction products to be used. Contractors must provide all the information necessary to prove that the products are compliant in all characteristics, fit for the intended use and will have similar behavior (at all levels) as the foreseen on the design. Yet, changes might occur meaning that the design update must be made, as well as all the required analysis to assure that the built object will achieve the intended performance/behavior. At this phase, all the available information is essential, as after being approved, the products will be checked on the arrival to the construction site and all the information must be stored for future use. With the entrance on site there is additional data that can be placed as to the specific product it is now possible to add "Production lot ID", "warranty start date", among others.

It is after construction during "Handover", that comes the AIM and the as-built version of the Digital Record, where it is stored all the construction products data as well as additional data to support the "In Use" phase of the built object.

During "In Use", construction products information is the base for the AIM and for eventual maintenance or replacement works, in order to observe the same or the best options to use on those works. Looking forward into a scenario of "End use" and possible deconstruction, these characteristics as well as other documents fit the requirements to easily perform a waste audit, one of the measures foreseen by the EU in terms of construction industry transition towards circular economy (European Commission, 2019).

From the point of view of this description, the process sounds quite stream and the information flows seem to work smoothly. However, in real situations it is not so simple, due to the amount of information, the different stakeholder's visions and the formats and documents where this information is stored from phase to phase (Hjelseth, 2010) (DSCiBE, 2020).

At this level, the manufacturer or trader perspective/vision can restrain the process right from the start. This type of stakeholder interacts with the construction process but, many times, are not within the process. Their qualifications are often not related with the traditional ones competing on the industry (such as engineers or architects). Therefore, economic information is, for them, much more relevant; sales balance, provisions, marketing and strategic actions. The products technical characteristics (those related with standards and regulations compliance, as well as sustainability analysis) can be presented in very different ways and many times they are not obvious to the potential buyer. Most of the manufacturers does not provide the information that is needed for the development of the simplest environmental analysis. The most common way for manufacturers to present information is on commercial catalogues. More specific characteristics need to be asked (normally there is no public access to it) and come usually on technical files that are delivered in .pdf format. From the design team and contractor point of view, the catalogues and pdf files are just useful to look for the characteristics and to transpose the information to different documents, such as drawings, written parts or to the BIM model. When comparison between products needs to be made, it can be difficult to build a matrix as some data might be common, but other can differ from manufacturer to manufacturer.

These two very different visions have been working together for many years. From this results a huge effort on combining and introducing information from one document to other or from the catalogues to software to perform the abovementioned analysis, outputs and controls. This amount of rework and the possible mistakes that come from the manual introduction were found to be a "normal situation on the process". Yet, these inefficiencies/waste, as well as many others, have contributed to the lack of productivity and competitiveness of the industry. Information traceability at this level is highly compromised. In addition and as stated, given the construction products presence along the life cycle, the assurance of the AIM or the Digital Record at the end of construction might be difficult to achieve and even more without mistakes or data lost.

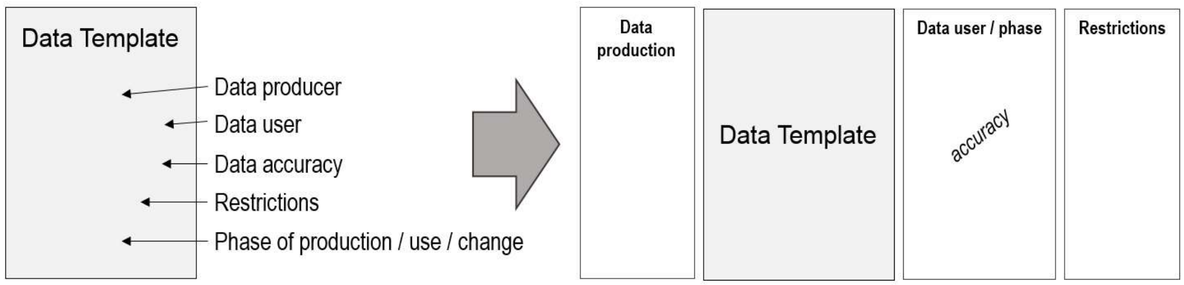
As a consequence, the first output presented in Table 1, is the stakeholder's roles/process requirements through the construction life-cycle matrix highlighting the different visions and information management difficulties.

TABLE 1
CONSTRUCTION PROCESS RIM GOALS/LIM REQUIREMENTS

	Pre-design	Design	Construction	Handover	In Use
Manufacturers	Marketing – potential customers	Marketing, influencing stakeholders for their products/solutions	Marketing, influencing stakeholders for their products/solutions and support	Marketing and support	Marketing and support
	Construction Products main uses and properties, general data	Provide technical data and support	Provide technical data and support	Provide support and awareness of the solutions to be placed and their costs, warranty support	Provide spare parts or compatible alternatives
Owners	Definition of the global object to be built and awareness of the possible solutions/construction technologies	Obtain a good global solution, main characteristics/requirements to consider and value of investment	Get the best built object within the budget. Assure compliance with the design and performance requirements	Assuring that the built object is as agreed and manage corrections and warranties	Improved management of the built object
	Cost estimate, basic requirements in terms of performance, technologies and behavior	Achieve to a compliant and integrated design, with all required elements and achieving the objects intended performance	Obtain a built object compliant with the design, with all the identified properties and fulfilling all regulations	Complete technical information (Final Drawings) and products specification allowing a streamlined facility management	Update and maintain the technical information related with the built object

Design Team		Deliver on time and on budget the design in accordance with owner requirements and compliant with regulations	Assure that the object is built in accordance with the solutions and behavior set on the design		
		Deliver detailed technical specification and drawings of all disciplines. Dimensioning, analysis, compliance, performance	Provide support and awareness regarding the solutions to place on site. Provide or validate alternative solutions in case of changes		
Contractor			Build the object in accordance with the design and compliant with the solutions pursuing the goal of economy	Develop warranty works with quality	Develop maintenance works with quality under new agreements
			Develop the work in compliance with the agreement and deliver the built object	Deliver the agreed technical information to support the In Use phase. Make the necessary corrections.	Develop the work in compliance with the agreement and provide technical information of the works made

FIGURE 4
INFORMATION REQUIREMENTS, ORIGINS, USES, DEFINITION AND FRAMEWORK FOR CASE STUDY DEVELOPMENT



From the establishment of this framework it becomes possible the development of a detailed analysis for the specific case study. For the case study it was selected, as previously mentioned a Data Template for an external paint. The reason for selecting this example is that it is a construction product with use both in infrastructures as on buildings and requires maintenance/replacement several times during the built object life-cycle. The DT for this specific product was developed using several references as the Cobuilder's GoBIM tool (Tune, 2016) or BIMRel website (Lombardia, n.d.). The DT is composed by more than 250 characteristics, meaning that Table 2 is just a small sample. They are grouped in Geometric data, Operations and Maintenance data, Manufacturer data, Features data, Environmental data and Performance data. These six groups comprise very different information and its fulfillment can range from the product manufacturing until the handover of the built object. Table 2 presents a sample of the characteristics that must be present in each group of a DT, setting relations with the agents, level of definition/traceability requirements during the construction process phases and potential restrictions to the information flow.

Looking in detail for each group, in terms of geometry, the information is always delivered by the manufacturer. This group of data in this particular case does not need to have a closed definition. In other products cases as isolation panel, the situation would be different as thickness is a characteristic that influences a lot a building thermal performance. For an external paint this data must become accurate during construction and some impressions can be specified during design. Regarding operations and maintenance, this data is not usually worked in many construction processes, at least with this detail. With this definition it becomes easier for all stakeholders what must be set by each one and in witch phase, introducing benefits on the process. It is possible to observe some variations related with the origin of this information:

- the warranty period is defined by the manufacturer;
- the warranty start date is defined by the contractor at the end of construction/during handover;
- service life duration is a characteristic provided by the manufacturer and defined during the construction process by the design team or contractor;
- the asset identifier is a nomenclature that can be established by the design team, on its own or from rules set by the owner, or defined by the contractor.

The general product and manufacturer data must be defined at all levels by the manufacturer. Yet, this data might involve constraints depending on the type of procedure adopted. If it is a "traditional" public procurement route, as Design-Bid-Build, this information can be delivered to the owner after the technical design. However, it cannot be present during the tender action and the contractor can provide alternatives if they comply with all the specifications. From this results that, depending on the type of procedure, changes on the proposed construction product might occur, meaning that the data on the data template might change. At this point it is relevant to highlight the traceability requirements for the purpose of establishing a digital record in accordance with what is proposed in Hackitt Review (Hackitt, 2018). Considering the product of the case study it is essential to trace in the performance data, what was the initial impression in terms of the paint fire rate, then what was specified in the design and what specific product was placed on the built object and what is the performance at that level.

The environmental data, as previously mentioned, needs to be defined by the manufacturers. This data is, at this level, identical to what was mentioned for Operations and Maintenance. Manufacturers must present the construction product values (according to one or more references; ex: according with EN 15804) and the design teams/contractors are the agents that during design or construction must select the product and specify the specific values. The evolution of the legal framework and the growing requirements in terms of life-cycle cost and environmental impacts evaluation are placing higher requirements for the development of analysis and simulations during design. This means that this information tends to be called on early stages of the design process, influencing the selected solutions. Several sustainability analysis tools are already demanding this data. LEED and BREEAM are well known systems and at European level LEVEL(s) being established.

Performance and Features data are, in the European zone related with the CPR. The first group is composed by the mandatory characteristics to be delivered and as so, they need to be provided by the manufacturers, as a Declaration of Performance. During the construction process, owners need to be aware of some of these characteristics or have impressions on the values/intended behavior. Similar situation occurs with features group, although there are some items that can be defined with more accuracy during design, such as color or texture. From this case study results the awareness on the global information involved/to be delivered/to be specified for a single construction product. It also becomes evident the restraints that different type of procedures introduce on the information flow, as well as the stakeholders influence on the data definition and phases of the construction process where it occurs.

DISCUSSION/FINDINGS

From the above presented, it results clear the importance of achieving data coherency and traceability in what relates to the construction products. The road to sustainable construction and Green Deal implies the development of performance analysis focused on environment, life cycle and management of built objects and its elements/assets. This aspect is one of the most crucial for the accomplishment of several industry targets and goals in terms of waste reduction/environment, efficiency and competitiveness.

It worth's to highlight that if all the environmental data is placed on the DT's it becomes possible to automate the estimation, among others, of CO2 consumption during construction, waste production, as well as the validation of sustainability methods for constructions.

Table 1 is essential to understand the potential mismatches in terms of visions and inherent information requirements/definition between the stakeholders involved in the construction process and dealing with products. One of the first steps towards the complete definition of the construction products information fabric is the stakeholder's awareness for the major project outcomes; the physical built object and its digital twin. In addition to the specific stakeholder mission and role on the construction project (leading to the agreed deliverables in a certain phase) all must be committed to deliver the two previously mentioned outcomes. In this respect, the internalization among all participants of the LIM and RIM concepts is found to be a priority. The publication of ISO 19650-1 disclosures the AIM concept as one of the project major achievements. This action supports the outcomes this approach that on the other hand strengths the BIM methodology in accordance with ISO.

There is a fundamental issue to deal with that is the one related with the extra work to be performed by manufacturers in order to deliver the required data on standard metadata formats. The added value of this type of agent, the clarification of its role within the construction process and wide perception of the economic value of the effort of delivering information in interoperable way instead of .pdf files is identified as one of the most delicate aspects that must be explored further in a close future.

TABLE 2
CASE STUDY DATA TRACEABILITY USING DATA TEMPLATE SAMPLE – EXTERNAL PAINT

Information origin	**DT Property**	**Construction process phases** Pre-design	Design	Construction	Handover	In Use	**Restrictions**
	GENERAL PRODUCT INFORMATION						Depending on the proc. route trademarks might not be allowed
Manufacturer	Product Type	impression	proposal	accurate		updated	
Manufacturer	Manufacturer	impression	proposal	accurate		updated	
	GEOMETRIC DATA						Design specifications and site product acceptance
Manufacturer	Specific weight		impression	accurate		updated	
Manufacturer	Density		impression	accurate		updated	
Manufacturer	Viscosity		impression	accurate		updated	
	OP AND MAINT DATE						
Manufacturer	Mean time between failure				impression	confirmation/ updated	
Manufacturer	Serive life duration	impression	proposal	accurate		confirmation/ updated	
Contractor	Warranty start date				accurate	updated	
Manufacturer	Warranty period		proposal	accurate		updated	
Contractor	Warranty end date				accurate	updated	
Manufacturer	Warranty content				accurate	updated	
Design team / Contractor	Asset identifier		accurate (#)	accurate (#)		updated	(#) This can be defined either during the design or construction

		MANUFACTURER DATA								
Manufacturer		Global trade item number				accurate		updated		
Manufacturer		Production year				accurate		updated		
Manufacturer		Production lot ID				accurate		updated		
Contractor		Actual erection date				accurate		updated		
Manufacturer		Actual production date				accurate		updated		
Manufacturer		Model reference			proposal	accurate		updated		
		FEATURES DATA								
Manufacturer		Component Materials				accurate		compatibility/updated		
Manufacturer		Volatile organic compounds		impression	proposal	accurate		updated		
Manufacturer		pH		impression				updated		
Manufacturer		Rain performance			proposal	accurate		updated		
Manufacturer		Color		impression	accurate			updated		
Manufacturer		Dry time				accurate		updated		
Manufacturer		Solids content in volume				accurate		updated		
Manufacturer		Applications			accurate			updated		
Manufacturer		Use				accurate		updated		
Manufacturer		Granulometric class			proposal	accurate		updated		
Manufacturer		Composition		impression	proposal	accurate		compatibility/updated		
		ENVIRONMENTAL DATA								
Manufacturer		Hazardous waste disposed (EN 15804)			impression	accurate		updated		
Manufacturer		Eutrophication (EN 15804)			impression	accurate		updated		
		PERFORMANCE DATA								
Manufacturer		Water vapour diffusion density			proposal	accurate		updated		
Manufacturer		Equivalent diffusion			proposal	accurate		updated		

Manufacturer		Water permeability			proposal	accurate		updated		
Manufacturer		Brilliance		impression	accurate			updated		
Manufacturer		Water vapour permeability			proposal	accurate		updated		
Manufacturer		Resistance to alkalis		impression	proposal	accurate		updated		
Manufacturer		Resistance to thermal shock		impression	proposal	accurate		updated		
Manufacturer		Resistance to staining		impression	proposal	accurate		updated		
Manufacturer		Covering power (contrast ratio)			proposal	accurate		updated		
Manufacturer		Resistance to washing		impression	proposal	accurate		updated		
Manufacturer		Dirt outlet				accurate		updated		
Manufacturer		VOC emissions		impression	proposal	accurate		updated		
Manufacturer		Permeability to carbon dioxide			proposal	accurate		updated		
Manufacturer		Release of smell			impression	accurate		updated		
Manufacturer		Resistance to mold		impression	proposal	accurate		updated		
Manufacturer		Resistance to disinfection agents		impression	proposal	accurate		updated		
Manufacturer		Resistance to high humidity		impression	proposal	accurate		updated		

It is assumed that DTs are the "skeleton" of Product DNA and the support to be used for the definition of the construction products data. From the development of the case study it was possible to observe the amount of information that needs to be delivered by the manufacturers. This data will be used by design teams and contractors, as well as owners. These last agents need to have impressions on some of the characteristics. DT's can help owners to improve their early requirements and foster their awareness. This will also lead to an improved definition of other characteristics by the design teams and contractors, leading to great benefits for the facility management. The data from these structures will also help on the compliance check in terms of life cycle cost and environmental analysis/behavior.

CONCLUSION

Data Templates are standard structures with the ability to capture all types of construction products data. At start, they can support the data that needs to be disclosed by manufacturers.

Following, this data will be used by design teams to make products selection as well as to perform different types of analysis, from regulatory verifications to dimensioning or other analysis as fire safety, thermal performance, acoustics, sustainability assessment, environmental and waste calculations, among others.

It is important to highlight what changes occur at this level. Data Templates are a game changer as these structures in accordance with ISO 23386 and ISO 23387 standards have the ability to work as an information exchange tool, meaning that interoperability aspects are assured and therefore the same structure feeds different tools for the purpose of the analysis. In traditional practice the required data to run the analysis was introduced by hand from products data disclosed in pdf files. Through the establishment of a Common Data Environment there is a single source of truth in terms of construction products data, which is the different Data Sheets.

Depending on the procurement route, the Data Sheets can suffer changes on its data fields. At this level traceability tools step in to assure the correct versioning and that the information is not lost, yet the structure of the data is the same; the Data Template.

During construction there is the final decision on the construction products and it becomes clear some of the relevant data related with the manufacturer, as "Production Year", "Lot ID", among others. Again, through these structures it is possible to streamline construction products acceptance on site, as well as delivery schedule, site logistics, or others.

At Handover/Commissioning all the construction products data is validated and becomes part of the Asset Information Model and Construction Digital Record.

In brief, Data Templates/Data Sheets are found to be the digital structures to foster products data disclosure, the information exchange framework for design analysis, the tool for information traceability and the foundation for built objects digital record. They materialize and support many of the construction trends in terms of efficiency and sustainability. They are a relevant part of the construction industry data driven digital supply chain.

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