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Digital Representation for a Circular Economy

Koutamanis, A.

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Chapter 1
From Building Information Modelling to Digital Twins: Digital Representation for a Circular Economy

Alexander Koutamanis

Abstract Building information modelling (BIM) has ushered in the era of symbolic building representation: building elements and spaces are described not by graphical elements but by discrete symbols, each with properties and relations that explicitly integrate all information. Digital twinning promises even more: a digital replica in complete sync with the building and its behaviour. Such technologies have obvious appeal for circularity because they accommodate the rich information it requires and link circularity goals to other activities in AECO (architecture, engineering, construction and operation of buildings).

Present implementations of BIM may fall short of the promise, and digital twinning may be hard to achieve, but they remain crucial not only for circularity but for all AECO disciplines. To realise the potential of such representations, information should be treated not as a product of integration but as the integrator of all activities. Similarly, digitalisation should be at the core of business models and deployment plans, not an additional or even optional layer at a high cost. This calls for a coherent approach that includes the full capture of building information, supports the detailed exploration of circular operations, uses the results to constrain decisions and actions and does so throughout the life cycle.

Keywords Information · Digitalisation · Representation · Building information modelling (BIM) · Digital twinning

1.1 Building Information Modelling and Digital Twinning

Rhetoric has three modes of persuasion: pathos, ethos and logos. Circularity is derived from pathos: appeals to emotions and ideals, expressing beliefs about the environment and materiality. It is reinforced by ethos: arguments from authorities and other credible sources, such as scientists and industry leaders. When it comes to

A. Koutamanis (✉)
Delft University of Technology, Delft, the Netherlands
e-mail: a.koutamanis@tudelft.nl

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implementing circularity, however, it is the logos that matters most: the reasoning that underlies business models, material flow calculations, feasibility assessments, implementation requirements, deployment plans, etc. Information is the basic resource for making such analyses and projections reliable and transparent: valid, meaningful data that describe past and future states of the world, providing input to and accommodating output from decision processes.

This chapter focuses on the critical, fundamental role of information in the context of circularity. It explains the two most relevant general-purpose technologies, building information modelling (BIM) and digital twinning, and links them to passports and logbooks proposed specifically for circularity. It then moves on to current and proposed uses of the technologies in AECO (architecture, engineering, construction and operation of buildings), including with respect to circularity, and concludes with guidelines for developing circularity business models and practical applications.

1.1.1 BIM

BIM is a frequently misrepresented and therefore misunderstood technology. Many poor definitions describe not the phenomenon itself but its applications and effects (Sacks et al. 2018), often from the perspective of existing analogue practices. The production of drawings and other conventional documents to incrementally improve efficiency or reduce errors takes up a disproportionate amount of the BIM literature but does not explain how BIM is structured and how its structure helps to achieve certain objectives. Instead, it makes BIM appear as a mere step in AECO computerisation. The truth is more revolutionary: BIM marks the transition to *symbolic representation* (Koutamanis 2022). While earlier technologies like computer-aided design (CAD) focused on the graphic implementation mechanisms of building representations, BIM makes explicit the symbols described by these mechanisms.

Symbolic representation is already the norm in many computer applications. In a digital text, the capital ‘A’ is not a group of three strokes, as in handwriting, but the Unicode symbol U+0041, explicitly entered through a keyboard and stored as such, regardless of how it appears on the screen. Any change to the symbol does not come from changing the three strokes but from changing the properties of the symbol (e.g. a different font or size) or switching to a different symbol (e.g. U+1D434 for the mathematical capital ‘A’). Symbolic representation underlies a lot of machine intelligence. In digital texts, knowing each letter allows computers to recognise words and sentences and subsequently understand grammar and syntax.

Similarly, in BIM, a window is not the group of line segments one sees in a graphic view like a floor plan but a symbol explicitly entered in a specific location of a wall. One can reposition the window in the wall, but changing its type or even its size may require switching to a different symbol. The interfaces of BIM software tend to depart from facsimiles of analogue drawing, which confuse users into

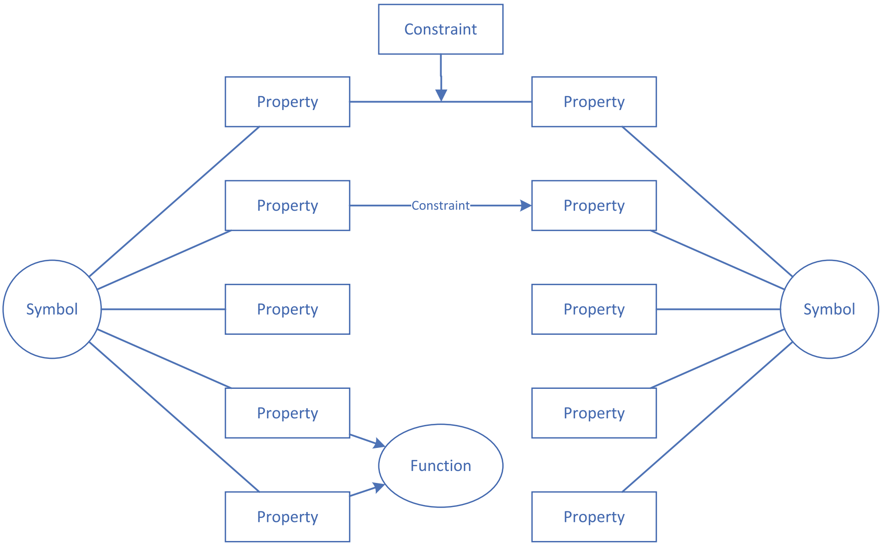

Fig. 1.1 Symbols, properties and connections

thinking that they are drawing and obscure the symbolic structure of the model. We should think of BIM models not as 2D or 3D drawings with additional data but as *graphs* of interconnected symbols. In fact, connections are between specific symbol properties (Fig. 1.1): the co-termination of two walls links the endpoints of their axes, while the orientation of a wall is inherited by the windows it hosts.

External constraints, such as the maximum height of a roof in planning regulations, are also linked to relevant symbol properties, while other constraints affect relations between two symbols, such as when windows are not allowed in certain wall parts. As a result, all primary information resides in the properties and relations of the symbols in a model. This allows for the derivation of further information through functions, e.g. calculations of fire resistance on the basis of the material composition of a building component. It also supports the production of various views of the model, including conventional drawings. As for machine intelligence, the potential is already evident in the *behaviours* of symbols: a window sticks to the hosting wall, and the shape of a room follows the bounding building elements.

Integration, a key selling point of BIM, comes from this symbolic structure. With all information residing in symbols, there are no multiple representations from different disciplines that must be combined to obtain a full description. Instead, all actors have access to different symbols, properties and relations in a model, in adjustable *worksets* that give them specific rights and responsibilities. This integration of information and its dynamic relation to authorship and custodianship also mean that information processing and AECO activities can be accommodated in BIM. The same holds for continuity through phases and stages: a symbolic representation can contain the entire history of a building.

BIM is often called 'object-oriented'. This is misleading because the term has a different meaning in computer science but also because we should not equate symbols with real things. In English, the letter 'a' corresponds to five different sounds (phonemes). Knowing how to pronounce the letter depends on the context (the word). When considering representations in building, the correspondence between symbols and things can be even fuzzier. A window may be considered a discrete component, but a wall is an assemblage with variable composition and indeterminate form. Its material layers often continue into other walls, forming construction networks that are not captured by wall symbols in BIM. A main reason for this is geometric bias: continuous walls are segmented into separate symbols by the geometry of their axes.

Despite such fuzziness and resulting ambiguities, the symbolic representation underlying BIM remains the obvious choice for AECO computerisation, with a potential similar to that of the Latin alphabet or the Hindu-Arabic numerals. The graph of symbols and their relations is a transparent, consistent and efficient foundation for any application. The capacity for integration and continuity means that information efforts can be consolidated into a single representation that caters for all aspects, goals and disciplines.

1.1.2 Digital Twinning

While the use of BIM has yet to reach a satisfactory level or achieve significant efficiencies, AECO has already adopted a new buzzword: digital twinning. In contrast to BIM, digital twinning has yet to consolidate into a recognisable technology. Quite frequently, any virtual model seems to qualify as a digital twin, purely on the basis of intent. However, a digital twin is more than a model: it is a digital replica of something physical. It describes the form, behaviour and performance of the thing, including uses, users and direct context – all that is required for precise and accurate analyses and forecasts of future states of the physical twin.

Information in a digital twin is dynamic and reciprocal: sensors in the physical twin that monitor temperature, light, sound, occupancy, vibration, etc., send their data to the digital twin, where they become attached to relevant properties of the appropriate symbols. The products of the digital twin travel in the reverse direction, guiding actuators in operational adaptations, e.g. the functioning of heating systems, and informing users through displays (Fig. 1.2). In other words, the twins are connected in both directions in near real time and are capable of communication and synchronisation (Chen 2017; Liu et al. 2018). Consequently, we can distinguish between representations (static models, as in BIM), shadows (representations which are updated by data from the physical things) and twins (full two-way synchronisation) (Fuller et al. 2020; Sepasgozar 2021).

Digital twins of buildings are invariably based on BIM (Boje et al. 2020; Sacks et al. 2020; Begić and Galić 2021; Mêda et al. 2021; Shahat et al. 2021; Tagliabue et al. 2021; Alibrandi 2022; Shaharuddin et al. 2022). At the same time, it is stressed

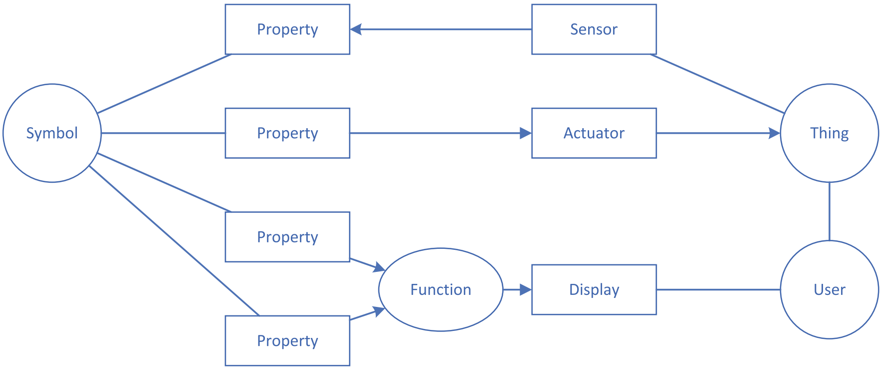

Fig. 1.2 Connections between symbols in a digital twin and things in a physical twin

that digital twinning is more than BIM, as it includes sociotechnical and process aspects, especially in use (Boje et al. 2020; Davila Delgado and Oyedele 2021; Sepasgozar 2021). This makes it significantly more demanding than as-built BIM in terms of reliability, precision and completeness. Furthermore, it is questionable whether BIM can accommodate and process the big data produced by sensors in the built environment. Rather than a foundation, BIM is a predecessor to digital twinning, based on the same symbolic approach to representation (Boje et al. 2020; Koutamanis et al. 2021).

More than on BIM, digital twinning relies on the Internet of Things (IoT): the networks that connect sensors, actuators and displays in a building, making it 'smart', i.e. automating certain operations, such as opening doors and regulating ventilation systems. In addition to such local automation, the IoT also collects data from all sources to capture the history and the overall conditions in a building. This improves local operations by connecting them to global goals and constraints. The IoT is not just an enabler but a necessity because digital twinning presupposes a building heavily populated by IoT for bidirectional communication and synchronisation, including feedback to users and operators (Farsi et al. 2020; Fuller et al. 2020; Lu et al. 2020; Sepasgozar 2021). The collection of data for digital twinning could be much more extensive than in most smart buildings, resulting in a lack of suitable physical twins and possibly rendering digital twinning a pipe dream. Alternatively, one could tolerate low-fidelity solutions as early deployment stages and encourage incremental development (Mêda et al. 2021). However, experience with BIM maturity levels suggests that such tolerance is self-defeating because it provides alibis for not taking the trouble to use the technology properly while continuing processes that actually undermine it. The degree of validation and verification required in digital twinning makes any attempt to pass off static models as twins as misguided as calling 2D drawings BIM.

1.1.3 Passports and Logbooks

BIM and digital twinning are general-purpose technologies. There are also stand-alone information technologies specifically developed for circularity in AECO. These are referred to by terms such as *building* or *material passport* or *logbook*. Chapter 5 by Honic et al. in this book describes the potential of such technologies and relevant life cycle and standardisation challenges in detail. Therefore, from the perspective of this chapter, it suffices to emphasise that BIM, as an integrated information environment, is more than a useful source of data (Durmišević 2018; Bertin et al. 2020). There is a significant overlap between BIM and material or building passports (Charef and Emmitt 2021), even when the latter are based on other sources for product composition breakdown.

The advantage of BIM is that it makes materials situated and connected to life cycle processes (Honic et al. 2019). This supports design for deconstruction and disassembly (Minunno et al. 2018; Xing et al. 2020; Marzouk and Elmaraghy 2021; O'Grady et al. 2021) and other circularity goals. Translating manufacturers' disassembly instructions into simulations in BIM improves legibility and completeness, especially concerning resources that may be available or required. It also verifies the disassembly procedures and validates designs with respect to them. Including the location of a component among its metaproperties in a passport does not offer the same advantages.

In conclusion, passports and logbooks are amenable to the integrating power of BIM and digital twins, which can accommodate product information (Kebede et al. 2022), life cycle energy data (Shah et al. 2023) and other key information in their properties and relations. In BIM, information collections such as material passports can become views of the model, similarly to bills of quantities. Linking their goals and constraints to all activities in design, construction and operation through BIM returns connections to information sources that help make material flow registration and analysis realistic and reliable (Miatto et al. 2022).

1.2 BIM in the Built Environment

There is general agreement that digital uptake in AECO is slow and limited, even though investment in digitisation may not be that low (Turk 2021; Koutamanis 2022). Nevertheless, BIM was received with unprecedented willingness and optimism as a solution to major inefficiencies and malperformances (Sacks et al. 2018; Ernstsen et al. 2021), but rapid adoption was not accompanied by a scope wide and coherent enough to effect fundamental changes. There are persistent complaints about BIM costs, complexity and social and organisational aspects that contrast with its arguably unrealistic promotion (Miettinen and Paavola 2014; Oesterreich and Teuteberg 2019) and put smaller enterprises at a disadvantage (Dainty et al. 2017; Murguia et al. 2023). BIM is commonly deployed in hybrid situations, where it overlaps with other technologies (Davies 2017). This conflicts with the holistic character of BIM and reduces its potential. As AECO remains attached to existing, document-based practices, BIM is generally restricted to office use and the production of such documents. Out of the office, the reliance of AECO on low-cost human labour does little to promote digitalisation.

Even in office use, BIM has not always facilitated innovation. Its emphasis on integration and interoperability is not linked to models of labour division and specialisation (Turk 2020). It is also questionable that complex assemblages such as buildings can be broken down into hierarchical ontologies by merely observing real-world buildings and following pre-existing, paper-based standards (Koutamanis et al. 2021). Unfortunately, such limitations are seldom experienced, as most applications and models tend to remain selective, partial and restricted to specific tasks, such as clash detection between load-bearing structures and building services.

BIM has yet to make its presence felt beyond design and construction, in the costly and resource-intensive use stage (Gao and Pishdad-Bozorgi 2019; Abideen et al. 2022; Benn and Stoy 2022; Durdyev et al. 2022; Matos et al. 2022; Pinti et al. 2022; Tsay et al. 2022). Making and especially maintaining as-is models appears to be beyond the scope or capacities of most organisations, which are already overwhelmed by the amount of existing information and the multiplicity of channels through which they exchange information.

1.3 BIM and Digital Twinning for a Circular Economy

BIM, while not perfect, remains preferable to its predecessors and indicative of the symbolic direction building representations are taking. Implemented properly, it offers information integration and continuity, unambiguous interpretation by both humans and machines and full and reliable support of complex analyses. This supports goals such as circularity and the information-intensive processes they require.

At the same time, present limitations in BIM create interest in technological advances. Digital twinning promises the additional capacity to accommodate and process all states of the physical twin, past and present (Rafael Sacks et al. 2020). This helps transform static evaluations into dynamic life cycle processes, combining, e.g. end-of-life assessment with adaptable planning (Chen et al. 2021). This transition from static to dynamic is demanding but seems justified by feasibility evaluations, which confirm a significant potential for improved life cycle assessment and control (Tagliabue et al. 2021).

Neither BIM nor digital twinning are goals for AECO; they are means towards domain-specific performances. Moreover, circularity may be viewed as an imposed, external societal constraint. As with any such constraint, it may conflict with established practices and be poorly served by existing tools, which are attuned to other priorities. To remove such obstacles, the general capacities of digital twinning, BIM and digitalisation should be taken for granted, and attention should be on specific, critical issues (Çetin et al. 2021). General intentions, such as reducing inefficiencies, improving communication, optimising design performance or just providing visualisations (Wong and Fan 2013; Akinade et al. 2017; Minunno et al. 2018; Charef and Emmitt 2021), can be relevant but do not amount to a specific, coherent approach.

1.3.1 Registration of Relevant Information

The first step in a coherent approach to circularity with BIM or digital twins is to learn to rely on symbolic representation. Any full model or twin can easily cover circularity information needs without additional investment, but in practice representations can be selective or opportunistic and hence incomplete or inconsistent. Deferring the information burden to any particular goal and its stakeholders (as with passports) is not a viable option. Instead, all AECO stakeholders should insist on joint, permanent working environments, not disconnected repositories or documentation for different phases. There can be no half-hearted BIM or digital twin deployment: economising on investment means severely limited potential and low returns.

The first reason why a digital solution cannot be made for circularity solely is *cost:* the value of what it supports can hardly be justified by the returns, certainly in the perception of most AECO stakeholders with different priorities. General-purpose solutions such as BIM are clearly preferable because they support most such priorities. If circular goals can be added to them, then circularity stakeholders can reap the benefits, while others are stimulated to include circularity in their considerations.

The perennial question in AECO is not so much who makes a BIM model but who maintains it, especially in the life cycle of a building. If this does not happen collaboratively by conjoining the core processes of all actors, and preferably automatically, there is little hope for success. Collaborative solutions also lower the participation threshold for smaller enterprises and offer enticing benefits in terms of digital support and room for fruitful specialisation. In return, the enterprises contribute to the completeness and up-to-dateness of information simply by using it.

The second reason for a lack of digital solutions for circularity is *selectivity:* any information solution motivated primarily or exclusively by circularity inevitably remains restricted to circularity factors and aspects. It may even suffer from inattentional blindness, which causes omissions of important data simply because we concentrate on other matters (Chabris and Simons 2010). One can naturally work with conscious concentration towards a full, inclusive solution, but then the results would amount to something akin to BIM or digital twins, i.e. a comprehensive solution that could only justify costs and improve returns by being open to other goals and priorities, too.

1.3.2 Exploration of Circular Operations

The second step towards circularity with BIM or digital twins is to utilise their capacities for exploring deconstruction and disassembly (Akanbi et al. 2019; van den Berg et al. 2021). In the same way that we simulate construction processes, we can also simulate the expected maintenance, refurbishment, renovation and deconstruction processes with the accuracy and precision required for feasibility, effectiveness and efficiency. This provides direct support for construction-related circularity goals (narrow and regenerate through efficiency improvement) and a useful background for others (slow and close through reliable life cycle projections). It also stresses the necessity of detail and realism. For deconstruction in particular, we should acknowledge that it is not a mere reversal of construction. As Van den Berg explains in Chap. 11 in the relevant chapter in this volume, information is a key issue in organising reverse logistics. As-is representations are essential for the identification and harvesting of reusable resources from existing buildings because as-built models (i.e. construction documentation) are neither sufficient nor reliable enough. Closing loops requires certainty about the state of components and materials, as well as about their physical context, which has changed from an accommodating construction site to a finished, functioning building. This calls for solutions that are full and realistic, including all details of deconstruction in space and time, e.g. how cranes and scaffolds would function in the existing building. Van den Berg (Chap. 11) describes a number of focused explorations and demonstrations that must graduate from opportunistic demonstrations of potential to standard facilities in BIM and digital twinning.

1.3.3 Constraining Design, Construction and Operation

Based on the second step, we should explicitly describe circularity dependencies and constraints in properties and relations of symbols (e.g. constraints on interfacing between components for effective deconstruction). Relations are of particular importance in this respect because they link interfacing between components to symbol behaviours. They can ensure that the building design and construction allow for deconstruction (Sanchez et al. 2021), e.g. avoid additions that spoil interfaces designed for disassembly, such as equalising layers of in situ concrete over demountable floor slabs. If symbols refuse to accept such additions to their properties or relations, similarly to a door not accepting positioning outside a wall, the scope for human error becomes much smaller. This is particularly important in the use phase, where changes are only too frequently improvised, in both refurbishment and maintenance. The representation can also anticipate circularity operations, such as the replacement of some components when they fall below a certain performance level, by including among the symbol triggers that adjust the timing of loops.

1.3.4 Life Cycle Registration and Guidance

The final step is an extension of the previous three: use 4D symbolic representations to monitor the detailed history of a building, preferably in near-real time. As symbol properties and relations can register the activities and effects of maintenance, refurbishment, etc., material flows are measured and managed not by questionable proxies but with primary, precise and accurate data (Minunno et al. 2018; Chen and Huang 2020; Marzouk and Elmaraghy 2021). Up-to-date information is essential for the planning of circularity operations: narrowing, slowing, closing and regenerating can be based not just on initial assumptions and projections but on constantly refinable and dynamic decision frameworks that include permanent validation and verification facilities for making sense of the existing building conditions for deconstruction (Van den Berg, Chap. 11). The bidirectional relation between digital twins and buildings is clearly advantageous in this respect, as it covers not only monitoring but also adaptations in the behaviour of the physical twins, e.g. adjusting the heating and ventilation of a building in order to reduce the extent of material ageing in specific components.

1.4 Current Applications of BIM and Digital Twinning to Circularity

Judging the efficacy of a technology or approach requires realistic applications that can be analysed with respect to both means and ends. However, most publications on circularity and digital twinning, as well as many on circularity and BIM, are programmatic or aspirational. They focus on aspects such as technology and platform development, enablers and challenges (Copeland and Bilec 2020; Fuller et al. 2020; Ganiyu et al. 2020; Rafael Sacks et al. 2020; Davila Delgado and Oyedele 2021; Sepasgozar 2021; Shahat et al. 2021; Ammar et al. 2022; Charef 2022). Actual case studies are thin on the ground and mostly presented as plans or untested prototypes. The best examples illustrate that highly specific subjects and goals are beneficial for both the setup of a digital twin and analyses in it (Funari et al. 2021). Laboratory case studies, however limited, represent useful steps forward, especially for learning and testing (Rocca et al. 2020; Marzouk and Elmaraghy 2021).

The narrow scope of digital twinning case studies is inherent to any early stage. With the sensitising of architects, engineers, authorities and clients to environmental issues and the life cycles of materials, ambition and attention inevitably become dispersed over a wide range of subjects and possibilities, from key applications in AECO to promising digital technologies (Hillebrandt et al. 2019; Çetin et al. 2021), arguably at the cost of coherence, consistency and effectivity. There is no uniform solution that applies to all aspects and goals. Each component, material or building has different potential, not just generically but in every instance and situation.

However, even advanced and convincing cases with a narrow and well-defined scope, such as bridge maintenance, still fall short of a full digital twin (Mahmoodian et al. 2022). Other studies are hampered by the small samples available, as longitudinal or long-term data are required for consistent and reliable results (Rita et al. 2022). This is particularly true of attempts to go beyond the microscale of materials and elements and extend to the macroscales of neighbourhoods and cities, so as to identify and promote synergies (Bejtullahu and Morishita-Steffen 2021). Such extensions inevitably shift attention from new designs to the existing stock. Existing buildings, especially historical ones, involve knowledge not easy to codify in systems developed for today. So, it is not only information we are lacking, it is also decision-making and design tools (Durmišević 2018; Bianchini et al. 2021).

One of the key problems with case analysis is that evaluation tends to be weak, based on opinion rather than objective criteria. Information collected through questionnaires, interviews and similar means (Charef and Emmitt 2021; Çetin et al. 2022) should not be taken at face value. It contains opinions, subjective estimates and uncorroborated reported results that indicate belief or strategic support for potential rather than tangible, verifiable results. As time-use studies demonstrate, personal estimates can be heavily biased by goals and emotions: stressed people overestimate how they spend their time and produce sums of more than 24 hours per day (Robinson and Godbey 1999). This calls for yet another use of BIM and digital twins: the collection of reliable, comprehensive and consistent data, which can be processed through generally accepted methods towards case analyses and benchmarks. Without such objective information processing, it is impossible to arrive at clear evidence that not only convinces but also shows what can be improved and how.

1.5 Business Models for BIM and Digital Twinning in a Circular Built Environment

Business models address organisational aspects, such as who, what, when and how in key tasks that contribute towards delivering desired results and outcomes. Information is of critical significance here, especially in product-as-service, bundling, dematerialisation, life extension and similar models that depend on fine-tuning or combinations (Charter and McLanaghan 2018; McCausland 2022). These require transitions from production-driven to customer-centred approaches and changes in collaboration patterns and supply chain structures (Qi et al. 2022; Wang et al. 2022; Xiang et al. 2022). Whether the business model follows an innovation or a resource strategy (Bocken and Ritala 2022), rich information is a prerequisite for reliability and feasibility (Shah et al. 2023). Projected states and indicators must be substantiated and monitored, so that lessons learned are fed back to related decisions.

The same organisational aspects and their goals are critical for the utilisation of information technologies. Despite the key role of information, the digitalisation of products and processes is not always included in digital twinning business models, which often retain legacy conditions and practices (Deckert et al. 2022). Digitalisation is still treated as external to core processes: a layer to be superimposed when needed. Consequently, the business case for digitalisation and information is hampered by investment and operation costs that are deemed too high, despite the promise of substantial efficiency improvement.

In AECO, digitalisation has yet to develop into a connecting tissue between all stakeholders and actors, as in other economic areas (Floridi 2014). Attachment to analogue practices and their information carriers remains too strong, regardless of changes in the objectives of projects, enterprises or society. This contrasts sharply not only with other industries but even more with daily life. The same AECO practitioners who are reluctant to fully embrace integrated digital information solutions in their professional activities make extensive use of social media, e-commerce, e-banking, etc., in their private lives. The result is that AECO computerisation is characterised by isolated islands, not the networks necessary for business value. BIM, digital twinning and all other forms of digital information are treated as the product of integration rather than the *integrator* that enables better collaboration and performance (Davila Delgado and Oyedele 2021).

This does not imply lack of attempts at new business models that build on digitalisation. On the contrary, there are many proposals from which we can learn. Looking at business models related to digital twinning (as the most demanding case) across application areas, industries and countries (Kumar et al. 2022), certain characteristics emerge:

- The emphasis is on potential (rather than effectiveness), particularly for competitiveness, which requires venturing beyond legacy solutions and comfort zones.
- Control applications appear to offer easier deployment than production applications, but in both cases the main promise is value co-creation through support for decision-making and management of operations and services (West et al. 2021).
- Differences between industries are largely due to legacy practices and industry structures (Morelli et al. 2022). There appears to be no uniform solution for universal transformation.
- Importance is attached to platforms, autonomous stakeholders operating on them and networks emerging from the interaction between stakeholders and platforms (Rocca et al. 2020).

In summary, digital twinning seems not easily attainable in practice, especially for subjects like buildings, which undergo many, often invisible changes in their protracted lifespans and require a high level of detail to capture both contexts and user experiences.

Some therefore argue that the business case should be motivated by a clear goal such as the reduction of energy consumption. This guides the development of business value towards measurable results while serving wider societal goals like sustainability and improving the lives of users and consumers. They also stress that data strategies should be imposed top-down, as part of business value, rather than left to the willingness or ability of stakeholders and actors (Apte and Spanos 2021).

Such arguments sound autocratic but nevertheless produce clear solutions in a notoriously fragmented and backward-looking industry like AECO. Judging from the half-hearted commitment and relatively low investment in computerisation, business models involving BIM or digital twinning need to include the technologies in their core and give them the primary role of integrator. Developing add-on business models for digitalisation on top of circularity models is self-defeating because it makes information technologies an option, moreover an expensive one, with tenuous connections to goals and values. So long as stakeholders are under the impression that circularity in the built environment is feasible without a radical digital reform of practically all processes, there is little hope for wide and effective deployment.

Digitalisation should be specified according to general principles, rather than specific objectives such as circularity, so as to ensure inclusiveness and completeness. This provides the necessary context for explaining how different aspects can support each other in the business model, e.g. how maintenance activities contribute to the fine-tuning of timely deconstruction, thereby alleviating the burden of fact-finding in circularity monitoring and assessment. Conversely, circularity constraints guide maintenance towards not only timely replacement but also higher performance in the building.

1.6 Discussion

One thing we no longer need to justify or defend is digitalisation. Everyone is aware of its importance and pervasiveness. The fact that information is key to digitalisation is sometimes less obvious, let alone that information is the integrator of human interactions. Goals like circularity are not only highly demanding in information, they also require radical changes in all related industries. These characteristics make circularity clearly dependent on the digital transformation of the whole of AECO, in the same way that digitalisation has transformed communications, entertainment, social contacts, etc. While such transformation is feasible, the problem with digitalisation in AECO is not lack of potential but low priority. So long as it is seen as a mere means to basic tasks, it cannot deliver its full promise. In turn, this reduces willingness to invest in digitalisation and hence the performance of digital solutions.

To break this vicious circle, brave plans are necessary. Circularity has to assume fully integrated digital information for the built environment and include it in the core of its processes as the connecting tissue between aspects, stakeholders and actors. In other words, the first, critical step is that AECO commits to BIM and applies it to all aspects and tasks. This ensures reliable and effective support for circularity, as well as a wide scope for it, for two key reasons. Firstly, being successful with just a few components or materials does not justify the circularity claims and investments – for circularity to be truly effective, it must apply widely to the built environment. Secondly, to achieve that, circularity must be present in all aspects, become embraced by the corresponding disciplines and made part of their goals and methods. Keeping it separate, as an additional layer, turns it into an afterthought and an option.

This information environment cannot be initiated by any single aspect or goal. Circularity may endorse it, but it is the whole of AECO that must sustain it throughout the life cycle. This sounds like a tall order, but thankfully BIM, properly and consistently applied, is a good starting point. Its limitations are not trivial but not such that they preclude effectiveness and efficiency in any discipline or the collaboration between disciplines. What AECO needs is more experience with working in such an environment – experience that can be invaluable in further transitions, e.g. to the enticing prospect of digital twinning.

1.7 Key Takeaways

- BIM has considerable potential to integrate information processing, thus providing comprehensive and situated information that covers most circularity needs.
- BIM seamlessly links circularity to other activities in design, construction and operation.
- Digital twinning promises even more: digital replicas in full synchronisation with the physical twin and its past, present and future states.
- The successful deployment of powerful technologies such as BIM and digital twinning requires significant investment, commitment and consistency.

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Alexander Koutamanis studied architecture in Greece and received his PhD from Delft University of Technology, where he is associate professor of computational design. He has also worked as a designer and consultant in practice. His research interests include representation, recognition, information, interaction, affordances, briefing and decision support. Recent publications include an open textbook on building information management, an edited volume on construction and demolition waste recycling (including a chapter on BIM) and journal papers on dimensions and potential in BIM.