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Position paper: digital engineering and building information modelling in Australia

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Abstract

Purpose – This position paper urges a drive towards clarity in the key definitions, terminologies and habits of speech associated with digital engineering and building information modelling (BIM). The ultimate goal of the paper is to facilitate the move towards arriving at an ideal definition for both concepts.

Design/methodology/approach – This paper takes the "explanation building" review approach in providing prescriptive guidelines to researchers and industry practitioners. The aim of the review is to draw upon existing studies to identify, describe and find application of principles in a real-world context.

Findings – The paper highlights the definitional challenges surrounding digital engineering and BIM in Australia, to evoke a debate on BIM and digital engineering boundaries, how and why these two concepts may be linked, and how they relate to emerging concepts.

Originality/value – This is the first scholarly attempt to clarify the definition of digital engineering and address the confusion between the concepts of BIM and digital engineering.

Keywords Digitisation, Building information model, Digitalisation, Industry 4.0, Digital construction, Virtual design and construction

Paper type Conceptual paper

Introduction

The construction industry is evolving towards integrating people and processes with information across the asset life cycle (Allen Consulting Group, 2010; Hosseini *et al.*, 2012). Developing and operating assets require data and information to be accessible to key actors, including clients/developers, architects, engineers, contractors, suppliers and facility/asset managers (Hosseini *et al.*, 2018; Sategna *et al.*, 2019). Getting the right data and information to the right actor is half the challenge; the other half is making data and information available to actors at the right time. The latter is particularly challenging as infrastructure assets have

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inherently long lifespans: the “right actor” may be a future actor in the asset’s life cycle (Elghaish *et al.*, 2020). To respond, an effective asset requires (1) a “golden thread” of data and information throughout the asset’s life–from project planning, schematic and detailed design, to fabrication and construction, to operations, maintenance and decommissioning; and (2) all actors’ understanding of the immediate and future data and informational needs (Jupp and Singh, 2016; Woodhead *et al.*, 2018; Succar and Poirier, 2020). Getting the right data and information to the right actor, at the right time, while ensuring future actors’ needs and processes are met is the crux of good information management. Good information management underpins effectiveness, utility, productivity and efficiency across the life cycle of an asset (Hosseini *et al.*, 2018; Love and Matthews, 2019).

The concept of building information modelling (BIM), a 3D object-oriented approach for creating, managing and using information about various aspects of an asset throughout its life cycle, is cited as one option for rising to this challenge (Khosrowshahi and Arayici, 2012; Turk, 2016). While many advances have been made in the application of BIM, limitations to its managerial, technological and collaborative capabilities persist at project and operational levels (Doan *et al.*, 2020). It is owing to these limitations that the concept of digital engineering (DE) has emerged. Conceptually, DE seeks to address BIM’s shortcomings by emphasising the strategic and business-oriented aspects associated with major infrastructure assets (Office of Projects Victoria, 2019).

Achieving agreed definitions of BIM and DE remains a structural challenge to harnessing good information management. Many articulate that these two concepts address different fundamental issues, while some define them as similar (Northwood, 2013; Foster, 2019a). Conversely, some perceive them as co-existent, while others perceive them as competing concepts (HKIE, 2019). Agreed definitions are the building blocks of meaningful conversations in any field; confusion about definitions can impede progress towards achieving the status of an agreed norm (Wacker, 2004). Clarifying the confusion between BIM and DE for the Australian construction industry is very much needed, particularly given the growing interest in these concepts (Krebs, 2018; Foster, 2019a). The definitions and selection of words used in any field inherently shape the outlook and affect behaviour in that field. In fields that change quickly, such as construction innovation and digital technologies, concerted attempts must be made to ensure key definitions, terminologies and habits of speech are contemporaneous, a point argued by Grudin (1993).

This position paper urges a drive towards clarity in the key definitions, terminologies and habits of speech associated with DE and BIM. The ultimate goal of the paper is to facilitate the move towards arriving at an ideal definition for both concepts [1]. To achieve this, the paper highlights the definitional challenges surrounding DE and BIM in Australia, to evoke a debate on BIM and DE boundaries, how and why these two concepts may be linked, and how they relate to emerging concepts.

Australian construction industry: the need for change

The construction industry is one of the largest sectors of the global economy (Barbosa *et al.*, 2017; Opoku *et al.*, 2019). On a global scale, construction-related spending accounts for 13% of the world’s gross domestic product (GDP). The total annual revenue of the sector is estimated to be around US$10 trillion and is predicted to rise to US$14 trillion by 2025 (Barbosa *et al.*, 2017, pp. 1–2).

The Australian construction industry is no exception. It is the largest non-services sector of the Australian economy, employing approximately 1.2m Australians directly, thus representing nearly 9% of the total workforce. The secondary job-creation impacts are notable: every job in the construction industry creates three jobs in the wider economy (LMIP, 2020; Loosemore, 2020). It is through this lens that the following question is posited: “if the Australian construction industry is such an effective vehicle for delivering community and economic benefit, then how can its performance be improved? And what is required to achieve this (Leviäkangas *et al.*, 2017; Sategna *et al.*, 2019)?"

The need for improvement focuses on the industry's cited challenges: high construction costs, unsatisfactory project performance, poor safety, low productivity and/or poor quality (Leviäkangas *et al.*, 2017; Loosemore, 2019). A prime example of these challenges surfaced in New South Wales (NSW) where around 85% of high-rise buildings built after 2000 showed some signs of structural failure (Ghosh *et al.*, 2020). Improving the industry through adopting technological innovations can resolve many of these issues (Hampson and Brandon, 2004; Hosseini *et al.*, 2012; Gruszka *et al.*, 2017; Loosemore, 2019). Of the various technological innovations, BIM is recognised as the "trend of the future", a new disruptive innovation for the industry and a promising avenue towards addressing the above challenges (Tulubas Gokuc and Arditi, 2017, p. 483).

Building information modelling (BIM) initiatives in Australia

BIM was first promoted as a reform initiative in the construction industry nearly two decades ago. In 2004, a strategy for digitalisation was introduced by releasing "Construction 2020 – A Vision for Australia's Property and Construction Industry". Of the nine key visions that emerged from the strategy, "Information and communication technologies for construction" and "Virtual prototyping for design, manufacture and operation" were front and centre (Hampson and Brandon, 2004). Both these visions were referring to BIM with its capability of creating virtual models for various project stages. The 2004 strategy was followed by several papers and policy positions including a 2009 paper (CRC for Construction Innovation, 2009) and the 2010 (Allen Consulting Group, 2010) report. These, among others, recommended the wide adoption of BIM by all involved in the industry as a remedial solution. Furthermore, BIM was seen to have the potential to improve productivity in the construction sector, thus raising economic well-being and the sector's competitiveness across the Australian economy.

Prior to 2018, most recommendations and policy positions promoted BIM as a panacea for woes in the Australian construction industry (Brewer *et al.*, 2012, buildingSMART Australasia, 2012; NATSPEC, 2019). The Australian Institute of Architects, Consult Australia (Holzer *et al.*, 2012), the Australian Institute of Building (AIB, 2013), the Australian Construction Industry Forum, the Australasian Procurement and Construction Council (AMCA, 2012; ACIF and APCC, 2017) and, more recently, the Australasian BIM Advisory Board (ABAB, 2018) (see Hampson and Shemery (2018) for a comprehensive list) are organisations that have all been cited for promoting the use of BIM to resolve the industry's challenges.

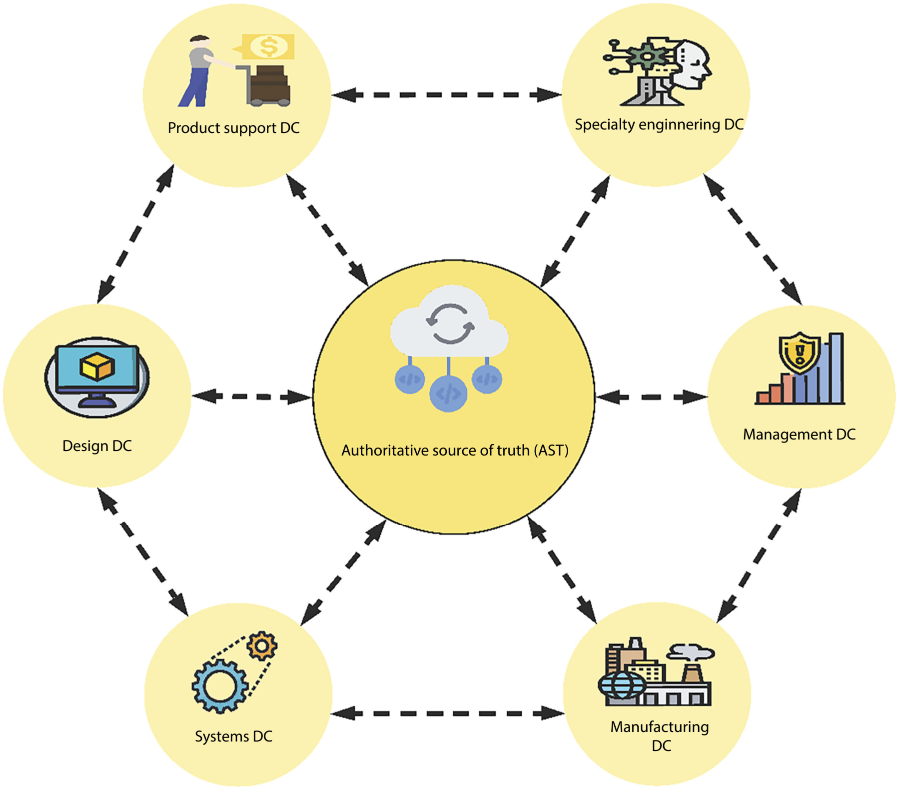
Foundations of building information modelling (BIM)

BIM is an object-oriented approach to creating, managing and using various geometric properties–such as dimensions and weight–alongside non-geometric properties, such as materials and cost data. BIM supports data visualisation; information management and documentation; inbuilt intelligence, analysis and simulation and workflow management (Jupp and Singh, 2014). Document and information management capabilities have merged and evolved with BIM applications (GhaffarianHoseini *et al.*, 2016). This has been achieved through embedding, appending or linking these traditional information management processes to object-based models to combine all forms of geometric and non-geometric data (Becerik-Gerber *et al.*, 2012, Hosseini *et al.*, 2018). Increasingly, BIM applications are becoming valued repositories for integrating domain knowledge from various actors, projects and the construction supply chain (Golizadeh *et al.*, 2018). With these attributes, the focus of BIM definitions is on the exchange of structured data across the project's life cycle. As an example, Volk *et al.* (2014, p. 110) define BIM as "a tool to manage accurate building information over the whole lifecycle" and NIBS (2015, p. 3) refers to BIM as "a business process for generating and leveraging building data to design, construct and operate the asset during its lifecycle. BIM allows all stakeholders to have access to all (or parts) of the information at the same time through interoperable platforms". The United Kingdom (UK)'s Building Information Modelling Task Group refers to BIM as "value creating collaboration through the entire life cycle of an asset, underpinned by the creation, collation and exchange of shared 3D models and intelligent, structured data attached to them" (Sawhney *et al.*, 2017, p. 9). Queensland Health (2019) defines BIM as the "sharing and leveraging of structured information over the asset lifecycle".

Based on the above definitions, BIM should conceptually be used across all phases of an asset's life cycle. In practice, however, its usage beyond the design and construction phases is low (Pärn and Edwards, 2017, Hosseini *et al.*, 2018). In practical terms, this means that BIM is not used across all phases of an asset's life cycle, which would be the ideal, with its benefits only partially realised (Edirisinghe, 2017; Merschbrock *et al.*, 2018; Pishdad-Bozorgi *et al.*, 2018; Woodhead *et al.*, 2018; Gao and Pishdad-Bozorgi, 2019). Many stakeholders involved in the design and construction phases use BIM to drive cost and time efficiencies, even though its potential goes beyond these areas of efficiency (Hosseini *et al.*, 2018; Gao and Pishdad-Bozorgi, 2019). Integrating BIM with other digital technologies and processes unlocks its potential (Jiao *et al.*, 2013; Ding *et al.*, 2019; Love and Matthews, 2019). The need for this integration, with the aim of synthesising information and data across all actors in the life cycle of assets, has given rise to the emergence of another concept: digital engineering (DE)(Golizadeh *et al.*, 2018).

Foundations of digital engineering (DE)

One of the first uses of the term "digital engineering (DE)" was in 1975, when DE was discussed in the context of electronic and logic circuit design. Future applications surrounded manufacturing, including "developing digital concepts and systems" (Kostopoulos, 1975, p. vii) and product life-cycle management (PLM) (Newman *et al.*, 2020). DE is also a natural extension of the term "engineering". Engineering refers to the use of scientific principles to design and build various assets and artefacts, either in manufacturing, for example, machines and vehicles, or in the built environment, such as bridges, tunnels, roads and buildings. All engineering disciplines today have evolved to improve practices: modern engineering needs to be supported by large amounts of data, with the aid of computers (Bone *et al.*, 2019; Engineers Australia, 2020). This requires the transformation of engineering practices to DE in which technological innovations are assembled to allow for an integrated, digital component (DC)-based approach that supports life cycle activities and develops a culture among stakeholders of working more efficiently (Defense Department, 2018). Thus, the aim of DE is to create a seamless thread of data and information throughout the product or asset life cycle, with this achieved through interoperability across heterogeneous systems, as well as integrated information management and data exchange (McMahon *et al.*, 2005; Kim *et al.*, 2010). At its core, DE entails radical digital transformations which require the conversion of all forms of data and information representations into digital components (DCs). In other words, the system and its elements, relevant processes, equipment, products, parts, functions, services, etc. in the operating environment must be presented in the form of DCs to provide a precise and versatile representation of them all (Defense Department, 2018; Huang *et al.*, 2020), as illustrated in Figure 1. A formalised DC creation strategy must be in place to govern the curation, sharing, integration and use of DCs across disciplinary teams, organisations and life cycle phases, with the support of an authoritative source of truth (AST). The AST is



Source(s): Adapted from Defense Department, 2018, Huang *et al*., 2020

Figure 1.
Core elements of DE

needed to provide a repository of, and access portal to, standardised DCs, data and other digital artefacts (Huang *et al.*, 2020).

The DE concept is equally applicable to the construction industry due to the knowledge-intensive nature of this industry, the prevalence of virtual organisations and teams, its fragmented work settings and the sector's scattered supply chain (Rezgui *et al.*, 2010; Hosseini *et al.*, 2012). The influence of DE concepts, methods and technologies is driving change within the Australian construction industry, changing assumptions about the value of data and information and increasing the importance of good knowledge management across the whole asset life cycle.

Digital engineering (DE) initiatives in Australia

In response to the challenges faced by the construction industry–such as ineffective communications, inconsistencies in information, loss of data and utilisation by stakeholders of out-of-date or wrong information and data to inform decision-making (Jupp and Singh, 2016; Mignone *et al.*, 2016, Hosseini *et al.*, 2018)–the Australian Transport and Infrastructure Council endorsed the National Digital Engineering Policy Principles (Transport and Infrastructure Council, 2016) in November 2019. Since then, Transport for NSW (TfNSW) has acted as a driving force promoting the adoption of DE in Australia to maximise quality and efficiency in delivering transport projects (Transport for NSW, 2018). Transport for NSW

(TfNSW) also leads the National Digital Engineering Working Group, comprising senior members of Australian federal, state and territory governments, with this being a federally sponsored group established to lead the way towards a consistent national approach to DE for transport infrastructure.

In 2012, TfNSW established a BIM/DE working group, composed of industry experts and stakeholders. In 2017, TfNSW released the Data and Information Asset Management Policy that formally recognises the value and critical importance of structured data. The DE Framework Program–a fully funded program–has been running since 2017, with the aim of bringing together experts from around Australia to develop practical, cost-effective DE solutions based on global best practices (TfNSW, 2018). The outcomes have resulted in the evolution and release of consecutive versions of the DE Framework: Release 1 (in September 2018); Release 2 (April 2019) and Release 3 (November 2019).

State and territory governments in Australia, as well as the private sector, have now recognised the great potential provided by DE for improving various aspects of delivering and managing buildings and infrastructure assets and networks (Hampson and Shemery, 2018, Shemery and Hampson, 2019). Queensland published its “Digital Enablement for Queensland Infrastructure” in November 2018 (State of Queensland, 2018). Victoria followed NSW in promoting DE, by releasing its “Victorian Digital Asset Strategy (VDAS)” (Office of Projects Victoria, 2019) in 2019.

Definition and concept confusion

A review of the literature shows that various approaches are being used to define BIM and DE within the Australian context. In one group of documents, the terms “BIM” and “DE” are used interchangeably, a recognition of little, if any, distinction between the DE and BIM concepts. This approach is typically adopted by industry practitioners (Northwood, 2013; Hardcastle and Hubert, 2014; TfNSW, 2015; Hampson and Shemery, 2018).

Conversely, some industry stakeholders recognise that BIM and DE are definitionally mutually exclusive–one can supersede or replace the other. Some define BIM as an obsolete concept, instead promoting DE as the “current version” of BIM (Krebs, 2018; Foster, 2019c). Others promote the idea of DE being a process that follows BIM in the project life cycle (HKIE, 2019).

Finally, many refer to DE, in relation to BIM, as a broader concept. This viewpoint typically revolves around the notion that DE is the outcome of the integration of various technologies–including BIM–to improve information management efficiency (Golizadeh *et al.*, 2018). This viewpoint is the one commonly aligned with what is proposed by some researchers; for example, Duc (2018) offers this definition of DE: “the result of the crossover of BIM, Internet of Things (IoT) and big data”. Similarly, Foster (2019b) proposes that “Digital Engineering is a broad term which gathers several other related technologies or processes together, such as Computer-Aided Design (CAD), BIM, Geographical Information Systems (GIS) and Data Science”, while BIM is viewed as the element of DE used in the design and construction phases. This type of definition defines BIM as a subset of a wider DE ecosystem. Here, discrepancies are found in the way that the boundaries between DE and BIM are defined. A more contemporary perception of the two concepts is that DE relies on BIM as a fundamental enabler (Hampson and Shemery, 2018). Stated more simply, a list of technologies, systems and processes can integrate with BIM to create DE. Definitions in this category offer competing lists of technologies that can create DE by being integrated with BIM. With this in mind, DE can be described as the Australian version of Industry 4.0 for the construction context (Newman *et al.*, 2020; Olugboyega *et al.*, 2020).

According to the seminal work by Alvesson and Sandberg (2011), confusion over the definitions of concepts must be addressed when discrepancies are observed among individuals or when available definitions offer contradictory or competing explanations. The case of DE and BIM in Australia, as discussed above, fits the criteria in this statement. Ongoing confusion is apparent among practitioners, researchers and policymakers with regard to the DE and BIM concepts (Foster, 2019a).

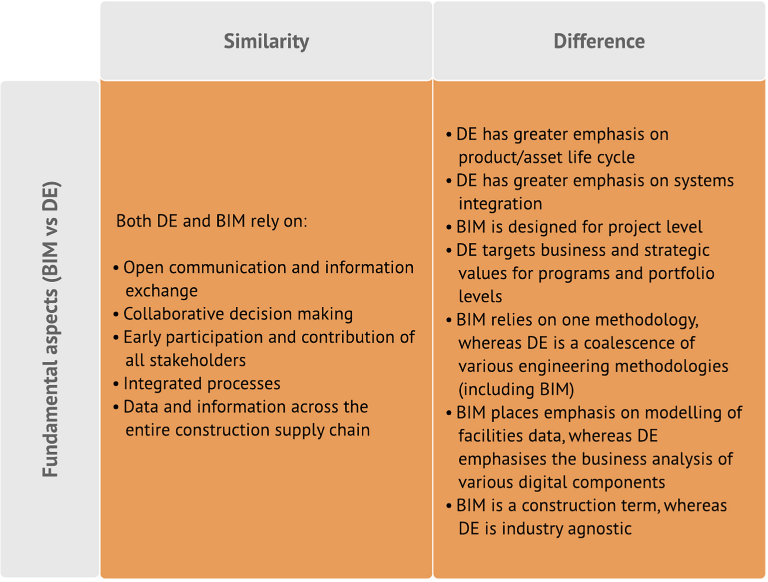
Resolving the confusion

In exploring the history of DE, as previously discussed, its birthplace is found to be within the engineering field where the term is clearly defined and concepts around DE are well established (Kostopoulos, 1975). Thus, the definition of DE in this position paper adheres to the norms of popular scientific discourse on DE within the engineering domain, following the definition of DE by Defense Department (2018), and as further explained by Huang *et al.* (2020). The confusion between these definitions is addressed through the use of a definitional chain approach, in which, instead of providing a single definition, a concept is defined in comparison to related terms, through text segments that introduce the term in conjunction with illustration and explanation (Gülich, 2003; Pilkington, 2019).

As illustrated in Figure 2, even though some fundamental similarities are observed, the major differentiators between BIM and DE on fundamental aspects should be recognised.

As illustrated in Figure 2, BIM is largely related to the modelling of information, whereas DE addresses the achievement of desired levels of systems integration, while taking a strategic business perspective. DE relies on a versatile set of methodologies to inform strategic decision-making, not only in projects–which is done by BIM–but also across program and portfolio levels (see Figure 3).

Unlike BIM, DE is seen as a holistic business concept that encompasses a business approach and a set of engineering toolsets to apply scientific methods to large data sets for problem solving. These methodologies have roots in various disciplines and domains whereas BIM is mostly confined to construction activities. Engineering "systems" are thus the enablers of DE, serving as hubs of product data (Golizadeh *et al.*, 2018) to support



	Similarity	Difference
Fundamental aspects (BIM vs DE)	Both DE and BIM rely on: • Open communication and information exchange • Collaborative decision making • Early participation and contribution of all stakeholders • Integrated processes • Data and information across the entire construction supply chain	• DE has greater emphasis on product/asset life cycle • DE has greater emphasis on systems integration • BIM is designed for project level • DE targets business and strategic values for programs and portfolio levels • BIM relies on one methodology, whereas DE is a coalescence of various engineering methodologies (including BIM) • BIM places emphasis on modelling of facilities data, whereas DE emphasises the business analysis of various digital components • BIM is a construction term, whereas DE is industry agnostic

Figure 2.
Comparison of BIM and DE

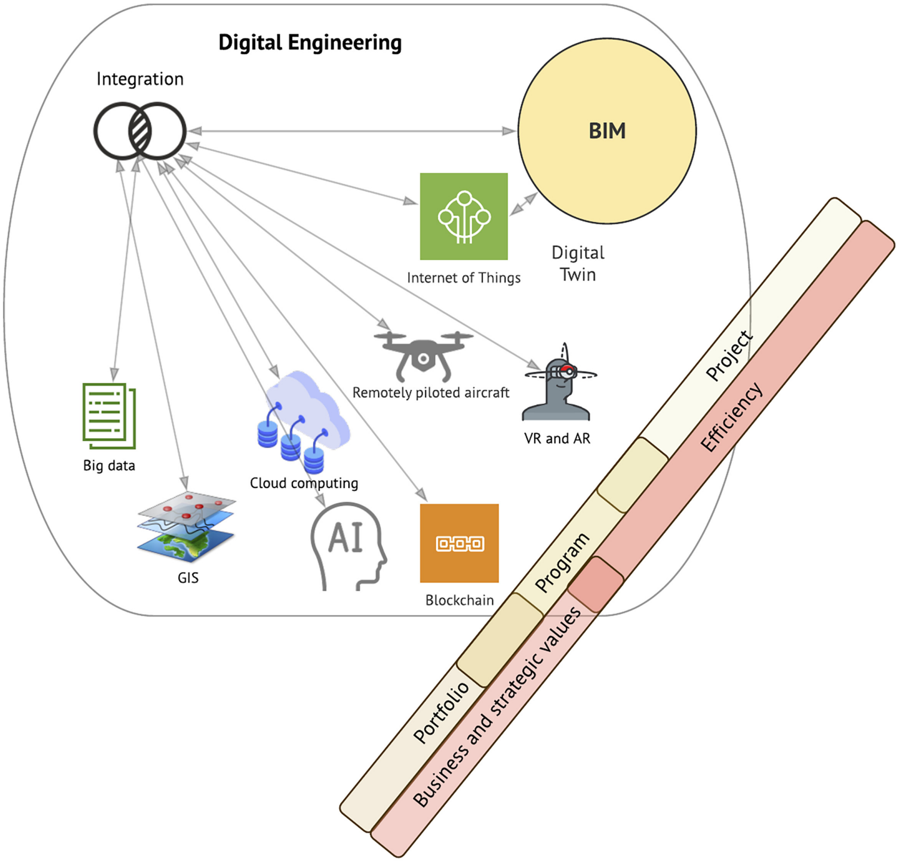


Figure 3.
BIM, DE and other fundamental concepts

Note(s): AR = augmented reality; VR = virtual reality; AI = artificial intelligence; GIS = geographic information system

collaborative design and production processes, as well as the use, traceability and management of information across the extended enterprise and by all actors involved in facility realisation and operations.

In the construction context, the implementation of DE means that information related to physical aspects of construction projects and the virtual computational space is highly synchronised. This allows for a new degree of control, surveillance, transparency and efficiency in the construction process. In DE, two parallel networks are linked: a physical network of interconnected tools related to various technologies (see Figure 3) and a cyber network of intelligent controllers and the communication links between them.

Concluding remarks and recommendations

This position paper has sought to assist the resolution of the confusion between the BIM and DE concepts. Both concepts have been used interchangeably across industry, government and academia. By reviewing the origins and foundations of BIM and DE, this paper increases the collective understanding of their definitional differences (and similarities), how these concepts came into being and what the implications are in practice. Although this paper has an Australian focus, similar patterns exist in the systems of other countries.

From a broader perspective, BIM is an element, paired with other methodologies, that collectively make up the DE concept. Ultimately, these elements support the DE environment for data analysis purposes through their links with the physical domain. Through using this logic, BIM is best described as a subset of DE. In this paper, DE is defined through the notion of the convergence of emerging technologies, while the definition of BIM is focused on improving businesses, projects and asset management practices. At the same time, DE is an industry-agnostic term that can help to initiate discussions and facilitate knowledge transfer to construction from other industries, such as manufacturing and computer science, where digital technologies have been highly developed, tested and diffused. Moving from a BIM-centric terminology towards DE is a step towards further digitalising the construction sector and allowing knowledge externalities to contribute to shaping its future, thus also being one step towards the adoption of "Industry 4.0" in the construction domain.

Two major areas must be addressed to facilitate resolving the confusion in definitions. First, the field needs more academic references for the concept of DE, particularly within the construction context. A common trend in science today is the replacement of older hardware-oriented terms by newer management-focused terms (Harris, 1979): this also needs to be the case with shifting from BIM to DE in academic journal articles.

Second, government publications and guidelines should be consistent. The available definitions largely emphasise "the benefits DE has in one's specific context" rather than "what DE is as a concept". Existing definitions mostly refer to the outcomes expected and provide an indeterminate list of technologies: they offer a meaning for DE that is limited to the boundaries of infrastructure projects. Consequently, this definition lacks broader meaning in the context of the Australian construction industry. Furthermore, it promotes the idea that DE can be adopted independently of other technologies, such as big data, BIM and the Internet of things (IoT). This is in contrast to one of the definitional viewpoints in which DE is defined as the direct outcome of integrating these technologies. Such discrepancies must be addressed in future editions of government publications and guidelines: DE and BIM need to each have one definition on which all must rely.

Note

1. Following the recommendation by Pilkington (2019), this task is pursued here not through a single definition, but through a definitional chain–a combination of several definitions that provide commonly recognised approaches to defining (such as *X* is *Y*) and novel ways of presenting scientific terminology (telling the reader what *X* does).

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