Innovation Realisation for Dutch Small Architecture Practices' Digitalisation: state of the art review

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ABSTRACT

Advancing digitalisation and sustainability is a priority for the construction sector. With intertwined agendas, digitalisation enables the achievement of sustainable outcomes. That is the case of EU initiatives exploring BIM as a facilitator to Circular Economy (CE). Thus, standardising BIM implementation through the ISO19650 information requirements represents a stepping stone towards a more sustainable sector.

A unified digitalisation vision is under development as part of the European Green Deal. However, the European Union has identified that the proposed approach has had limited effect on achieving sustainable outcomes. Amongst the issues is the complexity that hinders small and medium-sized (SMEs) organisations from contributing. This problem is exacerbated by the limited amount of published scientific research evidence explaining how SMEs incorporate resource-hungry processes into their resource-limited business models.

Therefore, to better understand the digitalisation for sustainability success cases within SMEs, this paper presents a state of the art literature review of academic articles, followed by a state of evidence review of grey literature. The review focuses on Dutch small architectural practices. The results highlight the importance of projects information requirements for SMEs and the multi-faceted challenges experienced by building design SMEs. This paper also suggests future research areas focusing on innovation realisation.

KEYWORDS

BIM, Small and medium-sized enterprises (SMEs), Small Architectural Practices (SAPs), Digitalisation, Circular Economy, Innovation Realisation (IR).

1 INTRODUCTION

The construction sector is failing to deliver innovation for essential sustainability and digitalisation drivers. Meaningful and embracing strategies for realising the benefits of these drivers are lacking worldwide. BIM implementation, for example, enables the achievement of sustainable outcomes (Purvis et al., 2019). It is acknowledged within policies as a means to advance sustainability and digitalisation outcomes and a driver to elicit value, innovation, and growth (EU BIM Task Group, 2018a). Nevertheless, the amount of evidence demonstrating how small to medium enterprises (SMEs) are incorporating resource-hungry BIM processes into these resource-limited businesses is negligible and stagnant (Makabate et al., 2021) despite the significant contribution they can make to accelerate or hinder sustainable outcomes within the construction sector (EU, 2019a).

While standards to structure the digitalisation of the construction industry abounds worldwide, its appropriateness to all business models remains unquestioned. The publication of the ISO 19650 standards in 2019 triggered the development of a series of new and unified protocols and guidelines for the construction industry (BSI, 2019). Their purpose was to create a BIM "common language". They now inform European (EU BIM Task Group, 2018) and UK (UKBF, 2019) and worldwide approaches to standardised BIM implementation across a (claimed) broad spectrum of stakeholders. There are standards for properties (ISO, 2020a), data templates (ISO, 2020b), data dictionaries (ISO, 2020b; IET, 2020, p. 31), and project information requirements. Building SMART has also created a machine-readable information delivery specification template (buildingSMART, 2021). Altogether, these standards enhance data reliability and the "predictability" of exchange workflows and establish a direct automated link between project information requirements and quality assurance. Undoubtedly, the plethora of standards seems to attend to the issues the industry has long experienced with the quality of the data it produces. It is proffered that standardised data exchange enables digitalisation and aids in realising projects' sustainable outcomes. However, if the success of standards is judged upon the optimisation of processes involving repeatable actions, having repeatable results the construction industry with its national, regional, project and discipline-based characteristics provide a substantial challenge for the operational success of said standards (Sriyolja et al., 2021; Ozorhon, B. et al., 2019). Although current European policy seeks to reduce regulatory burdens on SMEs (EU, 2021a, p.6) by acknowledging the significant “cumulative” impact of regulation, there appear to be inconsistencies in their guidance which could perpetuate, rather than resolve, existing issues for SMEs. From what appears (Dainty et al., 2017; Saka et al., 2021), such a sophisticated approach based on standards only targets large complex projects and organisations that can digest the overabundance of procedural steps associated with BIM.

It is not only BIM standards that have become more robust and complex. Digitalisation policies (European Commission 2021d) became a catalyst for sustainability targets, thus increasing the complexity of design deliverables. For example, the Dutch Government (RIVM, 2016, p. 27) and the European Green Deal policy advocate for digitalisation and the adoption of the Circular Economy (CE) model as a means towards European carbon neutrality in 2050 (EU, 2020b). Authors articulate the relationship between digitalisation and CE from various backgrounds, such as Çetin et al. (2021), Charef et al. (2021), Norouzi et al. (2021), and Hossain et al. (2020). CE ‘is an industrial system that is restorative or regenerative by intention and design’ (MacArthur, 2013 p. 7). Within construction, the application of CE principles to design (product), construction and decommission (end of use), as proposed by the European Circular Economy Action Plan (CEAP), supports reducing construction waste while increasing materials reuse. It proposed targets for buildings’ durability and adaptability, material recovery to be monitored through project digital twins with a basis on the robust and complex standards for digitalisation. In other words, all design firms, including SMEs, are being asked to do more in a more technologically complex operational environment with the same amount of resources.

Adding to the complexity is the digital monitoring of sustainable targets during the use life-cycle phase of buildings. Building use is not affected by CE principles; therefore, the only alternative to achieve sustainable policy targets via digitalisation is monitoring building performance through Digital Twins (DT). Although not explicitly linked to sustainable outcomes, this approach is already being studied (Sacks et al., 2020; Mêda et al., 2021). For example, it has been established that European construction data should comply with interoperability principles by aggregating information through standards in a project-based digital twin (EU BIM Task

Group, 2018a). As the “birth” of a DT occurs in the design phase, designers are also expected to follow DT data standards throughout the conceptual and realisation phases. Concerning DT, a definition specific to the European construction industry remains elusive and, at best, vague (Liu et al., 2021), thus delaying the assimilation of its standards into work practices. Within the Digital Europe (2020, p.5) policy, DT is defined as “a digital representation of (buildings) static and dynamic parameters to provide the information needed to meet optimisation goals.” In short, a digital twin enables performance gap analysis by comparing digitally estimated performance with the performance of the actual real-life building. It also serves as a repository of asset information necessary for maintenance and decommissioning (Codinhoto et al., 2021), and since it contains crucial information for establishing building material reuse during decommissioning (van Leeuwen et al., 2018; Savini, 2021), well-defined information requirements become critical to the success of sustainable outcomes. However, since DT standards are not yet fully developed, information requirements cannot be appropriately defined, and sustainable targets cannot be met through DT. Also, adding DT information requirements to a project increases the scope of work and its complexity (BNA, 2019; EU, 2021b).

While exploring the link between digitalisation and sustainable outcomes is timely and relevant, new knowledge about advancing both areas through SMEs is scarce. Even initiatives such as Europe 2020, which outlines a strategy for SMEs to transition digital workflows, thereby increasing the sustainable competitiveness of the European construction industry (COM103, 2020), do not contemplate solutions to address the continuous increasing of complexity emerging from digitalisation. Therefore, identifying innovative and creative ways to create scalable digitalisation solutions suitable for SMEs becomes essential for overcoming such a challenge, as Miettenen et al. (2014) and Arayici et al. (2011) recommended. Therefore, this research investigates innovative ways SMEs use to incorporate digitalisation enabled sustainable outcomes within their business models. The scope of the research is limited to European construction design SMEs as they represent 95% of the design firms in the sector (EU, 2020c), particularly Dutch small architectural practices (SAPs). Also, digitalisation was investigated by looking at BIM implementation and sustainability concerning the incorporation of CE information within projects. The research was based on an extensive literature review. Due to a reported lack of accuracy within the academic literature, this research also considered eligible grey literature as recommended by Tezel et al. (2020). The research aimed: 1) to understand whether there is an alignment between academic and grey literature about SAPs' digitalisation (BIM); and 2) to evaluate the impact of SAPs' digitalisation on triggering sustainable outcomes.

Dutch SAPs was considered relevant for this research because they are representative of SMEs (96% of architectural practices are SMEs - ACE, 2020, p. 38) and are inserted in a context of change, i.e. Dutch construction is transitioning to a circulation economy (RIVM, 2016), it has, potentially, one the highest levels of BIM maturity within Europe Azzouz et al. (2018), and is an area requiring further research as recommended by Siebelink et al. (2018). In addition, mandatory policies for built environment environmental performance started in January 2021 (Gov.nl, 2021; RVO, 2021; EU Factsheet, 2021), which means that SAPs are already under greater pressure to innovate and adapt in their role as managers of information requirements on projects, so to respond to the new policies. That can only be done by removing non-value adding activities from the proposed digitalisation standards (Vos et al., 2019; Vos et al., 2016).

2 RESEARCH DESIGN & METHOD

BIM is seen as an innovation that has radically transformed the production, distribution and collation of project information on construction projects (Shirowzhan et al., 2020; Papadonilolaki, 2018; Elmualim et al., 2014). BIM innovation research has been predominantly been underpinned by a social science approach; therefore, it was deemed appropriate for studying project-based innovations in the construction industry (Liu et al., 2020; Wang et al., 2021). As outlined by Holt et al. (2014), a mixed-method approach is suited to the fragmented, project-based nature of the construction industry. Accordingly, mixed methods were used, including an initial systematic literature review augmented by a review of grey literature focused on BIM as a significant part of the digitalisation agenda in construction. All stages were informed by a structured approach to snowball sampling (Naderifar et al., 2017; Lecy et al., 2012).

2.1 Systematic Literature review (SLR)

Systematic literature reviews are essential for generating evidence from existing studies and creating new knowledge by compiling the existing works directing new research (Denyer et al., 2009; Kitchenham et al., 2009, Tranfield, 2003). However, SLRs relating to SMEs' BIM implementation is scarce (Abbasnejad et al., 2021), even more so when exploring implementation from an operational perspective. Therefore, the research design mirrors the ‘synthesised’ approach recommended by Tezel et al. (2020). Qualitative content analysis was carried out based on thematic clustering analysis to group authors and themes within articles after Shehzad et al. (2020).

The literature review has been divided into two stages: Stage 1 refers to state of the art (SOTA), and Stage 2 refers to the state of the evidence (SoE). The SOTA was divided into two SLR reviews (SOTA 1 and SOTA 2 – with specific searching and inclusion/exclusion criteria as presented in Figure 1. The SoE was based on reviewing EU policy and comparing the findings against the evidence from the SOTA. The use of grey literature as a supplement to systematic literature reviews broadened the scope of the academic enquiry and benefit the analysis of hypotheses by providing a more comprehensive view of available evidence. However, validating the results of grey literature can be challenging (Mahood et al., 2014). Despite these challenges, the inclusion of grey literature was considered beneficial for validating the results of the SOTA.

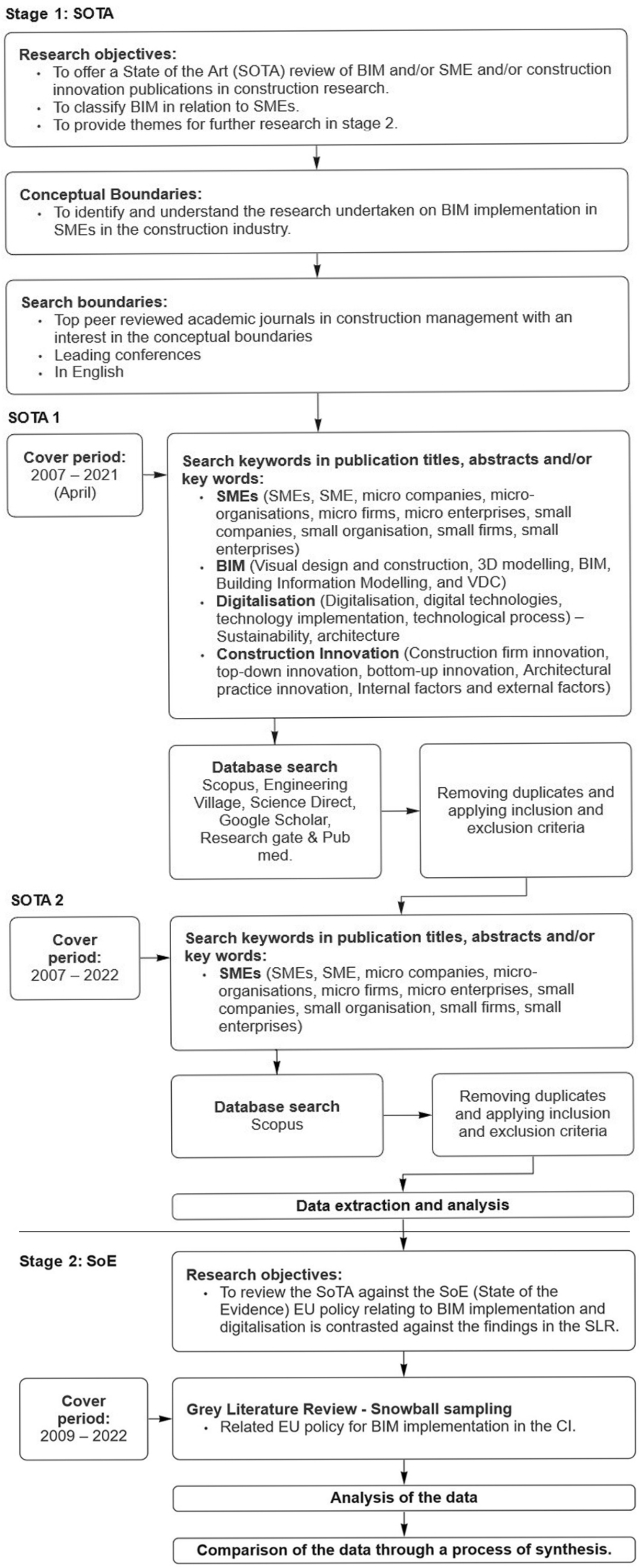
Stage 1: SOTA
Research objectives:
To offer a State of the Art (SOTA) review of BIM and/or SME and/or construction innovation publications in construction research.
To classify BIM in relation to SMEs.
To provide themes for further research in stage 2.
Conceptual Boundaries:
To identify and understand the research undertaken on BIM implementation in SMEs in the construction industry.
Search boundaries:
Top peer reviewed academic journals in construction management with an interest in the conceptual boundaries
Leading conferences
In English
SOTA 1
Cover period: 2007 – 2021 (April)
Search keywords in publication titles, abstracts and/or key words:
SMEs (SMEs, SME, micro companies, micro-organisations, micro firms, micro enterprises, small companies, small organisation, small firms, small enterprises)
BIM (Visual design and construction, 3D modelling, BIM, Building Information Modelling, and VDC)
Digitalisation (Digitalisation, digital technologies, technology implementation, technological process) – Sustainability, architecture
Construction Innovation (Construction firm innovation, top-down innovation, bottom-up innovation, Architectural practice innovation, Internal factors and external factors)
Database search Scopus, Engineering Village, Science Direct, Google Scholar, Research gate & Pub med.
Removing duplicates and applying inclusion and exclusion criteria
SOTA 2
Cover period: 2007 – 2022
Search keywords in publication titles, abstracts and/or key words:
SMEs (SMEs, SME, micro companies, micro-organisations, micro firms, micro enterprises, small companies, small organisation, small firms, small enterprises)
Database search Scopus
Removing duplicates and applying inclusion and exclusion criteria
Data extraction and analysis
Stage 2: SoE
Research objectives:
To review the SoTA against the SoE (State of the Evidence) EU policy relating to BIM implementation and digitalisation is contrasted against the findings in the SLR.
Cover period: 2009 – 2022
Grey Literature Review - Snowball sampling
Related EU policy for BIM implementation in the CI.
Analysis of the data
Comparison of the data through a process of synthesis.

Figure 1 - Systematic literature review (After Tezel et al., 2020)

3 RESEARCH FINDINGS

3.1 SOTA1 and SOTA2

In SOTA 1, the selected main keywords ‘BIM and SMEs’, ‘digitalisation’ and ‘construction innovation’ were searched in publications indexed in Scopus, Engineering Village, Science Direct, Google Scholar, Research gate & Pub med. The review focused on European research; therefore, the ASME index was not included. In SOTA 2, the selected main keywords were ‘circular economy’ and ‘digital twins’ combined with ‘BIM & SMEs’ from SOTA 1 and were searched in publications indexed in Scopus. The keywords were searched in the abstracts, titles, and (or) keywords of the publications in three search rounds. In addition, complementary keywords (Table 1) corresponding to each main keyword were also searched in the same databases to ensure adequate coverage of the literature.

Table 1 - Systematic Literature Review Stage 1 – Search Terms

SOTA	Keywords	Complementary keywords
1 and 2	BIM & SMEs	(Visual design and construction OR 3D modelling OR BIM OR Building Information Modelling OR VDC) AND (SMEs OR SME OR micro-companies OR micro-organizations OR micro-firms OR micro-enterprises OR small companies OR small organisation OR small firms OR small enterprises)
1	Digitalisation	Digitalisation OR digitalisation OR digital technologies OR technology implementation OR technological process
1	Construction Innovation	Construction Innovation OR Construction firm innovation OR top-down innovation OR bottom-up innovation OR Architectural practice innovation OR Internal factors OR external factors
2	Circular Economy	Circular Economy

2	Digital Twins	(Digital Twins OR Digital Twin)

Duplicates were removed within the searched articles, and the inclusion and exclusion criteria (Table 2) were then applied. Conference papers were assessed for quality and included due to their relative importance to the keyword terms and research topics. The database search and exclusion processes were repeated for SOTA 1 and SOTA 2.

Table 2 - Inclusion and Exclusion Criteria

Inclusion criteria	Exclusion criteria
Top peer-reviewed academic journals in construction management with interest in the conceptual boundaries.	SOTA 1: Articles that do not primarily consider BIM and/or Digitalization and/or Innovation within construction SMEs.
Leading conferences.	SOTA 2: Articles that do not primarily consider BIM and/or Circular Economy and/or Digital Twins within construction SMEs.
In English.	Articles that are out of the construction domain.

3.2 Bibliometric analysis

Qualifying the evidence involved screening the literature according to their bibliographic and content features. The bibliographic analysis considered the publication dates, publication types, top authors, countries of the first author, and the publication media. The content analysis focused on preferred research methods and contents of the literature. Figure 2 shows the process step of the research. Within SOTA1, after the exclusion process, 84 articles were selected. When the selected articles were classified by their publication dates and publication types, it was found that the interest in BIM and SAPs increased significantly after 2011, while the interest in digitalisation and construction innovation largely increased after 2015 (Table 3). Furthermore, it was found that the number of articles started to increase significantly from 2016, indicating that BIM in SMEs has received more attention in recent years. Similarly, it was found that the number of articles focusing on circular economy and digital twins both started to increase from 2019 (Figure 3). Also, journal papers significantly outweighed other types of publications (58 of 84 in total). For SOTA2, 45 articles were considered for investigation. The analysis based on publication dates and types revealed that the relationship between the CE, BIM and SMEs is emergent and not yet determined. Also, evidence relating to DT is emergent, with various discipline-based definitions still being used.

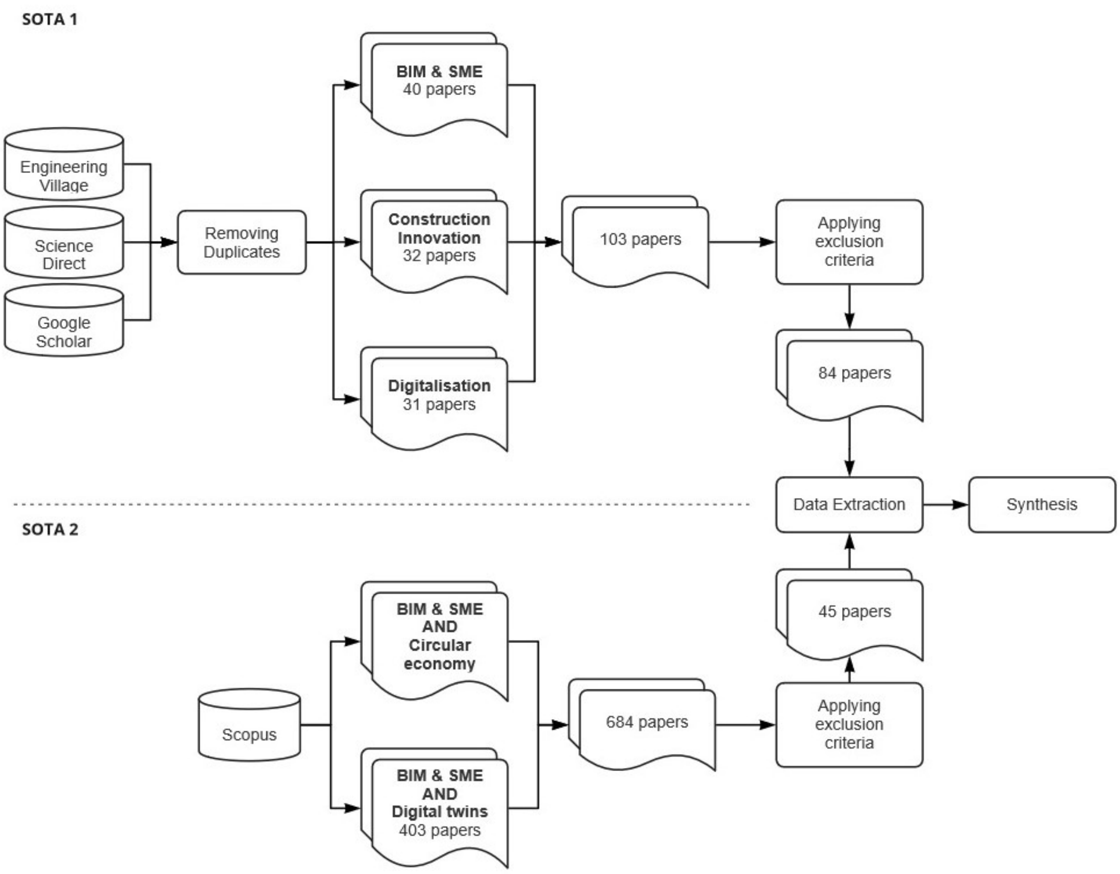

Figure 2 - SLR Synthesis process

Table 3 - Detailed list of number of publications by year, type and focus

	SOTA 1 - Publication focus			SOTA 2 - Publication focus	
Year and publication type	**BIM & SMEs**	**Digitalisation**	**Construction Innovation**	**Circular Economy**	**Digtal Twins**
2008 Journal paper		1			
2009 Journal paper			1		
2010 Journal paper			2		
2011 Journal paper	2				
2011 Conference paper	1				
2012 Journal paper	1	1	1		
2013 Journal paper	1	1	1		
2014 Journal paper		1			
2014 Conference paper	1				
2015 Journal paper	1				
2015 Conference paper		1			
2016 Journal paper	1	1	1	1	
2016 Conference paper	5		1		
2017 Journal paper	3	4	1	1	
2017 Conference paper	1	1			
2018 Journal paper	4	1	5	1	
2018 Conference paper	2	4	1		1
2019 Journal paper	1	8		5	1
2019 Conference paper	1		1		1
2020 Journal paper	7	2	3	11	2
2020 Conference paper	2	2	2	1	
2021 Journal paper	1	1		11	8
2021 Conference paper				2	
2022 Journal paper	-	-	-	3	
Total	**35**	**29**	**20**	**36**	**13**
		Grand total: 84		**Grand total: 49**	

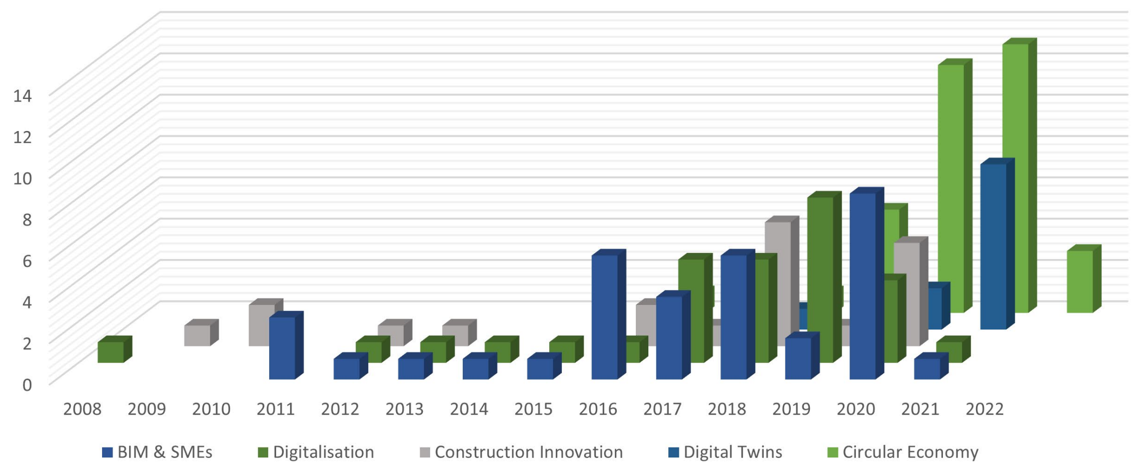

Figure 3 - Number and type of publication by year

Concerning the analysis by country of origin of the first authors (Figure 4), the United Kingdom (UK) based academic institutions have produced the highest number of publications since 2008 (37 in total), followed by Australia (15 in total), the United States (10 in total), and Italy (10 in total).

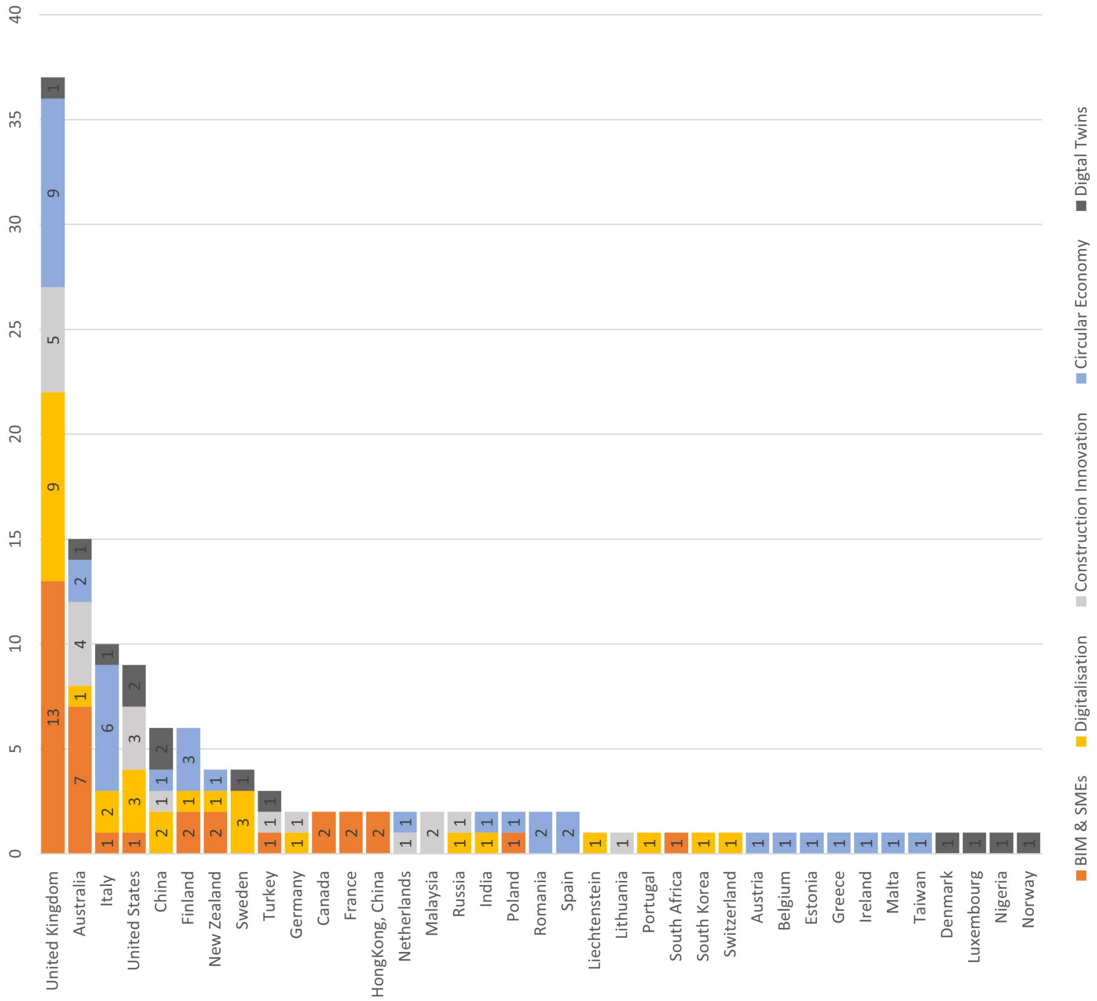

Figure 4 - Number of publications by country of origin of the first author's institution

Regarding leading authors, Dr Hosseini has authored four BIM and SMEs related articles; Dr Papadonikolaki has authored seven articles focused on digitalisation; Dr Ozorhon has authored two articles focused on construction innovation; Dr Bassi authored three articles focusing on the CE; All articles focusing on digital twins had different leading authors. A more detailed ranking of the most prolific authors can be seen in Table 4. The most cited publications within these areas are listed in Table 5.

Table 4 - Most prolific authors by the number of publications and publication focus

Top authors (Overall)	
Author name	**No. of articles**
Eleni Papadonikolaki	7
M. Reza Hosseini	4
Ali Ghaffarianhoseini	3
Bassi, F.	3
Bethan Morgan	3
Arman M Kouch	2
Beliz Ozorhon	2
David Arditi	2
Dias, J.G.	2
Järvenpää, A.M.	2
Mäntyneva, M.	2
Yusuf Arayici	2

SOTA 1 - Publication focus

BIM & SMEs		Digitalisation		Construction Innovation	
Author name	**No. of articles**	**Author name**	**No. of articles**	**Author name**	**No. of articles**
M. Reza Hosseini	4	Eleni Papadonikolaki	7	Beliz Ozorhon	2
Yusuf Arayici	2	Bethan Morgan	3	Other	67
Arman M Kouch	2	Other	76		
Other	123				

SOTA 2 - Publication focus

Circular Economy		Digital Twins	
Author name	**No. of articles**	**Author name**	**No. of articles**
Bassi, F.	3	Other	13
Dias, J.G.	2		
Järvenpää, A.M.	2		
Mäntyneva, M.	2		
Other	27		

Table 5 - Most cited publications

Publication name	Publication year	Authors	Country	Publication type	Publication medium	Empirical or theoretical	Primary research method	Research focus	No. of citations on Google Scholar	Comments
Organizing for Innovation in the Digitized World	2012	Youngjin Yoo, Richard J. Boland, Jr., Kalle Lyytinen, Ann Majchrzak	USA	Journal	Organization Sience	Theoretical	Conceptual discussion	Digitalisation	1480	There is no mention of SME's & BIM but does successfully predict the importance of digital platforms & convergence of digital innovations
BIM implementation throughout the UK construction project lifecycle: An analysis	2013	Robert Eadie, Mike Browne, Henry Odeyinka, Clare McKeown, Sean McNiff	UK	Journal	Automation in Construction	Empirical	Survey	BIM & SMEs	646	Explains the impact of BIM implementation of construction projects. Does not focus on SME's.
Technology adoption in the BIM implementation for lean architectural practice	2011	Arayici, Y., Coates, P., Koskela, L., Kagioglou, M., Usher, C., & O'Reilly, K.	UK	Journal	Automation in construction	Empirical	Case study	BIM & SMEs	560	Highlights how BIM may be implemented in an Architectural SME.
Modelling (BIM) uptake: Clear benefits, understanding its implementation, risks and	2017	Tookey; Amirhosein Ghaffarianhoseini; Nicola Naismith; Salman Azhar; Olia Efimova; Kaamran	New Zealand	Journal	Renewable and Sustainable Energy Reviews	Theoretical	Literature review	Digitalisation	352	Investigates the risks and challenges associated with the adoption of BIM.
BIM adoption and implementation for architectural practices	2011	Y. Arayici, P. Coates, L. Koskela and M. Kagioglou	UK	Journal	Structural Survey	Empirical	Case study	BIM & SMEs	299	This research focuses on the implementation of BIM in a small architectural practise in the UK.
Aligning building information model tools and construction management methods	2012	Hartmann, Timo; Meerveld, Hendrik van;Vossebeld, Niels; Adriaansec, Arjen	Netherlands	Journal	Automation in construction	Empirical	Data analysis	Construction Innovation	296	Research allowed for the close alignment of BIM tools with existing work routines.
Implementation of circular economy business models by small and medium-sized enterprises (SMEs): Barriers and enablers	2016	der Gaast W., Hofman E., Ioannou A., Kafyeke T., Flamos A., Rinaldi R., Papadelis S., Hirschnitz-Garbers M.,	Belgium	Jornal	MDPI	Theoretical	Literature review	Circular Economy	294	Describes the barriers and enablers to implementing Circular economic principles in SME's.
BIM Implementation – Global Strategies	2014	Peter Smith	Australia	Journal	Procedia Engineering	Theoretical	Literature review	Digitalization	258	Highlighted importance of national and global BIM standards, legal protocols to address liability issues, BIM certification, education and training and articulating the business case for BIM implementation. No focus on SME's.
The digital transformation of innovation and entrepreneurship: Progress, challenges and key themes	2019	Satish Nambisan; Mike Wright; Maryann Feldman	USA	Journal	Research Policy	Theoretical	Literature review	Digitalization	242	Proposes digital technologies as having broader implications for value creation and value capture in organisational transfromation and scoial relationships than previously foreseen.
Adopting a platform approach in servitization: Leveraging the value of digitalization	2017	J.Cenamor; D.Rönnberg Sjödin; V.Parida	Sweden	Journal	International Journal of Production Economics	Theoretical	Case study	Digitalization	205	Focus on innovation in manufacturing firms.
Disruptive Innovation: An Intellectual History and Directions for Future Research	2018	Christensen, Clayton M ; McDonald, Rory ; Altman, Elizabeth J ; Palmer, Jonathan E	USA	Journal	Journal of management studies	Theoretical	Conceptual discussion	Construction Innovation	170	Proposes new areas for research in disruptive innovaiton related to; response strategies, performance trajectories, and innovation metrics.

With regards to methodology, both empirical (63 articles) and theoretical (68 articles) research methods were used among the researched articles, with case studies being the most popular research approach among the research methods (33 in total). Selected articles focusing on digitalisation (10) used literature review as their primary research approach. As for the CI articles, the most popular research approach was conceptual discussion (4) and case studies (4). For CE focused articles, data analysis (13) was the most used research approach, while for

DT articles, the most used approach was literature review (4). An overview of the preferred research approaches in the field can be seen in Figure 5:

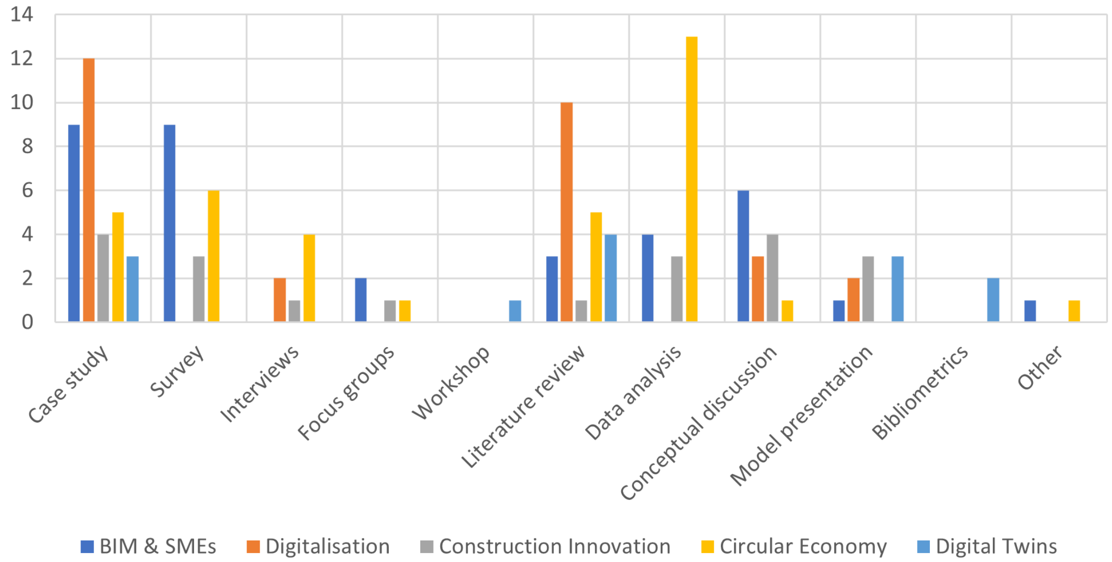

Figure 5 – Digitalisation and sustainability methodological approaches per area

The content analysis keywords and topics within the selected articles revealed content clusters that are common and relevant to multiple publications, as summarised in Table 6. Concerning BIM and SMEs articles, 15 articles were clustered around 'BIM implementation process or factors' , followed by eight publications primarily discussing 'barriers to BIM adoption for SMEs'. For digitalisation, 14 articles were clustered around 'implication of digitalisation', in which six articles emphasised that BIM is key to the digital transformation in the AEC industry. Concerning construction innovation articles, six articles were clustered according to 'construction innovation process or factors', followed by three publications introducing 'BIM-based innovation' in architectural companies and three 'bottom-up innovation that relates to low carbon design'.

Table 6 - Content clusters from publication content

Content Cluster	No. of publications	Examples from the literature
BIM & SMEs	**35**	
BIM implementation process or factors	15	Arayici, Y et al. (2011)
Barriers to BIM adoption for SMEs	8	Hosseini, M et al. (2016)
BIM applicability and performance	6	Makabate, C et al. (2021)
BIM readiness and future actions	6	Dainty, A et al. (2017)
Digitalisation	**29**	
Implication of digitalisation	14	Talamo and Bonanomi (2020)
Application of digitalisation	9	Tumbas, S et al. (2015)
Digitalisation readiness and future actions	4	Papadonikolaki, E et al. (2020)
Barriers of digitalisation (BIM-based)	2	Ghaffarianhoseini, A et al. (2017)
Construction innovation	**20**	
Construction innovation process or factors	6	Kale and Arditi (2010)
BIM-based innovation	3	Hartmann, T et al. (2012)
Bottom-up innovation and low-carbon	3	Fleiter, T et al. (2018)
Barriers to construction innovation	2	Aouad, G et al. (2010)
Innovation and sustainability	2	Halicioglu, F H (2020)
Motivation in construction innovation	2	Fang, C et al. (2016)
Evaluation of construction innovation	1	Davis, P et al. (2016)
Disruptive innovation	1	Christensen, C et al. (2018)
Circular Economy	**36**	
Enablers and barriers to Circular Economy in SMEs	10	Rizos V. et al. (2016)
Digital technologies to enable a Circular Economy in the construction industry	9	Charef R., Emmitt S. (2021)
Transition to a Circular Economy in SMEs	10	D'Amato D. (2020)
Transition to a Circular Economy in European SMEs	2	Chatzistamoulou N., Tyllianakis E. (2022)
Enablers and barriers to Circular Economy in the construction industry	2	Scipioni S. et al. (2021)
Bottom-up approach to implementing the concept of Circular Economy	1	Brendzel-Skowera K. (2021)
Other	2	
Digital Twins	**13**	
Current knowleadge and application of Digital Twins in the CI	10	Boje C. et al. (2020)
Potential of a Digital Twin-based approach for sustainable goals	3	Kaewunruen S. et al. (2019)

3.3 SOTA Discussion

The literature review highlights increased interest in BIM implementation in SMEs between 2007 and April 2021. While a publication by Arayici et al. (2011) remains the most relevant research concerning the keyword search terms, it is already a decade old, and new evidence to support its argument has not been produced. It is evident from the literature review that there is insufficient research attending to BIM implementation in Architectural SMEs and SMEs in the construction industry in general. A substantial amount of the literature discusses the implications and barriers to BIM implementation. , The key identified barriers include; 1) Cultural change required; 2) Resistance to change; 3) Lack of skill and in-house personnel; 4) Lack of training and education; 5) Lack of BIM implementation guidance; 6) Lack of new or amended forms of construction contracts. However, these studies do not differentiate between project type, discipline type, or the organisation's size. These results corroborate research from Ozorhon, et al. (2010; 2017), for they questioned how BIM implementation had been done concerning the unique factors which impact construction innovation. The research found that the construction industry is fragmented and project-based, with multiple stakeholders involved in collaborative activities. While it is also highlighted that differentiation between these specific characteristics must be considered when talking about construction innovation in the CI (Ozorhon, B.; Oral, K., 2017). When looking at the geographic location of the research concerning 'BIM and SMEs', the UK holds most publications, whereas within the EU, there were only 6 out of 35 'BIM and SMEs' publications deemed relevant to the research discussion. For construction innovation, this number is even lower within the EU, indicating that the scientific evidence of SMEs contributing to construction innovation within the EU is limited or not studied.

The content analysis showed that concerning digitalisation and BIM in SMEs, the preferred research method is case study and literature review. Concerning data collection, only a few used focus groups or interviews. This indicates that the existing research does not focus on discussions with SMEs to understand better the issues they experience.

In the content cluster analysis, existing research relating to the search term 'BIM and SMEs' focuses on BIM implementation processes and barriers, but not the SMEs themselves. This tendency is also recognised by Tezel et al. (2020), which highlighted that the SMEs are seen as a piece in a more extensive BIM implementation discussion and not a focus. This confirms the findings of Charef et al. (2019, p. 19), showing that BIM implementation struggles to be obtainable for most SMEs within the EU. In general, the relevance of the publications relating to SMEs is questionable and tends towards a discussion of implementation rather than the specificities of SMEs in the CI. This tendency is confirmed by research by Dainty et al. (2017), who highlighted the dichotomous relationship between BIM implementation in SMEs and BIM policy. In short, there appears to be a disconnect between BIM policy and SMEs.

3.4 State of the Evidence (SoE)

The Netherlands has positioned itself as a front runner to the CE by committing to transitioning since 2016. However, the most recent figures from the Dutch Circularity Gap Reporting Initiative (CGRI) label the Dutch economy as 24.5% circular. This means significant improvements are needed to achieve 2030 targets. Two areas that need further research specific to the Dutch construction industry are identified as (1) advanced construction practices (2) high-value recycling (CGRi, 2021). Table 7 below highlights how EU policy has impacted the Dutch construction industry. Standards from the EU have directly impacted the Dutch construction industry since it decided to transition to a CE in 2015.

Table 7 - SoE (State of the Evidence) findings EU Policy Grey Literature

		Policy Domain			
Grey Literature relating to EU policy on Digitalisation and Sustainability	Year	BIM & SMEs	Digitalisation	Construction Innovation	Circular Economy
CEN/TC 350 - Sustainability of construction works (Parent)	2004	x	x	x	x
CEN/TC 350/WG 1 - Environmental Performance of Buildings	2012	x	x	x	✓
EU Public Procurement Directives Revised	2014	x	✓	x	x

UN SDP's Sustainable Development Goals	2015	✓	✓	✓	✓
EN 15978:2011 - Sustainability of construction works - Assessment of environmental performance of buildings - Calculation method	2018	✓	✓	✓	✓
EU BIM Task Group	2016	✓	✓	x	x
CEN Technical Committee 442 on Building Information Modelling	2016	x	✓	x	✓
EU BIM Task Group Handbook	2018	✓	✓	x	x
A Europe fit for the Digital Age	2019	✓	✓	✓	✓
A European Green Deal	2019	✓	✓	✓	✓
CEN/TC 350/SC 1 - Circular economy in the construction sector (Subcommittee)	2021	x	✓	x	✓
The Energy Performance of Buildings Directive (EPBD) Revised	2021	✓	✓	✓	✓
European Industrial Strategy	2021	✓	✓	✓	✓
Digital Europe	2021	✓	✓	✓	✓

The Dutch Norms Agency (NEN) have produced a series of 'guides' for framework and definitions, measuring circularity and material passports. These have been developed directly as a result of committees set up by the EU to normalise information requirements on European construction projects. So the work of the CEN work committees becomes specific in the NEN norms within the Dutch construction industry. Table 8 highlights how EU policies are articulated in the Dutch construction industry.

Table 8 - SoE findings Dutch Policy Grey literature

		Policy Domain			
Grey Literature relating to Dutch policy on Digitalisation and Sustainability	Year	BIM & SMEs	Digitalisation	Construction Innovation	Circular Economy
VISI - Appointment system for the digital exchange of formal communication	2002	x	x	x	x
BIM Loket - Dutch Standards & Guidelines	2015	✓	✓	✓	✓
Circular Dutch economy by 2050	2016	✓	✓	x	x
Circular Economy Dutch Construction Industry Transition	2016	✓	✓	✓	✓
NTA 8035 - Semantic data modelling in the built environment.	2020	x	✓	x	✓
Circular Economy Implementation Programme	2021	x	x	✓	✓
BENG Calculations following Building Type in the Netherlands	2021	✓	✓	x	x
NEN 2660 - Modelling rules for information in the built environment – this standard is currently under development	2021	-	-	-	-
NTA 8800:2022 - NTA 8800 has been designated in the building regulations, and the new Energy	2022	✓	✓	✓	✓

Performance of Buildings System comes into effect.					
Quality Assurance Act for Construction	2022	✓	✓	x	x

The database search and exclusion process were as follows (Table 9).

Table 9 - Inclusion and Exclusion Criteria

Inclusion criteria	Exclusion criteria
EU related grey literature informing policy relating to the research domain.	Policy that does not primarily consider BIM and/or Digitalization and/or Innovation within construction SMEs.

Concerning the SoE, it was found that within the EU, Committees are responsible for setting legal requirements associated with Life Cycle Analysis (LCA). The requirements form the basis for assessing the sustainability of construction work. These ‘standardised’ assessments are linked to the United Nations (UN) sustainable development goals and directly related to the CE transition. A committee is a ‘parent’ to a series of ‘sub-committees’ and ‘work groups’. Sustainable value and the CE become explicit and tangible within this umbrella structure. Assessment methods are precise and calculating compliance is critical for lawmakers as compliance frameworks. Agreed standards inform legal obligations, which become contractual obligations. The establishment of obligations is guided by the need for a better quality of information that assists the CE's sustainability compliance and materials traceability.

BIM has been promoted as the medium of digitalisation for the construction industry. It is explicitly mentioned in the European procurement directives but only as an option. Considering EU policies, the shift towards “digitalisation” has been more pronounced since 2019. BIM is not an obligation from the EU perspective but is encouraged in standards, most notably the ISO 19650. The ISO 19650 are also the cornerstone of the approach undertaken by the EU BIM Task Group. The committees contribute to standardising structured semantic life-cycle information for the built environment. The aim of harmonising European standards is to counteract the fragmented nature of the construction industry and enable adoption throughout the construction industry, inclusive of SMEs. The group produced a handbook informing policy and strategy relating to BIM implementation in EU countries. SMEs are outlined as a challenge that needs to be addressed, particularly in digitalisation strategies.

3.4.1 Reflecting on European Policy

In the European Industrial Strategy (European Commission, 2021a), digitalisation and digital strategies are described as necessary for the transition to the CE. For example, the European Industrial Strategy (European Commission, 2021a) points to sustainability being obtained by digital technologies. It describes finding new solutions to sector-specific challenges through new public-private partnerships. It explains that digital solutions can lead to more flexible supply chains – stating that; ''It is now more evident than ever that companies pursuing sustainability and digitalisation are more likely to succeed than others. ''

The European Commission (European Commission, 2020d) promotes the potential of digital solutions to reduce CO_2 emissions and reduce resource use. Furthermore, the European Commission's roadmap (European Commission, 2021c, p. 6) states that Europe's future is determined by the achievement of the twin digital and green transitions. The top-down effort to address sustainability is evident in such policies. However, direct policy implementation is are not necessarily feasible for all types and sizes of organisations. Thus, fulfilling policy targets also requires bottom-up efforts, which has been under-investigated concerning BIM and CE.

Looking at the EU procurement directive (EU, 2014, p. 296), the benefit of BIM is recognised for public works contracts and design contests, linking BIM to digital communication and information exchange. However, the directive highlights that BIM must be generally available and interoperable with generally used ICT (Information and Communication Technology) products not to restrict access to the procurement procedure. However, there is a groundswell of evidence showing that neither availability nor interoperability are fully available and completely operational yet.

3.4.2 ‘Contradictions in relation to SMEs

The EU position concerning BIM implementation at SMEs seems to be contradictory. For example, while the EU Industrial Strategy (European Commission, 2021a, p. 14) recognises that SMEs needs to be kept in mind in all actions when it comes to innovation, it also mentions the regulatory burdens for SMEs without offering an alternative for such organisations. This lack of support has been already recognised. Furthermore, with 95% of the companies involved in construction projects in the EU being classified as SMEs, “the EU needs to provide leadership that supports these companies”. All in all, to date, the tension between the need for robust processes and workflows required for BIM implementation and the lack of guidance, support and leadership for implementation at SMEs has not been resolved (EU BIM Task Group, 2021).

If one looks at reports issued from the EU concerning the “Digitalisation in the construction sector” (European Commission, 2021b), one can see consistencies affecting the EU construction sector. These relate to the cost of equipment and software and, more importantly, the lack of a skilled workforce and awareness and understanding of digital technologies. These standards inform policy in member states and impact the ‘’artefacts’’ which can realise sustainable innovations within projects, such as the project information requirements. The current method of assessing the performance of buildings began as a directive in 2012. The most recent revision was released in 2021 and is related to the 2018 calculation method for the sustainability of construction works. Other sub-committees & workgroups relate to standardising the transition to the circular economy and standardising data templates to aid environmental assessments of BIM models .The European public procurements directive (2014) dictates trade terms and conditions through legal frameworks. BIM is only mentioned once within the framework (2014, p.94) as an option for construction projects. Digital Europe is a trade organisation charged with leading the digitalisation of the EU. Their Digital Europe programme explicitly promotes BIM (p.2) for public procurement purposes. They also advocate the implementation of European frameworks and standards for digitalisation and the creation of Digital Twins.

3.4.3 The Dutch Construction Industry

The Dutch construction industry becomes essential as it transitions to the CE, more specifically in the construction sector, which produces most of the waste within the country. The revised circular implementation plan (EU, 2021) identifies areas such as pre-fabrication and renewable materials as possible means to address the continued transition to alternative means of creating sustainable value. The BIM Loket (2015) was instigated to create a shared resource from which to digitalise the Dutch Construction industry. By operationalising EU standards and using Open BIM, the BIM Loket aims to facilitate a more sustainable and circular built environment.

They provide a series of BIM Execution plans, protocols and Information delivery plans which act as guidelines to multiple disciplines within the Netherlands. The BIM Loket is an independent, non-profit foundation informed by a diverse group of industry professionals. The information delivery specifications define the exchange requirements of model-based exchange on BIM-based construction projects.

4 FINAL REMARKS

The SOTA and SoE have contextualised the research literature. The SOTA highlights a lack of research relating to SAPs in the European construction industry. An emergent body of work is attending to these issues, but information relating to the discipline of architecture & SAPs and their transition remains scarce. The relationship between the research keywords forming part of stage 1 of the SLR confirms this. The research keywords from the second stage highlighted an emergent body of research that better encompasses the operational environment of SAPs and their innovation capacity concerning the transition to a Circular Economy. However, a focus on BIM, SMEs, the Circular Economy, and digital twins are also scarce.

The literature anticipates the need for research attending to SMEs as part of the most recent EU policy for the construction industry but presents few case studies and does not attend to the convergence of the research keywords. The SoE confirms that European Policy has identified BIM as the means to digitalise the construction industry and the impediments to SMEs' implementation of these policies. The importance of SMEs has been acknowledged in digital policy for the European construction industry to achieve its objective of carbon neutrality by

2050. The evidence acknowledges the need for ethnographic and case study research to supplement existing policies. Also, a focus on project and discipline-based implementation of innovations such as BIM need further attention.

A focus on innovation within Dutch SAPs would be highly beneficial for supplementing research being undertaken on EU digitalisation. The Dutch market and its implementation of Circular policies within the construction industry and high level of BIM maturity becomes a valuable example for other European member states and global partners. This research would also benefit European policymakers in understanding SAPs and their innovation capacity, enabling more effective guidelines to be produced, particularly for the digital transition to the Circular Economy. What is clear is that the implementation of BIM in SMEs relates to complex operational environments in which the multi-faceted nature of projects challenge the conventions associated with standards propagated by EU based policymakers. An innovation-based realisation framework, predicated on the EU BIM Performance levels (EU BIM Task Group, 2019), would benefit the discourse relating to BIM implementation and its value for achieving sustainable value on construction projects.

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5 REFERENCES

A. Azzouz, P. Hill, and E. Papadonikolaki (2018) 'Gorse, C and Neilson, C J (Eds) Proceeding of the 34th Annual ARCOM Conference, 3-5 September 2018, Association of Researchers in Construction Management', pp. 240–249.

Abbasnejad, B., Nepal, M. P., Ahankoob, A., Nasirian, A., & Drogemuller, R. (2021) 'Building Information Modelling (BIM) adoption and implementation enablers in AEC firms: a systematic literature review', Architectural Engineering and Design Management, 17(5-6), pp. 411-433.

ACE (2020) The architectural profession in Europe 2020 – ACE sector study. Available at: https://www.ace-cae.eu/activities/publications/ace-2020-sector-study/ (Accessed: 02-03-2022)

Arayici, Y. et al. (2011) 'Technology adoption in the BIM implementation for lean architectural practice', Automation in Construction, 20(2), pp. 189–195. doi: 10.1016/j.autcon.2010.09.016.

B. Kitchenham, O. Pearl Brereton, D. Budgen, M. Turner, J. Bailey, and S. Linkman (2009) 'Systematic literature reviews in software engineering - A systematic literature review', Information and Software Technology, 51(1), pp. 7–15.

BIM Loket (2015) –'BIM Loket' Available at: https://www.bimloket.nl/main.php (Accessed: 02-03-2022)

BNA (2019) 'Architect 2030: Act now'. Available at: https://www.sfa-architecten.nl/wp-content/uploads/2019/04/BNA_ARCHITECT_2030_ACT_NOW.pdf (Accessed: 02-03-2022)

Bos-de Vos, M., Volker, L., & Wamelink, H. (2019) 'Enhancing value capture by managing risks of value slippage in and across projects', International Journal of Project Management, 37(5), pp. 767-783.

Bos-de Vos, M., Wamelink, J. H., & Volker, L. (2016) 'Trade-offs in the value capture of architectural firms: the significance of professional value', Construction management and economics, 34(1), pp. 21-34.

BSI (2019) 'Introducing the new international standard for BIM, ISO 19650'. Available at: https://www.bsigroup.com/globalassets/localfiles/en-gb/built-environment/bsi-bim-iso-19650-brochure-final022019.pdf (Accessed: 02-03-2022)

buildingSMART (2021) Machine readable Information Delivery Specification. Available at: https://technical.buildingsmart.org/projects/information-delivery-specification-ids/ (Accessed: 02-03-2022)

Çetin, S., De Wolf, C., & Bocken, N. (2021) 'Circular digital built environment: An emerging framework', Sustainability, 13(11), p. 6348.

Charef, R., & Emmitt, S. (2021) 'Uses of building information modelling for overcoming barriers to a circular economy', Journal of cleaner production, 285, p. 124854.

Codinhoto, R., Becher, O., Heron, J. N., & Donato, V. (2021) 'BIM Bin: Waste Management Through BIM and Digital Twin', Handbook of Research on Developing Smart Cities Based on Digital Twins, pp. 265-294.

COM103 (2020) COM/2020/103 final. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1593507563224&uri=CELEX:52020DC0103 (Accessed: 02-03-2022)

D. Tranfield, D. Denyer, and P. Smart (2003) 'Towards a Methodology for Developing Evidence-Informed Management Knowledge by Means of Systematic Review', British Journal of Management, 14(3), pp. 207-222.

Dainty, A., Leiringer, R., Fernie, S., & Harty, C. (2017) 'BIM and the small construction firm: a critical perspective', Building research & information, 45(6), pp. 696-709.

Denyer, D., and Tranfield, D. (2009) Producing a systematic review. In The Sage handbook of organizational research methods. Edited by D.A. Buchanan and A. Bryman. Sage Publications, Thousand Oaks, CA. pp. 671–689.

Digital Europe (2020) 'Digital building transformations for Europe's green renovations: Sustainable living and working'. Available at: https://www.digitaleurope.org/resources/digital-building-transformations-for-europes-green-renovations-sustainable-living-and-working/#_ftn5 (Accessed: 02-03-2022)

Elmualim, A., & Gilder, J. (2014) 'BIM: innovation in design management, influence and challenges of implementation', Architectural Engineering and design management, 10(3-4), pp. 183-199.

EU (2014) Directive 2014/25/EU of the European Parliament and of the Counci. On procurement by entities operating in the water, energy, transport and postal services sectors and repealing Directive 2004/17/EC. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32014L0025 (Accessed: 07-01-2022)

EU (2019a) Supporting digitalisation of the construction sector and SMEs. Available at: https://ec.europa.eu/docsroom/documents/38281 (Accessed: 02-03-2022)

EU (2020b) A European Green Deal. Available at: https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en (Accessed: 02-03-2022)

EU (2020c) Renovation Wave: doubling the renovation rate to cut emissions, boost recovery and reduce energy poverty. Available at: https://ec.europa.eu/commission/presscorner/detail/en/IP_20_1835 (Accessed: 02-03-2022)

EU (2020d) 'Shaping the digital transformation in Europe'. Available at: https://op.europa.eu/en/publication-detail/-/publication/917c520f-fd56-11ea-b44f-01aa75ed71a1 (Accessed: 07-01-2022)

EU (2021) 'Çircular Economy Action Plan' Available at: https://ec.europa.eu/environment/strategy/circular-economy-action-plan_nl (Accessed: 07-01-2022)

EU BIM Task Group (2018a) EU BIM. Available at: http://www.eubim.eu/ (Accessed: 14-12-2021)

EU BIM Task Group (2018b) About the EU BIM Task Group. Available at: http://www.eubim.eu/about-the-eu-bim-task-group/ (Accessed: 14-12-2021)

EU BIM Task Group (2019) 'Handbook for the introduction of Building Information Modelling by the European Public Sector'. Available at: http://www.eubim.eu/handbook-selection/ (Accessed: 07-01-2022)

EU Factsheet (2021) Netherlands. Available at: https://ec.europa.eu/energy/sites/default/files/documents/nether.pdf (Accessed: 02-03-2022)

European Commission (2021a) European Industrial Strategy. Available at: https://ec.europa.eu/info/strategy/priorities-2019-2024/europe-fit-digital-age/european-industrial-strategy_en (Accessed: 07-01-2022)

European Commission (2021b) European Construction Sector Observatory - Analytical Report - Digitalisation in the construction sector. Available at: https://ec.europa.eu/docsroom/documents/45547?locale=en (Accessed: 06-01-2022)

European Commission (2021c) 'Roadmap'. Available at: https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12900-Europe-s-digital-decade-2030-digital-targets_en (Accessed: 07-01-2022)

European Commission (2021d) 'Europe's Digital Decade: EU digital principles'. Available at: https://ec.europa.eu/commission/presscorner/detail/en/ip_21_2288 (Accessed: 08-03-2022)

Gov.nl (2021) Taking measures to save energy. Available at: https://business.gov.nl/regulation/taking-measures-to-save-energy/ (Accessed: 02-03-2022)

Holt, G. D., & Goulding, J. S. (2014) 'Conceptualisation of ambiguous-mixed-methods within building and construction research', Journal of Engineering, Design and Technology.

Hossain, M. U., Ng, S. T., Antwi-Afari, P., & Amor, B. (2020) 'Circular economy and the construction industry: Existing trends, challenges and prospective framework for sustainable construction', Renewable and Sustainable Energy Reviews, 130, p. 109948.

IET (2020) 'Digitisation for construction product manufacturers: a plain language guide'. Available at: https://www.theiet.org/media/8843/digitisation-for-construction-product-manufacturers-main-guide.pdf (Accessed: 02-03-2022)

ISO (2020a) ISO/FDIS 12006-3 - Building construction - Organization of information about construction works - Part 3: Framework for object-oriented information

ISO (2020b) ISO 23386:2020 - Building information modelling and other digital processes used in construction - Methodology to describe, author and maintain properties in interconnected data dictionaries

Lecy, J. D., & Beatty, K. E. (2012) Representative literature reviews using constrained snowball sampling and citation network analysis. Available at SSRN 1992601.

Liu, H., Skibniewski, M. J., Ju, Q., Li, J., & Jiang, H. (2020) 'BIM-enabled construction innovation through collaboration: a mixed-methods systematic review', Engineering, Construction and Architectural Management.

Liu, S., Bao, J., Lu, Y., Li, J., Lu, S., & Sun, X. (2021) 'Digital twin modeling method based on biomimicry for machining aerospace components', Journal of manufacturing systems, 58, pp. 180-195.

Mahood, Q., Van Eerd, D., & Irvin, E. (2014) 'Searching for grey literature for systematic reviews: challenges and benefits', Research synthesis methods, 5(3), pp. 221-234.

Makabate, C. T., Musonda, I., Okoro, C. S., & Chileshe, N. (2021) 'Scientometric analysis of BIM adoption by SMEs in the architecture, construction and engineering sector', Engineering, Construction and Architectural Management.

Mêda, P., Calvetti, D., Hjelseth, E., & Sousa, H. (2021) 'Incremental Digital Twin Conceptualisations Targeting Data-Driven Circular Construction', Buildings, 11(11), p. 554.

Miettinen, R., & Paavola, S. (2014) 'Beyond the BIM utopia: Approaches to the development and implementation of building information modeling', Automation in construction, 43, pp. 84-91.

Naderifar, M., Goli, H., & Ghaljaie, F. (2017) 'Snowball sampling: A purposeful method of sampling in qualitative research', Strides in Development of Medical Education, 14(3).

Norouzi, M., Chafer, M., Cabeza, L. F., Jiménez, L., & Boer, D. (2021) 'Circular economy in the building and construction sector: A scientific evolution analysis', Journal of Building Engineering, 44, p. 102704.

Ozorhon, B. et al. (2010) ‘Innovation in Construction: A Project Life Cycle Approach’, SCRI Research Report 4.

Özorhon, B., & Karaciğan, A. (2019), ‘Drivers of BIM Implementation in a High Rise Building Project’, Eurasian BIM Forum, pp. 28-39.

Ozorhon, B., & Oral, K. (2017) 'Drivers of innovation in construction projects', Journal of construction engineering and management, 143(4), p. 04016118.

Papadonikolaki, E. (2018) 'Loosely coupled systems of innovation: Aligning BIM adoption with implementation in Dutch construction', Journal of management in engineering, 34(6).

Purvis, B., Mao, Y., & Robinson, D. (2019) 'Three pillars of sustainability: in search of conceptual origins', Sustainability science, 14(3), pp. 681-695.

RVIM (2016) 'Circular economy in the Dutch construction sector' Available at: https://rivm.openrepository.com/handle/10029/595297 (Accessed: 07-03-2022)

RVO (2021) Innovation fund. Available at: https://english.rvo.nl/subsidies-programmes/innovation-fund (Accessed: 07-03-2022)

Sacks, R., Brilakis, I., Pikas, E., Xie, H. S., & Girolami, M. (2020) 'Construction with digital twin information systems', Data-Centric Engineering, 1.

Saka, A. B., & Chan, D. W. (2021) 'BIM divide: an international comparative analysis of perceived barriers to implementation of BIM in the construction industry', Journal of Engineering, Design and Technology.

Savini, F. (2021) 'The circular economy of waste: recovery, incineration and urban reuse', Journal of Environmental Planning and Management, 64(12), pp. 2114-2132.

Shirowzhan, S., Sepasgozar, S. M., Edwards, D. J., Li, H., & Wang, C. (2020) 'BIM compatibility and its differentiation with interoperability challenges as an innovation factor', Automation in Construction, 112, p. 103086.

Siebelink, S., Voordijk, J. T., & Adriaanse, A. (2018) 'Developing and testing a tool to evaluate BIM maturity: Sectoral analysis in the Dutch construction industry', Journal of construction engineering and management, 144(8), p. 05018007.

Sriyolja, Z., Harwin, N., & Yahya, K. (2021) 'Barriers to Implement Building Information Modeling (BIM) in Construction Industry: A Critical Review', IOP Conference Series: Earth and Environmental Science, 738(1), p. 012021.

Tezel, A., Taggart, M., Koskela, L., Tzortzopoulos, P., Hanahoe, J., & Kelly, M. (2020) 'Lean construction and BIM in small and medium-sized enterprises (SMEs) in construction: a systematic literature review', Canadian Journal of Civil Engineering, 47(2), pp. 186-201.

UKBF (2019) ‘Information management according to BS EN ISO 19650 - Guidance Part 2: Processes for Project Delivery’, UK BIM Alliance. Available at: https://www.ukbimalliance.org/stories/information-management-according-to-bs-en-iso-19650/ (Accessed: 02-02-2022)

van Leeuwen, K., de Vries, E., Koop, S., & Roest, K. (2018) 'The energy & raw materials factory: role and potential contribution to the circular economy of the Netherlands', Environmental management, 61(5), pp. 786-795.

Wang, J., & Lu, W. (2021) 'A deployment framework for BIM localization', Engineering, Construction and Architectural Management.