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AN INVESTIGATION OF CONCEPTS FOR THE SPECIFICATION OF GRAPHICAL EXCHANGE INFORMATION REQUIREMENTS IN BUILDING INFORMATION MODELLING

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SUMMARY: *Previous studies have investigated frameworks for the specification of Exchange Information Requirements (EIRs). So far, these efforts have concentrated on the specification of non-geometrical data. Graphical information specification is often carried out through the application of subjective criteria. Moreover, the definition of variables used in existing specification frameworks has acquired various meanings among practitioners and organisations. To address this gap, this study's aim is to identify and analyse the concepts that influence the specification of the graphical data in BIM-enabled projects. The BIM literature tends to consider problems from a technological standpoint. The current dichotomy in the BIM body of knowledge demands research that account for the context of industry practices and organisations in which the specification of graphical data is performed. To address its aim, this study adopts a qualitative strategy, employing a cross-sectional design and a grounded theory approach for data collection and analysis. The iterative nature of the grounded theory approach, particularly of its theoretical sampling feature, was addressed by dividing data collection and analysis into two stages. In exploring the concepts that define the specification of graphical data in EIRs, six main themes were identified: model use, project stage, project actors, processes and objects definitions, graphical granularity, and model attribute. Moreover, the findings support the suggestion that contextual factors play a role in the implementation of these variables and associated processes. There is a suggestion that practices at the industry and organisational context level, such as the existence of mandates, could be influencing the way practitioners specify information. These results can be employed to extend the understanding of the considerations made in the definition of graphical information in EIRs documentation. Moreover, this work could inform the activity of practitioners and the development of new technologies focused on the automation of information specification.*

KEYWORDS: *Building information modelling (BIM), Exchange Information Requirements (EIR), Level of development (LOD), Level of Information (LOI), Level of Information Need, Graphical information*

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1. INTRODUCTION

The implementation of BIM technologies and related information management processes are believed to bring benefits to projects in terms of time, quality and budget (Sacks et al., 2018; Franz and Messner, 2019). These benefits materialise, for instance, through the automation of tasks such as code compliance checking (Zhang et al., 2013; Tan et al., 2010) and the modelling of existing conditions (Xiong et al., 2013). Similarly, in the context of briefing for design and construction, various initiatives have investigated the specification of exchange information requirements (EIRs) and the potential enhancement of this activity in BIM-enabled projects (Hooper, 2015; Lee et al., 2016a). However, despite the suggested benefits and the constant development of new functionalities, BIM has not yet reached its full potential across the industry (Lindblad, 2019; Zomer et al., 2020). This also holds true for the specification of EIRs in BIM-enabled projects. Practitioners still have to adopt a unique and consistent approach for carrying out this task (Bolpagni and Ciribini, 2016), despite ongoing development of specification frameworks and technology which supposedly increases the feasibility of doing so (e.g. Liebich, 2010; NBS, 2020).

Previous studies have investigated alternative frameworks for the specification of EIRs (e.g.. Fai and Rafeiro; 2014; Carrato and Wilson, 2016; Abou-Ibrahim and Hamzeh, 2016; Abualdenien and Borrmann, 2019; Uusitalo et al., 2019). So far, these efforts have concentrated on the specification of non-geometrical data. Graphical information specification is still carried out for the most part through the application of subjective criteria (Hooper, 2015; Treldal et al., 2016; Abualdenien and Borrmann, 2020a).

Studies on BIM implementation indicate that contextual factors play a role in the adoption of technology and processes such as the ones proposed for the specification of EIRs (Poirier et al., 2015; Zomer et al., 2020). However, most BIM literature tends to consider problems from a technological standpoint, giving only anecdotal evidence of contextual factors (Santos et al., 2017; Oraee et al., 2017). The current dichotomy in the BIM body of knowledge demands research that includes a contextual perspective in the investigation. This study makes use of a cross-sectional design in order to integrate technical and contextual aspects of BIM. This study's aim is to gain an insight into the variables used to define the graphical data that should be inserted in information models when practitioners are defining EIRs for the project.

2. BACKGROUND

This section gives some background on the historical development of frameworks for the specification of EIRs, highlighting some of the strengths and flaws of the different approaches studied by extant literature. Tools and processes have evolved to make specification of EIRs more seamless. However, the specification of graphical information remains a manual, labour-intensive task (Hooper, 2015; Treldal et al., 2016; Abualdenien and Borrmann, 2020a).

2.1 Existing frameworks for the specification of EIRs

From a historical development standpoint, the stages of development of frameworks for the specification of EIRs can be appraised through the wedge diagram created by Bew and Richards (BSI, 2013). The development of tools and processes used to manage information in construction projects, specifically, the process of defining EIRs, could be mapped to the stages depicted in the diagram. The diagram is composed of four BIM levels referring to production, delivery of data and their related process management. Although the concept was updated in ISO 19650-1 (BSI, 2019), the goal remains the same: to reach a level of interoperability and process management that enables seamless information exchange, where the right data is given to the right people at the right time (BSI, 2019). The following is a review of the development of methods for the specification of EIRs.

2.1.1 Specification of EIRs in BIM Levels 0 and 1

New information technologies such as the advent of CAD tools addressed the issues stemming from paper-based processes, which made the coordination of information impractical in large-sale projects (Sacks et al., 2018). The continued development of these systems has allowed for information about buildings and civil engineering works to be incremented with increasingly richer data (e.g. 3D representations, associated descriptions). As technology matured, BIM tools have been developed, responding to users' increasing need to integrate and share building data.

In a BIM environment, graphical and data attributes can be attached to representations of building objects and elements that have parametric functionalities. This facilitates data analysis such as quantity take-off and energy consumption analysis, enabling various uses for a model. In this context, specialists perform model development and analysis on the requested pieces of information (Hadzaman et al., 2016; Cavka et al., 2017). On the other hand, for these benefits to materialise, stakeholders need to improve the way they communicate their information requirements, including graphical requirements.

In BIM Levels 0 and 1, the need to communicate information requirements is addressed by the implementation of unsystematic paper-based processes. However, a structure for information exchange might not exist altogether (Abou-Ibrahim and Hamzeh, 2016; Grytting et al., 2017; Uusitalo et al., 2019). These paper-based processes generally do not efficiently assist stakeholders in communicating EIRs. For instance, practitioners report that an unsystematic approach to the specification of EIRs leads to a mismatch between the amount of data carried by digital models and the use made of this data (Fai and Rafeiro, 2014).

2.1.2 Specification of EIRs in BIM Level 2

As BIM functionalities enable multiple uses, information could be used for tasks that were not anticipated by the model's authors (Bedrick, 2008). To address this issue, various initiatives around the world started to develop frameworks for classifying the quality and suitability of information in BIM-enabled projects (e.g. AIA, 2008; BIPS, 2006). The first document formalising a framework of this kind was published by the American Institute of Architects (AIA, 2008), officially introducing the use of the term Level of Development (LOD). The specification documents supported by this framework give element-specific definitions of EIRs as well as intended model uses.

Extant literature also identifies challenges with the use of LOD categories for the specification of graphical EIRs. For example, while these frameworks allow for a more precise specification of information requirements, they do not eliminate the necessity for practitioners to interact with complex, labour-intensive tables (Hooper, 2015; Abualdenien and Borrmann, 2018). Some studies question the efficacy of LOD definitions in improving the communication of EIRs as LOD definitions lack the granularity necessary to specify information in different scenarios (Hooper, 2015; Abou-Ibrahim and Hamzeh, 2016). In light of this, many studies focus on proposing new frameworks with alternative measurements (e.g. Fai and Rafeiro, 2014; Hooper, 2015; Abou-Ibrahim and Hamzeh, 2016). However, the proliferation of frameworks across different organisations and countries could cause practitioners to attribute different LOD values to the same set of data (Bolpagni and Ciribini, 2016; Hadzaman et al., 2016; Treldal et al., 2016). A correlated issue is the ambiguity with which LOD specifications can be interpreted (Tolmer et al., 2017; Nøklebye et al., 2018).

As the specification of graphical EIRs becomes an increasingly labour-intensive and complex process, it becomes less accessible for non-specialists (Gigante-Barrera et al., 2017). In fact, a subsequent process of this activity is checking whether the requirements have been met by the stakeholders issuing the information. Because LOD specifications are written in natural language, that is, language that is not directly interpretable by computers, these requirements are usually carried out manually by BIM experts (Nøklebye et al., 2018). To reduce the risk associated with the process, practitioners resort to the overspecification of information requirements (Hooper, 2015). This is concerning as considerable effort is put into upgrading models in order to increase their LODs (Leite et al., 2011). Moreover, unnecessary data can hinder the effective use of models at later stages (Dias and Ergan, 2016). From a lean management perspective, it is argued that it is a waste of resources to spend hours developing the model in too much detail ahead of the actual demand (Uusitalo et al., 2019, p. 3).

2.1.3 Specification of EIRs in BIM Level 3

Other methodologies support the specification of graphical EIRs. The Information Delivery Manuals (IDM) change the focus from object-oriented definitions to a process-oriented definition of information requirements. Moreover, there is a greater focus on defining a standardised, machine-readable, and transferrable language for information requirements using international standards. IDM approaches are displayed in stage 3 of the BIM wedge (BSI, 2013) and usually promote the specification and checking of information requirements on digitised systems instead of the manual paper-based approaches associated with LOD. The IDM methodology is detailed in ISO 29481:2016 (BSI 2016) and defines how to detail the information that is to be exchanged at a specific stage of the project (Jeon and Lee, 2018, p. 2).

The validity of LOD measurements for the specification of graphical EIRs has received considerable criticism in literature. Risks to the project are introduced and the possibility of automating validation processes are narrowed as EIRs documents employing LOD frameworks are often written in plain language, using non-standardised terms (Hooper, 2015; Abualdenien and Borrmann, 2018). The IDM approach is supported by standards such as Business Process Modelling Notation (BPMN) for process mapping, and IFC for data structuring. This is expected to improve communication of EIRs between stakeholders (Wix and Karlshøj, 2010) and make the automation of information specification and the associated verification feasible. Along these lines, recent studies (e.g. Lee et al., 2016a; Abualdenien and Borrmann, 2019) suggested that the Model View Definitions generated as a product of the IDM process could be used for both specifying and checking the validity of an exchange of information, addressing some of the challenges inherent to the use of LOD measurements for the specification of graphical EIRs.

Despite its apparent strengths, the use of IDM by industry is still limited. From an end-user perspective Krijnen and Van Berlo (2016) point out limitations to this approach, suggesting that IFC allows users to misclassify elements, or classify them in broad terms, making automated rule checking difficult. The authors indicate that most authoring tools do not fully support IFC exporting functionalities or lack the capability for MVD specification. Moreover, literature identifies some gaps during transitions between IDM stages. Namely, there are no established standards on how processes are translated into use cases and then in MVDs (Jeon and Lee, 2018; Mondrup et al., 2014).

2.2 Contextual factors in BIM implementation

The AEC is considered by recent literature to be a complex environment for innovation implementation (Sackey et al. 2015). Moreover, contextual factors play a role in how technology implementation is shaped (Shibeika and Harty 2015; Jacobsson et al. 2017; Dowsett and Harty 2019). BIM is seen as a disruptive technology that requires the redefinition of processes, tasks and roles in order to achieve its full potential (Poirier et al., 2015; Zomer et al., 2020). However, typically little regard is given to how these technologies and processes will interact with the existing contexts. In academia, for example, despite acknowledging that contextual factors play a role in innovation implementation, most scholarly works investigating BIM have explored the implementation of new technologies and processes from a prescriptive standpoint (Santos et al., 2017). On the institutional side (e.g. government mandates), there is a belief in the efficacy of deterministic transformational agendas (Dainty et al., 2017). Overall, there is an assumption that the recommendations made will be readily accepted due to the benefits that new technologies can bring (Dowsett and Harty 2019). Therefore, it is worth analysing how contextual factors interact with the innovation enactment process.

Previous case studies targeting contextual factors employed different theoretical lenses in order to examine how BIM has impacted project delivery. Sackey et al. (2015) adopt a sociotechnical systems (STS) perspective. The authors analyse how the process of implementation was framed by the interaction of the elements that compose the sociotechnical system (task, actor, structure, technology). Gledson (2016) employs the innovation-diffusion process as described by Rogers (2003) in order to formulate his research questions. Different approaches emerge depending on whether the study has a qualitative or quantitative design. Poirier et al. (2015), for example, draw the contextual factors influencing BIM implementation from a mixed-method research.

Poirier's contextual framework is particularly well-suited to the analysis made in this study because it takes into account a number of contextual dimensions. Namely, Poirier’s contexts are: (1) the industry context; (2) the institutional context; (3) the organisational context; and (4) the project context. Poirier's categories have been successfully employed in previous studies. In Zomer (2020), for example, the contextual factors allow the classification of observed patterns in a qualitative study. Even when not directly referenced by other authors, the categories Poirier proposes can often be associated with the conceptualisation categories devised in other studies (e.g. Jacobsson et al., 2017). This is exemplified in Fig. 1, which maps out Porier’s et al. (2015) to Succar’s (2009) interlocking field of BIM activity. Moreover, in comparison to theoretical frameworks such as activity theory, Poirier's categories seem more adequate to the nature of this analysis. This is because, as opposed to the aforementioned studies, the focus here is not on unveiling new categories of contextual factors, but on enriching the investigation by considering a framework of contextual factors.

Therefore, the inclusion of the contextual dimension in this investigation is a way to acknowledge the latest developments in BIM literature, which challenges the perception of innovation enactment as a linear process. By including contextual factors in the analysis, the study covers the influence of socio-historical constructs on the implementation of new processes, breaking with the prescriptive technology-oriented tone of earlier investigations.

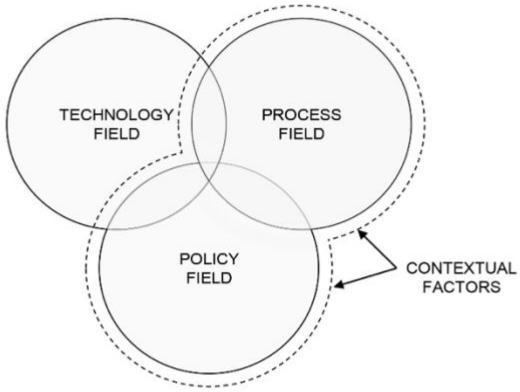

FIG. 1: Situating contextual factors in Succar's (2009) interlocking fields of BIM activity

In order to respond to the demands of an approach that covers the technological aspects of information specification and their interaction with contextual factors, a qualitative strategy was adopted. Another factor influencing the adoption of a qualitative approach is the difficulty in establishing an adequate sampling framework for a quantitative approach in the initial stage of the research. This is because literature shows that the concepts employed for specifying graphical EIRs vary across practices (Hooper, 2015; Treldal et al., 2016).

Moreover, rather than exploring the historical development of specification processes, the focus in this study is to explore the variables employed in the definition of graphical information requirements in current practice. Employing a cross-sectional design allows for the collection and analysis of current processes described in information specification frameworks and used by a number of practitioners which, in turn, grants access to patterns of association between concepts (Bryman, 2012, p. 59). Supported by these principles, the investigation on the graphical-related variables used to specify EIRs can be explored as follows.

3. METHODOLOGY

A grounded theory approach was devised for data collection and analysis. The impossibility of defining a clear sampling frame at this stage played a role in the choice of this approach. At initial stage of the research, the variables used to define graphical information requirements were still unclear. Therefore, it was unfeasible to define a sampling frame of practitioners as the questions were still too general. The grounded theory approach allowed for an iterative process to be established, where questions could be progressively structured (Bryman, 2012) until a point where a sampling frame with practitioners could be defined. The collection of data from practitioners was particularly relevant as one of the goals of the study is to include the analysis of contextual factors in the application of information specification processes. The iterative nature of the grounded theory approach, particularly of its theoretical sampling feature (Charmaz, 2006), has been addressed by dividing data collection and analysis into two stages.

The first stage comprised a narrative literature review in which scientific publications, publicly available documentation and industry standards were selected and analysed based on their relevance to the research questions (Hammersley, 2001), namely, the discovery of different variables and frameworks used in the specification of EIRs. As literature has consistently explored various approaches for the specification of information in BIM-enabled projects, this allowed for the comparison of frameworks, the identification and analysis of concepts used in the specification process, and the narrowing of the study's focus.

The concepts collected in the initial stage of investigation were used to structure a discussion with practitioners. In Stage 2, the participants were invited to give their views on the concepts collected during the literature review. However, it was important that participants could be free to contribute with new concepts and variables they found to be relevant to the specification of graphical EIRs. This was accomplished through the application of a questionnaire. The data collection tool was designed to capture the emergence of new concepts, to further refine the variables revealed in the first stage, and to evaluate their interaction with contextual factors. Fig. 2 displays a summary of the methodology employed in this study. The following is a detailed description of the two stages.

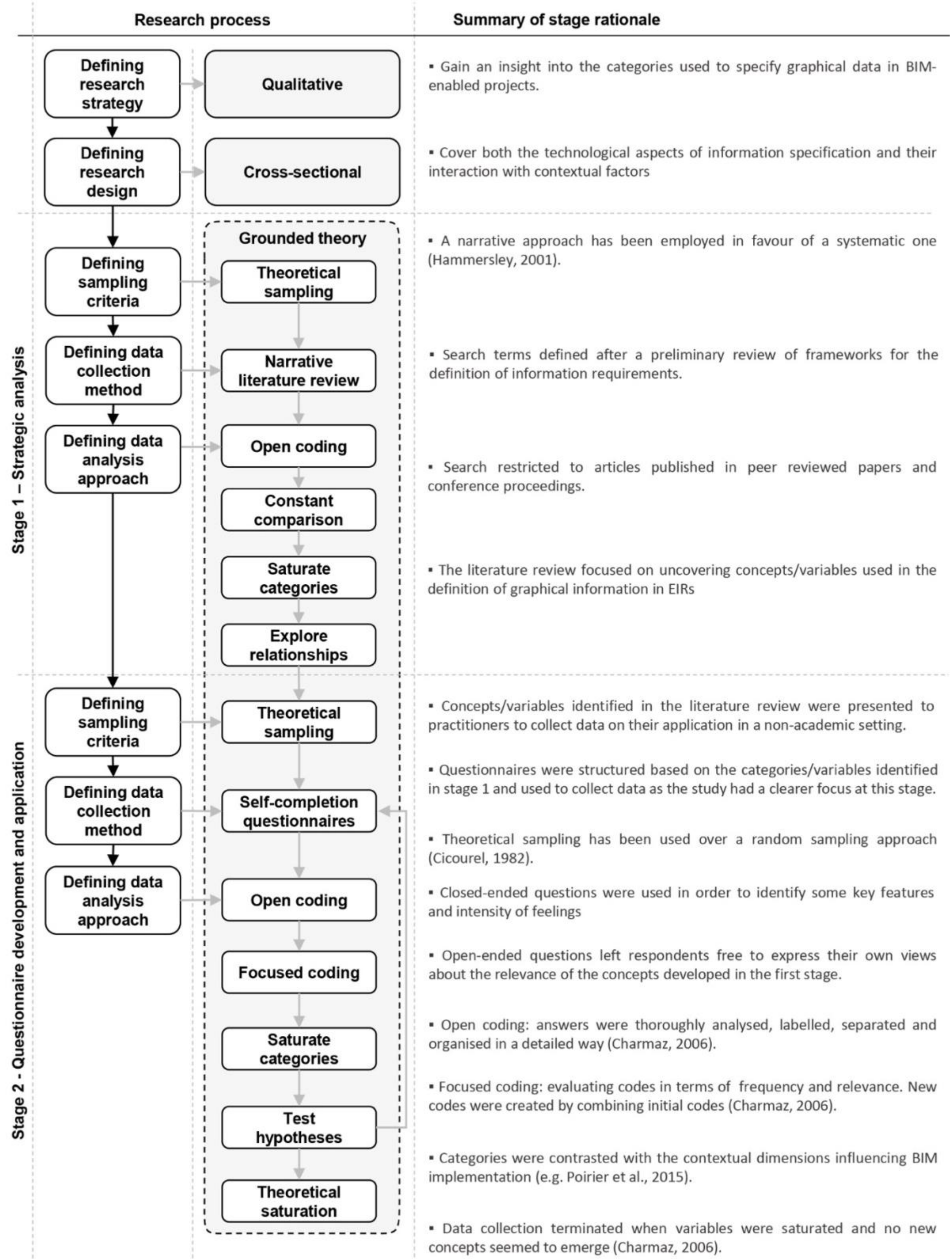

FIG. 2: Research methodology.

3.1 Stage 1 – Strategic analysis

In order to better delineate research questions, methodological approaches such as 'design research' recommend research for an initial investigation of solutions to be carried out within social settings relevant to the research (Hevner and Chatterjee, 2010). However, in the case of the investigation into the variables for the specification of information requirements it is difficult to establish an appropriate sampling framework. Employing this approach, for example, would require most specialists to make use of a particular concept (e.g. LOD definitions) in their practices or for them to use these concepts in the same standard way. However, as suggested by literature, LOD and IDM uses vary across practices (Hooper, 2015; Treldal et al., 2016). In fact, practitioners find it difficult to define to which level a model was developed when presented with an example (Berlo and Bomhof, 2014). Moreover, nothing guarantees that specialists have familiarity with these concepts at all. Therefore, collecting data on the variables that influence the specification of EIRs directly from practitioners could be problematic in the first stage of the research.

On the other hand, literature has consistently explored a number of approaches for the specification of EIRs. Although the body of knowledge on the topic has never been portrayed in a systematic way, a preliminary search revealed various scholarly works offering insights into the strengths and weaknesses of different methods. In a similar way to previous works (e.g. Fai and Rafeiro, 2014; Trani et al., 2015; Gigante-Barrera et al., 2017; Abualdenien and Borrmann, 2019; Uusitalo et al., 2019), the first stage in this study adopted a deductive approach, comprising the revision of literature on the different existing methods for the specification of EIRs in BIM enabled projects. The review focused on uncovering concepts employed in the definition of graphical information in EIRs as well as the development and issues of different approaches. The search was conducted on Scopus database, the platform with the largest collection of articles in the field (Chadegani et al., 2013). The terms searched were defined after a preliminary review of frameworks for the definition of information requirements (AIA, 2008; BIM Forum, 2020; BSI, 2013; BSI, 2019; BSI, 2020). The search was restricted to articles published in peer reviewed papers and conference proceedings, in order to retrieve material that had gone through a quality appraisal process. Lastly, articles retrieved in the aforementioned steps were filtered based on their relevance to the research question. Another portion of the data collected and analysed at this stage was elicited from information specification frameworks. As shown in section 2, over the years, the development of various methods has aided practitioners in communicating which data should be inserted into the information model to complete specific tasks. The articles investigating processes for the specification of information and specification frameworks are listed in Appendix 1.

Due to the open-ended nature of the research question, a narrative approach was employed in favour of a systematic one. Some researchers advocate that systematic reviews can be used to find evidence of the most effective practices in a given field (Evans and Benefield, 2001). This reasoning can be observed in BIM literature (e.g. Chong et al., 2017; Oraee et al., 2017). Supporters of the method, however, tend to carry an overly positivist view justifying the superiority of the method on the assumption that a better understanding can be achieved through the accumulation of knowledge (Hammersley, 2001). Additionally, the rules employed in a systematic review are ultimately the result of interpretative and subjective reasoning (Hammersley, 2001). Therefore, this study adopts Hammersley's (2001) view that a literature review is an exercise in judging the validity of the studies' findings, and connecting these to one another as well as to the overall question under investigation. This exercise is guided by the researcher's own experience and by the issues raising from methodology and relevant theory.

While the analysis of literature was illuminating in terms of the approaches used to specify EIRs, it did not generate many insights into their interaction with contextual factors. Therefore, it was necessary elicit a discussion on the relevance of different approaches in a non-academic setting and the possible impact of contextual factors on their implementation. The concepts regarding the specification of graphical EIRs, presented in an unstructured and disperse manner in literature (Hooper, 2015; Treldal et al., 2016; Abualdenien and Borrmann, 2020a), were organised in themes before they were presented to practitioners in the second stage. This was important as, practitioners could have different interpretations of the concepts and methods (Bolpagni and Ciribini, 2016).

3.2 Stage 2 – Questionnaire development and application

Self-completion questionnaires composed of close-ended questions and open-ended questions were used to collect data in the second stage of the study. This method has been successfully employed in previous qualitative research (Adamson et al., 2004) and is usually used when the study has a clearer focus since questionnaires support the investigation of a narrower range of issues (Bryman 2012, p. 472). A narrower set of concepts could be formulated from the categories found in the previous stage. From a grounded theory perspective, the objective in this stage is to establish an iterative process, in which the categories are refined in order to improve the validity of the findings (Bryman, 2012, p. 571). A further aim is to enrich the categories unveiled in the previous stage with the inclusion of contextual dimensions. Therefore, categories elicited from data collected during literature review could be refined and enriched the data collected from practitioners.

Close-ended questions were derived from concepts originated in the initial open coding of extant literature. These questions were used in order to identify how participants interact with some key aspects of the specification of information task (e.g. familiarity with standards, agreement or disagreement on given points). For example, on the topic of interoperability (Abualdenien and Borrmann, 2019), it was important to gather information on whether participants believe that the specification of exchange information requirements should be structured around standards for information exchange such as IFC. Data on how contextual factors influence the decisions made by practitioners were also collected through close-ended questions. For example, in order to investigate Poirier's et al. (2015) industry context, it was necessary to know whether government mandates have some impact on the use of one specification framework or another. For the set of questions related to contextual factors, a multiple-indicator Likert scale was employed, as the goal was to measure the intensity of feelings about the topic of enquiry (Bryman, 2012, p. 166).

However, asking exclusively closed-ended questions is not recommended when there is variation in the interpretation of terms used in the questions. Therefore, the variation in the interpretation of terms pointed out by Bolpagni and Ciribini, (2016) also played a role in the questionnaire design. This is because, if respondents interpret questions differently, then the data collected and its subsequent analysis could have validity issues (Adamson et al., 2004). Therefore, the inclusion of open-ended questions left respondents free to express their own views about the relevance of the concepts/variables to their practices. Open-ended questions were derived from concepts originated in the initial open coding of extant literature. The questions were designed in a way that allowed for the inclusion of new relevant concepts and variables for the specification of graphical requirements by the respondents. This would not be possible if the questions were restricted by a range of closed-ended questions. As one of the goals in this stage was to enrich the categories generated throughout the literature review, a short explanatory video introducing the topic of the research as well as the concepts gathered previously was shown to the participants before they started completing the open-ended questions. This was done so that the questions could be contextualised and respondents could be stimulated by the research rationale. Moreover, this was to help them consider alternatives to their habitual practices, instigating a wider range of responses (Harper, 2002).

Even though there was a clear sampling frame, in this case BIM specialists, a random sampling approach was not the most suitable one. Firstly, using a random sampling approach raises questions over whether the respondents have knowledge on the topic of the enquiry or indeed if the topic is of any relevance for their activities (Cicourel, 1982). As stated previously, concepts and methods for the specification of data requirements are understood and used differently across industry (Bolpagni and Ciribini, 2016). Furthermore, there is the possibility that a probability sampling would result in the selection of practitioners that do not make use of these frameworks, and who are not familiar with the study subject altogether. These circumstances would result in a flawed measurement process as respondents would not necessarily have the same interpretation of terms in questions (Cicourel, 1964, p. 108).

Secondly, as it is not feasible to define a sampling frame of "BIM specialists that use concept 'X' according to standard 'Y' for the specification of EIRs", another sampling strategy had to be defined. The sampling approach used in this study is theoretical and focused on the groups for whom the use of criteria for defining graphical information requirements is a relevant activity, and who were likely to give an insight into the research questions – namely, BIM managers, BIM coordinators, consultants working for clients, and the operational staff that need to meet the requirements. In total, the views of 39 specialists were collected during this stage. Their profiles are shown in Table 1. These groups were targeted because when a research issue is salient to the respondent, that is, the questions being posed have a connection with their daily activities, there is a better likelihood of obtaining higher response rates (Altschuld and Lower, 1984). Additionally, the sampling gathered the comments of respondents who differ from each other in features that are relevant to the research question. For instance, members of different organisation sizes were invited to answer the questionnaire. This was done to allow for maximum variations in the concepts (Corbin, 2015). Data collection pursued the theoretical saturation of concepts expressed by respondents and was terminated when the variables for the specification of graphical information requirements were saturated and no new concepts seemed to emerge (Charmaz, 2006).

Due to its qualitative nature, the data collected in this stage was analysed through coding assisted by CAQDAS software based on a grounded theory framework. Literature recognises that the coding process moves from concepts that are closely linked to observations, to concepts with a certain degree of abstraction (Bryman, 2012). Therefore, as a first step the answers obtained from respondents were thoroughly analysed, labelled, separated and organised in a detailed way (Charmaz, 2006). The following stage comprised a focused coding, in which the codes were evaluated in terms of their frequency and their relevance to the aims of the study. In this stage researchers can create new codes by combining initial codes (Charmaz, 2006). Lastly, in order to place the interpretations elicited into a socio-scientific frame, the ideas were 'further interpreted in terms of the concepts, theories, and literature of a discipline' (Bryman, 2012, p. 31). The categories were contrasted with theories from investigations on the contextual dimensions influencing BIM implementation, especially those devised by Poirier et al. (2015). Fig. 2 summarises the description of the two research stages and shows the steps taken throughout the grounded theory method, as well as the rationale and results obtained in each stage.

Table 1: profile of participants

Participants	Work experience (years)	Highest educational qualification	Role
Participant 01	8	Bachelor's in Mechanical Engineering	Digital Engineering Manager
Participant 02	14	Bachelor's in Architecture	Project Manager
Participant 03	6	Master's in Civil Engineering	BIM Manager
Participant 04	14	Master's in Urban Engineering	BIM Manager
Participant 05	6	Bachelor's in Architecture	BIM Manager
Participant 06	4	Bachelor's in Civil Engineering	Project Manager
Participant 07	6	Master's in BIM management	BIM Specialist
Participant 08	9	Master's in BIM	Architectural Designer
Participant 09	14	Master's in Architecture	Executive Director
Participant 10	4	Master's in BIM	BIM Modeler
Participant 11	14	Master's in BIM	Senior Consultant
Participant 12	8	Master's in Sustainable Assets	BIM Specialist
Participant 13	24	Bachelor's in Electrical Engineering	BIM Manager
Participant 14	4	Bachelor's in Architecture	BIM Analyst
Participant 15	5	Bachelor's in Civil Engineering	Senior BIM Implementation Consultant
Participant 16	10	Doctor of Philosophy in Civil Engineering	Project Manager
Participant 17	13	Bachelor's in Architecture	Architect
Participant 18	18	Bachelor's in Architecture	Consultant
Participant 19	13	Master's in Building Construction Technology	Director of Innovation
Participant 20	5	Bachelor's in Architecture	Entrepreneur
Participant 21	10	Bachelor's in Architecture	Architect
Participant 22	21	Master's in Computer Science	BIM Champion
Participant 23	12	Master's in BIM	Team Leader
Participant 24	11	Master's in Industrial Management	BIM Consultant
Participant 25	14	Bachelor's in Civil Engineering	Entrepreneur
Participant 26	11	Master's in BIM	BIM Analyst
Participant 27	15	Bachelor's in Industrial Design	Technical Manager
Participant 28	13	Bachelor's in Architecture	BIM Manager
Participant 29	18	Master's in Contractor Companies Management	Business Developer

Participants	Work experience (years)	Highest educational qualification	Role
Participant 30	12	Master's in Architecture	BIM Manager
Participant 31	7	Diploma in Architecture	BIM Consultant
Participant 32	29	Master's in Innovation in Construction	BIM Consultant
Participant 33	10	Master's in Construction Project Management	BIM Coordinator
Participant 34	12	Master's in Architecture and Technology	Technical Sales Specialist
Participant 35	10	Bachelor's in Architecture	Architect
Participant 36	40	Doctor of Philosophy in Architecture	University Professor
Participant 37	11	Bachelor's in Architecture	BIM Specialist
Participant 38	11	Bachelor's in Civil Engineering	BIM Manager
Participant 39	34	Bachelor's in Civil Engineering	BIM Specialist

4. RESULTS AND DISCUSSION

The collection, analysis and classification of concepts related to the specification of graphical data in EIRs at stages 1 and 2 allowed for the identification of six main themes: model use, project stage, project actors, processes and objects definitions, graphical granularity and model attributes. These categories as well as the main action supported by their use are shown in Fig. 3 The following sections give an insight into how these variables are understood by literature and practitioners as well as their implication for BIM practice. The analysis goes on to evaluate how contextual factors impact the use of these variables in current practice.

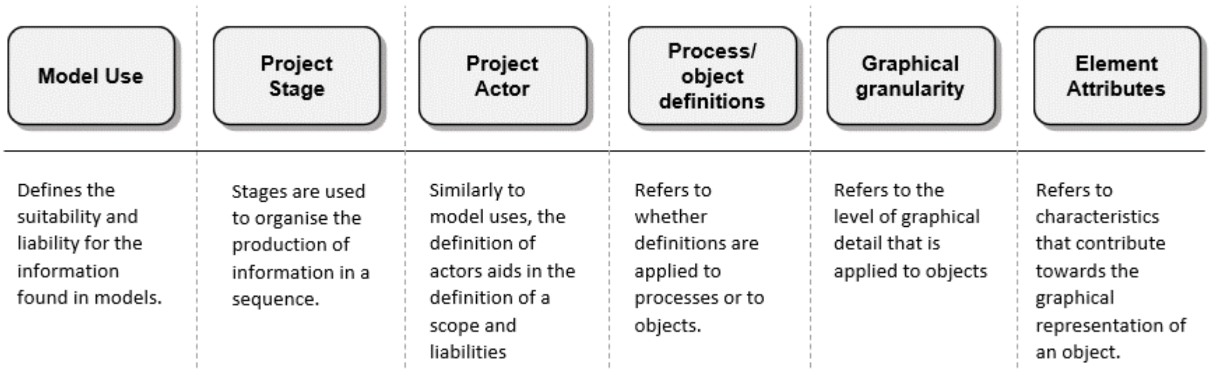

FIG. 3: Variables used to define graphical requirements in BIM-enabled projects

4.1 Analysis and discussion of the variables considered in the specification of graphical requirements in EIRs

4.1.1 Model use

In theory, BIM authoring tools allow for an endless amount of information to be inserted into the model and for this information to be used in countless ways. For this reason, previous works evidenced the necessity of developing models around predefined uses for the information contained within them (Hadzaman et al., 2016; Cavka et al., 2017). Moreover, defining model uses sets the suitability of the information, decreasing the likelihood of unauthorised uses for the model (Bedrick, 2008). These observations were largely mirrored in the data collected from practitioners. A common concept observed in the responses is that the specification of model uses supports the definition of the information that a model should contain as well as its structure..

Such specifications, in turn, facilitates the definition of deliverables and the resources that suppliers need to mobilise to fulfil these requirements. Therefore, data collected from participants also suggested that considerations around model use are not only employed for defining the amount of information that will be inserted in the model, but also for managerial tasks like measuring the resources necessary to complete the task, checking model quality and measuring progress. The support of managerial tasks enabled by information specification was also verified in Hooper (2015).

With regards to the graphical component of EIRs, the definition of model uses impacts directly on elements' graphical granularity (see section 4.1.5.) prescribing their representation. The responses to the questionnaires indicated that the graphical granularity of models uses seen in early design stages such as models for feasibility, for example, might differ from other model uses (e.g. models for manufacturing, models for clash detection)

Defining graphical information according to model uses can also aid in the management of some technical aspects of model development. Answers to the questionnaires indicated that model production that are not supported by the specification of a model use could become onerous to the information supplier. This is because, virtually, an endless amount of information could be inserted in the model. In this way specifying a model use could render the production and review of information in a model more effective. Moreover, it could also give a basis to the specification of technologies that could support the intended model use.

Lastly, a common remark among participants was that the specification of graphical information based on model uses can reduce waste in the modelling effort by decreasing rework and/or over modelling. When uses are not defined, some practitioners feel that they end up providing more information than it is actually needed as a way to cover unforeseen model uses. Additionally, if uses are not defined, the model can be built in a way that does not allow an intended task to be completed. In this case the model would have to be reworked. For example, a model produced for quantity surveying might not be prepared for construction scheduling analysis as the modelling strategies to enable these uses could be different.

4.1.2 Project stage

The finding from the literature review indicates that, not all the existing frameworks for the specification of EIRs include project stages as a variable. For example, BIM Forum's LOD specification states that levels of development are not prescribed by the framework as this is something that should be defined by each project team (BIM Forum, 2020, p. 5). Other frameworks, such as the BS EN 17412-1 'Level of information Need' (BSI, 2020), require that delivery milestones are considered in EIRs. This is because at any one given information delivery milestone, information can vary for different objects. Although divergent opinions on the relevance of a 'project stage' variable could also be found in the data collected in the questionnaires, most respondents argue in favour of considering project stages for the definition of graphical EIRs.

Firstly, the data collected from respondents suggests that stages are often used as a 'hard' model variable, that is, a variable included associated with model elements in the authoring tool environment. The value of this variable defines the existence or the absence of the graphical representation of elements in the project. For instance, the detailed representation of some building systems (e.g. the representation of products as manufactured) is not needed in conceptual stages of a project, while information on the position in relation to coordinates is relevant at early project stages.

In addition to practical considerations, participants suggested that stages are used to organise the production of information in a sequence. The data collected revealed that model uses are closely linked to project stages. This is because, currently, the development of a model for a given use is necessarily linked to a period of time. Therefore, the definition of project stages is often based on the time needed to enable a project use. In turn, project stage and model use have an impact on the graphical attributes of elements in the model and are used to communicate which information will be under evaluation at a point in time.

Moreover, participants highlighted that when model uses become enabled at the end of a time span, the information contained in the models allows decisions to be made. After decisions are made a new stage can start, in which new information can be inputted, enabling a new cycle of decision making supported by model uses. Therefore, the consideration of stages in the specification of graphical information helps practitioners to define a decision-making sequence and, consequently, decide in which order graphical information will be inserted in the model, For example, participants stated that if some piece of information is more relevant for a decision to be made, then the sequencing of information delivery in stages could support the prioritisation of the information to be inserted in the model.

4.1.3 Project actor

The analysis of the data collected from specialists has revealed a concern with the inclusion of variables that aid practitioners with managerial tasks, such as defining the size of the team required to complete a model (see section

4.1.1.). Managerial tasks were also mentioned with regards to project stages. In addition to aiding in the sequencing of information production, the definition of project stages also helps practitioners to perform managerial tasks such as evaluating the progress of a model based on a contractual deadline. In this way, by setting the graphical EIRs which should be delivered by the end of a deadline, project managers can develop a sense of how the project is progressing. Specialists remain concerned about the managerial side of BIM, often mentioning the definition of 'actors' as a parameter for the specification of graphical EIRs.

In literature, actors are included in specification documents as a way of defining a scope and establishing liability for the delivered information (AIA, 2008; Hooper, 2015). The use of LODs, for example, varies depending on which side of the contractual balance stakeholders find themselves. On the demand side, appointing parties use LODs to establish data requirements and define which party should provide the data. For instance, the appointing party could ask for plans for the application of a building permit before commencing construction works. Through a schedule of model elements and their respective LODs the appointing party would clarify which information should be inputted in the model for this specific use and who would be responsible for delivering this information at the specified milestone. This process could be confirmed in the data collected from respondents. Some respondents proposed methods (e.g. tables) to assign modelling responsibilities and deadlines to specific project actors. The appointed party would then make the arrangements to provide the data necessary to supply this need.

On the supply side, literature shows that appointed parties use LOD to define liabilities to the data that they themselves have generated. In this case LOD levels define what this data can be reliably used for (AIA, 2008; Hooper, 2015). For instance, the appointed party establishes that a set of data is ready to be used for building permit application. The appointed party would not be liable for detrimental consequences should the data be used for construction activities, for example. In this way, the consideration of authors in the specification of graphical requirements is relevant for making clear the network of task interdependencies that arise from actions and responsibilities defined by the production methods used by project participants. This concept was largely mirrored in the data collected from practitioners. Therefore, while most participants do not directly link the specification of authors to the way information is graphically represented in the model, the actor variable is still a component to be considered in the specification of graphical EIRs, as it defines who is responsible for the production of a piece of information and who is liable for it.

Another less current, but relevant, view found in the data collected in Stage 2 is that the specification of model authors in EIRs could act as information filters. In this way the definition of authors moves towards the concept of MVDs found in IDM frameworks (Wix and Karlshøj, 2010). This concern with model authors was highlighted by some participants and described as a way to simplify the visibility of information and create filters, as much of the information contained in a model is of interests to only a few project participants. Therefore, the consideration of graphical EIRs based on model authors has a direct impact on how graphical information is going to be displayed in the model.

4.1.4 Process and object definitions

Literature suggests that specification of graphical EIRs on an object basis is characteristic of an intermediate level of BIM development (BSI, 2013). Indeed, the data collected from practitioners suggest that object-oriented specifications, such as LODs, are often considered ambiguous and "bureaucratic". Some participant described LOD definitions as confusing and likely to lead to the over-modelling of model elements, without adding much information to the project, however. Therefore, object-oriented definitions are regarded as contributing to over-modelling, in which information that is not needed is added to the model.

Conversely, in literature, frameworks that focus on process are often associated with a higher level of BIM capability, a concept that was also mentioned by many participants. Some expressed that the IDM approach is more systemic and leads to a better analysis of the needs for requiring a piece of information and its real usefulness However, defining EIRs on a per process basis was often considered too complex to be implemented. Participants expressed their concerns about the complexity that this approach could bring to the project, the high initial learning curve for project participants and the impossibility for practices to adapt to this process.

Despite arguments supporting or disregarding one approach or another, the most prevalent view found in the data collected from specialists was that both approaches can be employed jointly. Many arguments were put forward to support this view. A common point was that some project team members (e.g. technicians) might find it hard to have a processual vision of the project, which would make it difficult for them to specify information on a process basis. On the other hand, managers might have only a high-level view of the project, lacking the understanding of specificities contained within each process.

Some arguments were put forward to support a mixed approach that could start with the definition of a process and become increasingly granular, arriving at the definition of model objects. A process-based approach could be associated with high-level definitions found in EIR while an object-based method could be more suitable to granular definitions found at later stages of the project when delivery plans are established. Therefore, the use of one approach or another could also be connected to the division of a project in stages where high level definitions are used in the initial stages and more granular ones, towards the end of the design stage.

4.1.5 Graphical granularity

Data collected from participants suggests that a traditional view of graphical information progression according to the advancement of project stages and processes is still held by many specialists. However, many remarks were made about the inadequacy of this model to current BIM practices. Most participants observed that graphical information has a heterogeneous development in BIM-enabled projects. That is, specific building components or assemblies might require a high level of graphical detailing in the early design stages while others remain undefined. Participants highlighted that the incremental granularity in the graphical representation of objects according to the project stage does not always take place linearly. The opposite can also be observed. Participants observed that this is because project teams develop object models pre-populated with relevant information and have them ready to be used at the beginning of the project. In turn, this minimises the notion that information is being incremented as the project transition from one stage to another. Therefore, the discussion around a graphical granularity taxonomy becomes relevant among practitioners in order to set the expectations with regards to the product that is going to be delivered in the new project paradigm set in BIM.

Data analysed during the literature review has revealed that, currently, there is no single standard way of defining graphical granularity in BIM models. Current frameworks diverge on the number of granularity categories and what these represent. The content analysis of a number of frameworks (AIA, 2008; BIPS, 2006; BSI, 2013; BSI, 2019; BSI, 2020; BIM Forum, 2020) as well as studies proposing new classifications (Fai and Rafeiro, 2014; Carrato and Wilson, 2016; Abou-Ibrahim and Hamzeh, 2016; Treldal et al., 2016; Abualdenien and Borrmann, 2019; Uusitalo et al., 2019) has allowed for the identification of a common denominator in terms of graphical granularity categories. These are represented by the following taxonomy: (1) symbolic plan representation; (2) bounding box representation; (3) approximate shape representation; (4) fabrication shape; (5) real-world representation.

The translation of the concepts related to each graphical granularity category into levels could represent a challenge in terms of data collection. Previous works acknowledge that it is hard to elucidate a common understanding of the meaning of levels among BIM specialists (Hooper, 2015; Treldal et al., 2016). Therefore, participants were presented with the conceptual description of each of the five categories to collect their view on the application of them in current practice. The analysis of the data collected suggests that these categories are employed consistently in several projects. Moreover, as illustrated by Fig. 4, most respondents affirmed that the five categories could represent most of the graphical granularity categories they have seen in BIM-enabled projects.

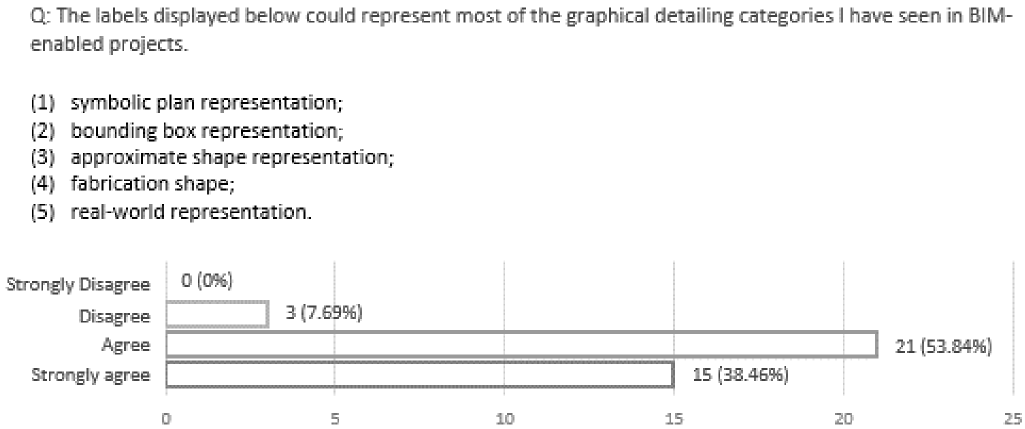

Fig. 4: Use of graphical detailing categories among respondents

However, despite the near consensus among participants, some reservations were expressed. Firstly, the link between model use and graphical granularity was evidenced as some participants were keen to point out that more than one category of graphical granularity could be assigned to a single model element at the same time. For example, the modelling of electrical systems could require the existence of symbolic and a realistic representation for the same object as drafting conventions require for them to be represented in different ways depending on the view being provided. Another example: some jurisdictions ask for 2D deliverables as part of the application process for obtaining a building permit. These jurisdictions set their own graphical representation standard (e.g. certain model elements must be represented as symbols), which applicants must follow. If other model uses are added on top of the building permit purpose, a given element might have more than one category of graphical granularity.

4.1.6 Element attributes

The data collected in the literature review stage revealed that the first published frameworks and studies on the specification of EIRs (e.g. AIA, 2008; Fai and Rafeiro, 2014) tend to consider alphanumerical attributes, graphical attributes and graphical representation under a single category defined by levels. Later, frameworks started to consider the division of alphanumerical information and graphical information (e.g. BSI 2013, BSI 2020). Yet, when describing the method for the specification of graphical information, these frameworks do not make a distinction between the geometric representation context, representing the concept of a particular geometric and/or topological representation (BSI, 2016), and a style representation context, representing the concept of a defined presentation style established by a material, or other attributes (Ibid.). However, data collected from participants suggests that this distinction could be relevant for specialists. Respondents expressed that, this distinction could support the development of different design products, directed to different markets. An example given was of an architectural practice that needs to produce models for an analysis of the accessibility and another model to present a photo-realistic image of a design solution.

Therefore, the analysis of the data also focused on the attributes that are related to graphical content but fall outside the geometric representation context. The exercise revealed the prominence of five attributes among the participants.

- Materials: refers to the application of material representation to shapes in the model. Often associated with conceptual presentation and heritage conservation uses.
- Location: refers to the representation of a shape in relation to a given coordinates system. Practitioners employ this attribute in order to define tolerances and uncertainty factors.
- Quantities: although this attribute might not seem related to graphical information, participants highlighted that the way objects are graphically represented could influence on how measurements are displayed (e.g. surface area, volume).
- Clearances: summarised by a respondent as "the representation of geometries that show minimum free access areas/volumes. Example: the free area around equipment to guarantee maintenance or disassembly access".
- Parametric behaviour: a functionality added to an element allowing it to change its representation characteristics according to the value of other information associated with that element (BSI, 2020).

Most participants affirmed they currently use standards for interoperability such as Industry Foundation Classes (IFC) (BSI, 2016), in their daily activities and agreed that the specification of graphical attributes should be structured around standards for information exchange. This would decrease the risk of interoperability issues related to software choice and modelling approach. However, this is not always possible as some authoring tools lack the functionality of translating their semantics into standardised ones.

The concepts emerging from the data collected in the questionnaires and exemplified in the answers of some participants are summarised in Fig. 5 and can be employed to extend the understanding of the considerations made when specifying the graphical component in EIRs documentation. However, the analysis of contextual factors suggests that considerations around these variables diverge across practices depending on the context in which they are implemented.

Categories	Concepts
Model Use	▪ Defining model uses sets the suitability of the information. ▪ Defining model uses decreases the likelihood of unauthorised uses for the model. ▪ Considerations around model use are employed for defining the amount of information that will be inserted in the model. ▪ Considerations around model use are employed for managerial tasks like measuring the resources necessary to complete the task. ▪ Considerations around model use are employed for checking model quality. ▪ Definition of model uses impacts directly on elements' graphical granularity. ▪ Defining graphical information according to model uses can aid in the management of some technical aspects of model development (i.e. hardware and software requirements). ▪ The specification of graphical information based on model uses can reduce waste in the modelling effort by decreasing rework and/or over modelling.
Project Stage	▪ Despite the contradictory views shown in literature, most respondents argue in favour of considering project stages for the definition of graphical EIRs. ▪ Stages are often used as a 'hard' model variable, that is, a variable associated with model elements in the authoring tool environment. ▪ Stages are used to organise the production of information in a sequence and define in which order graphical information will be inserted in the model ▪ The consideration of stages in the specification of graphical information helps practitioners to define a decision-making sequence. ▪ The definition of project stages helps practitioners to perform managerial tasks such as evaluating the progress of a model based on a contractual deadline.
Project actor	▪ Actors are included in specification documents as a way of defining a scope and establishing liability for the delivered information. ▪ Actors are defined for clarifying the actions and responsibilities of those involved on the project. ▪ Actors are used for establishing the relationship of dependency between teams. ▪ The definition of project actors can also act as a 'filter' for what type of information will be inserted in the model.
Process and object definitions	▪ Object-oriented specifications, such as LODs, are often considered ambiguous and "bureaucratic" . ▪ Object-oriented definitions are regarded as contributing to over-modelling. ▪ Defining EIRs on a process basis is often considered too complex to be implemented. ▪ The most prevalent view is that process and object definitions can be employed jointly. ▪ A process-based approach could be associated with high-level definitions of EIR while an object-based method could be more suitable to granular definitions.
Graphical granularity	▪ A traditional view of graphical information progression according to the advancement of project stages and processes is deemed to be incompatible with current BIM practices. ▪ The definition of a graphical granularity for the model sets the expectations with regards to the product that is going to be delivered. ▪ The content analysis of a number of frameworks has allowed for the identification of a common denominator in terms of graphical granularity categories: (1) symbolic plan representation; (2) bounding box representation; (3) approximate shape representation; (4) fabrication shape; (5) real-world representation. Over 90% of respondents affirmed that these categories could represent most of the graphical granularity categories they have seen in BIM-enabled projects. ▪ There is a link between model use and graphical granularity - more than one category of graphical granularity could be assigned to a single model element at the same time depending on the model use.
Element attributes	▪ The distinction between the geometric representation context and/or topological representation (BSI, 2016), and a style representation context is relevant for specialists. ▪ Five attributes that are related to graphical content were identified: materials, location, quantities, clearances, parametric behaviour. ▪ the specification of graphical attributes should be structured around standards for information exchange (i.e. IFC).

Fig. 5: Summary of the concepts collected with participants and their classification into variables.

4.2 Analysis and discussion of contextual factors

The implementation of the processes required to fulfil the requirements expressed by the variables described in section 4.1 are potentially disruptive, and could require the redefinition of traditional processes, tasks and roles (Poirier et al., 2015; Zomer et al., 2020). Literature suggests that contextual factors could influence the extent to which new processes are adopted (Zomer et al., 2020). Without careful consideration of contextual factors, inefficient hybrid systems might be put in place, provoking duplicated effort, mismanagement and reducing available time (Gledson, 2016). Therefore, this section analyses how contextual factor could interact with the use of the variables for specification of graphical EIRs. The analysis was conducted using Poirier's (2015) embedded contexts as a theoretical framework (see section 2.2).

Most of the remarks made by participants could be placed on a scale defined by two extremes. At one end of this scale, practitioners employ the variables for the specification of EIRs exclusively to enable gains in their own projects, specifying the information that their own organisations will need to perform their tasks. On the other end of the scale, practitioners employ the variables to align expectations and objectives with regards to their models, and to enable the use of their models by other stakeholders down the supply chain and at later project stages. This concept is illustrated by Fig. 6.

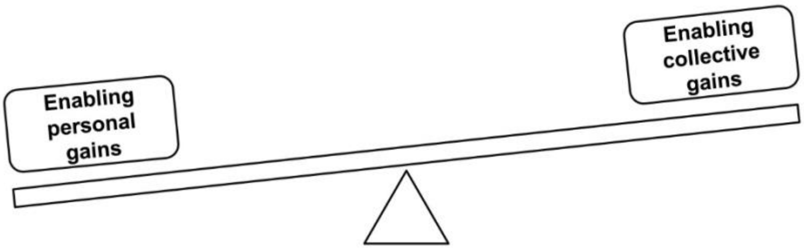

Fig. 6: The balance between the specification of information for personal gains vs. collective gains

4.2.1 Industry context

The industry context was found to exert some influence on practitioners' decisions with regards to the activity of information specification. Due to traditional competitive bid arrangements, lower-price mentality, and the network of actors formed on a project-to-project basis, functionalities that show quick economic benefits are more likely to be implemented than long-term inter-organisational systemic innovations (Jacobsson et al., 2017). This is evidenced, for instance, in participant's frequent mention of concepts that allow for the implementation of functionalities such as clash detection, or the control of quantities, which could be grouped under the graphical granularity variable. On the other hand, although most specialists agreed on the use of open data standards, many of them gave less importance to ensuring the interoperability of data, which could influence the way EIRs are specified across project stages, actors, and processes.

Moreover, literature suggests that contextual factors at the industry level such as market forces can act in favour of the improved control enabled by the adoption of a specification framework. The market's demand for the lowest price as a tender policy encourages stakeholders to control the consumption of resources used in the project (Jacobsson et al., 2017). In turn, this promotes the adoption of processes that aids monitoring activities. This could be verified in the data collected from participants as some highlighted that the definition of variables could support them to measure and control the production of information in the model against project's key decision points. I this way, practitioners could be able to better estimate the resources used to produce the information and carry out quality improvement processes on recurring tasks.

Practitioners also pointed out that this could be achieved through a detailed specification of the EIRs, considering the different variables that define the graphical content of a model. Another example is the improved control of physical resources. BIM implementation often requires the upgrading of existing information technology infrastructure in order to deal with larger data sets (Gledson, 2016). Better specified EIRs prevent over modelling which, in turn, results in smaller data models, requiring less computing power.

4.2.2 Institutional context

Existing literature indicate that standards assume a central role in an industry characterised by its fragmentation, ensuring that the modules developed independently by different stakeholders will be compatible at a later stage

(Lindgren, 2016). The existence (or lack) of standards of practice, mandates and industry maturity were also found to have an impact on how practitioners compose their EIRs. For instance, the answers collected from practitioners showed that some frameworks for the specification of data are more likely to be used than others simply because they are more diffused in the industry. Therefore, this has an impact on the way EIRs are established as some standards prioritise the definition of some variables over others.

Finally, literature posits that the factors that usually promote innovation implementation in other industries such as the centrality of communication to project performance seem to be less relevant to the construction industry, in which actors work in their own interest and focus on improving their own processes (Jacobsson et al., 2017). In this way, certain variables such as the definition of actors and processes that will consume the information being produced and the definition of model uses should be considered less important than those that enable immediate performance improvement. However, this concept was contradicted by some participants who were keen to point out the importance of composing EIRs to align expectations and prevent rework. Some compared the EIR to a roadmap that indicates the way that project participants need to take to achieve BIM-related goals. This concept, nevertheless, was found less often in data.

4.2.3 Organisational and project context

Considerations around organisational contextual factors were also found in the data collected. Literature suggests that the size of the organisation might influence how innovation is implemented. Small and medium-sized organisations, for instance, typically lack a clear strategic vision for innovation and tend to implement solutions that have a proven track record (Poirier et al., 2015). In terms of information specification, this could mean a tendency to adopt more self-centred ways of working, such as the specification through LODs and less consideration to variables that span organisational boundaries, such as model uses and actors. However, when questioned about this, specialists agreed that making use of a framework for the specification of EIRs should be considered in both small and large organisations contexts.

Moreover, the data collected in the literature review pointed that frameworks for the specification of EIRs leave the task of defining information requirements to contracting organisations (e.g. BSI, 2019). Gu and London (2010), however, suggest that contracting organisations often lack the knowledge of the prerequisites necessary to implement BIM in a project. When questioned about this point, specialists often mentioned that this task should lie with consultants or BIM champions who should assume the role of project information managers and have managerial roles within the organisation. This is because composing EIRs is considered a complex task. Participants expressed frustration with the task of implementing current standards and frameworks, as these technical documents are seen as bureaucratic and ambiguous. However, participants also pointed out that information manager are often not appointed in the projects they have participated.

Overall, the analysis of contextual factors suggests that, although several variables are commonly considered among specialists, there is no definitive solution for the specification of graphical information requirements. Different contextual dimensions influence how these variables are employed in practice. A summary of concepts is displayed in Fig. 7. Therefore, frameworks need to be flexible enough to accommodate the different contexts in which they are implemented. This could be accomplished by leaving more room for choices rather than imposing a process on practitioners. Respondents were keen support this concept, highlighting that organisation have different goals and objectives, and provide different services to different markets. Furthermore, practitioners responsible for the definition of EIRs should consider their own context when performing this task.

5. CONCLUSION

The development of technologies has not yet enabled the full benefits of BIM across the construction industry. Literature suggests that this is due to the focus on technical aspects, while contextual factors are given little consideration. This is particularly true for the activity of practitioners who are entrusted with specifying graphical information requirements. Additionally, the definition of variables used in frameworks focus on non-graphical requirements and has acquired various meanings among practitioners. Therefore, there is a debate around the way that graphical elements should be specified in EIRs.

Categories	Concepts
Industry context	**Variables used to enable instant gain over long term gain** ▪ Traditional competitive bid arrangements, lower-price mentality, and the network of actors formed on a project-to-project basis make functionalities that show quick economic benefits more likely to be implemented than long-term inter-organisational systemic innovations (Jacobsson et al., 2017). ▪ Frequent mention of variables that allow for the implementation of functionalities such as clash detection, or the control of quantities. **Proprietary formats over open standard formats** ▪ Less importance given to the specification of open standards in EIRs to ensure the interoperability of data between project stages, actors and processes. **Variables used to enable improved control** ▪ Market forces can act in favour of the improved control enabled by the adoption of a specification framework.
Institutional context	**Use of variables specified in standards** ▪ The existence (or lack) of standards of practice, mandates and industry maturity were found to have an impact on how practitioners compose their EIRs. **Variables used to enable immediate performance improvement** ▪ Certain variables such as the definition of actors and processes that will consume the information being produced and the definition of model uses are considered less important than those that enable immediate performance improvement such as graphical granularity.
Organisational and project context	**Variables influenced by organisation size** ▪ The size of the organisation might influence how innovation is implemented. Small and medium-sized organisations, for instance, typically lack a clear strategic vision for innovation and tend to implement solutions that have a proven track record (Poirier et al., 2015). **Variables influenced by the availability of skills in the organisation/project team** ▪ Contracting organisations often lack the knowledge of the prerequisites necessary to implement BIM in a project (Gu and London, 2010). ▪ The task of defining information requirements should lie with consultants or BIM champions. ▪ The information management role "is not being appointed often enough currently".

Fig. 7: Summary of the contextual factors and the concepts shown by participants

This study has employed a qualitative strategy, a cross-sectional design and a grounded theory approach for data collection and analysis. The first stage covered extant literature, standards and frameworks for the specification of information. This granted access to the various methods for the specification of graphical EIRs and an initial definition of concepts. As part of the iterative process established by the grounded theory approach, the second stage gathered the views of practitioners. A questionnaire has been employed to collect data. This allowed for the emergence of new concepts and the refinement of the variables revealed in the first stage. Moreover, this approach granted access to data that could be used in the analysis of contextual factors.

Through this research it has been demonstrated that considerations around model use, project stage, actor definition, process vs. object definitions, graphical granularity and element attributes are discussed in literature and are relevant to practitioners. Moreover, the findings support the suggestion that contextual factors play a role in the implementation of BIM technologies and associated processes. The views of practitioners collected throughout the study suggest that existing practices at the industry and organisational context level could influence the way practitioners use a given set of variables when defining graphical information requirements in BIM-enabled projects.

These results extend the understanding of the specification of graphical information in BIM-enabled projects, and could inform the activity of practitioners. Preceded by a contextual analysis, the categories set out in this study could be used as parameters to define the graphical information that is going to be inserted in the model, who is going to produce this information and when it is going to be delivered. Moreover, the set of variables demonstrated here could form a basis for the development of new technologies focused on facilitating or automating the activity of information specification and checking processes.

The limitations of the study arise from the grounded theory approach adopted. Methodologically, the approach was found suitable as the lack of common understanding among practitioners did not allow for an inquiry on the relevance of certain definitions to be conducted in a quantitative manner. However, the question of external validity arises when such an approach is adopted. This issue was tackled by making data collection and analysis more robust with the inclusion of an iterative two-stage process, which allowed for some data triangulation. In the event of the development of a common definition among practitioners, future research could enhance the generality of the results presented here by applying a deductive quantitative approach.

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APPENDIX 1

Table 2: Selected articles and their main contribution towards the specification of information requirements

Source	Objective	Contribution towards information specification
Abou-Ibrahim and Hamzeh (2016)	To investigate the implementation of Transformation, Flow, and Value theory focusing on Design product	Develops a new LOD framework in order to link the detailing of a model element to a specific design context
Abualdenien and Borrmann (2018)	To enable the description of uncertainty and the verification of requirements in information models	Develops a LOD meta-model in order to explicitly specify the LOD of a model element
Abualdenien and Borrmann (2019)	To ensure the consistency of the geometric and semantic information across design stages	Proposes further developments to a LOD meta-model in order to explicitly specify the LOD of a model element
Abualdenien and Borrmann (2020a)	To show an approach that presents the uncertainties associated with information elements	Develops a LOD meta-model which supports the specification of overall and specific information requirements at a particular design stage
Abualdenien and Borrmann (2020b)	To present a multi-LOD meta-model to explicitly describe LOD requirements	The LOD meta-model incorporates geometric and semantic information and the potential fuzziness of individual elements
AIA (2008)	To establish the protocols, expected levels of development and authorised uses for information models	Gives definitions for different Levels of Developments. There are 5 levels: 100, 200, 300, 400, 500
AIA (2013)	To establish the expected levels of development for model elements	Gives definitions for different Levels of Developments. There are 5 levels: 100, 200, 300, 400, 500
Bedrick (2008)	To aid teams to agree on the uses for the information model and the level of detail of elements at a specific stage	Gives examples for different LODs and relates the levels to model uses
Biljecki et al. (2016)	To present a set of LODs which provide a stricter specification in the context of GIS	A description of a framework with 16 levels is provided. The LODs focus on the graphical detail of the exterior geometry of buildings
BIM Acceleration Committee (2019)	To define the concept of LOD and its use	Gives definitions for different Levels of Developments. There are 5 levels: 100, 200, 300, 400, 500
BIM Forum (2015)	To provide information requirements and graphical examples of the different LODs for building elements	It specifies the required alphanumerical and graphical information for building elements at 6 levels: 100, 200, 300, 350, 400, 500
BIM Forum (2020)	To provide information requirements and graphical examples of the different LODs for building elements	It specifies the required alphanumerical and graphical information for building elements at 5 levels: 100, 200, 300, 350 and 400
BIPS (2006)	To specify a working method for 3D models to be created, exchanged, and re-used throughout the entire project	Specifies a level of information framework comprised of 7 levels
Bolpagni and Ciribini (2016)	To provide an overview of the approaches used to define the content of a Building Information Model	There is no univocal approach to define the content of an information model and different definitions are used across practices
BSI (2013)	To specify the information management process used to achieve 'BIM Level 2' with focus on project delivery	Describes the information management process including definitions 'Levels of model detail and model information' per project stage
BSI (2019)	To specify the requirements for information management within the context of the delivery phase of assets using BIM	Describes the information management process and includes the description of the 'Level of Information Need' and gives the rationale for its implementation
BSI (2020)	To specify a methodology for specifying level of information need within the context of BIM	Describes a framework for defining alphanumerical and graphical information requirements in BIM-enabled projects
Carrato and Wilson (2016)	To describe an enhancement to LOD frameworks in order to support two extra activities	Describes a new framework that supports procurement stage and construction planning and execution activities
Cavka et al. (2017)	To present an approach used to the identify and characterise owner requirements	Provides a case study describing the process used to define information requirements
Ciribini (2013)	To investigate the process of information specification during the commissioning stage of the project	The commission management process is modified by the way information is specified in BIM-enabled projects
Dias and Ergan (2016)	To identify the facilities operators' information requirements with regards to the maintenance of HVAC systems	Describes a case study where a LOD framework was used to define information requirements for HVAC maintenance
Eastman et al. (2010)	To define procedures for developing information delivery manuals	Exemplifies how an IDM approach is used to capture detailed level information requirements from end users
Fai and Rafeiro (2014)	To discuss the process used to define LODs in the context of heritage conservation	Provides the description of a case study where a LOD framework was used to define information requirements for heritage conservation
Fritsch et al. (2019)	To discuss the suitability and limitations of BIM for representing landscape elements	Provides the description of a case study where a LOD framework was used to define information requirements for landscape architecture

Source	Objective	Contribution towards information specification
Gigante-Barrera et al. (2017)	To propose LOD implementation via an IDM process method in a manufacturing company	Provides the description of a process where a LOD framework was used to define information requirements for a manufacturer
Grytting et al. (2017)	To assess how creative design processes can be scheduled in projects using BIM tools	Exemplifies how a LOD framework can be employed to control the design process
Hadzaman et al. (2016)	To investigate how processes established in a BEP take place in a mega-construction project	Provides a description of how a LOD framework was used to define information requirements in the context of a mega-project
Hong et al. (2019)	To propose an evaluation method to forecast the net costs of BIM implementation at different LODs	Exemplifies how the specification of different LODs can have an impact on the costs of BIM implementation
Hooper (2015)	To reveal new insights into the application of LOD frameworks from a design management perspective	Presents a method for automatically comparing planned model progression with the current state of the model utilising LOD definitions
Hooper and Ekholm (2010)	To define the requirements for information management through the stages of a BIM-enabled construction project	Provides the description of a case study where researchers developed a process to define information requirements
Jeon and Lee (2018)	To review previous efforts to support the development of the information delivery manual	Describes the current limitations of the IDM approach
Krijnen and van Berlo (2016)	To illustrate how the body of technical means (e.g., classification systems) can be employed in automated rule checking	Provides a description of how LODs are currently used in the task of defining information requirements
Lee et al. (2006)	To discuss the use of the Georgia Tech Process to Product Modelling method to generate IFC views	Describes a method for implementing an IDM process
Lee et al. (2013)	To propose a new Process to Product Modelling method for integrated and seamless IDM and MVD	Provides a description of the IDM process and MVDs uses
Lee et al. (2016a)	To suggest a robust MVD validation process using a modularized validation platform	Uses a case study to show a method for confirming the quality of received data pertaining to a MVD
Lee et al. (2016b)	To propose a new approach for formalising a domain knowledge and defining accurate data modules for MVDs	Describes the challenges related to the implementation of the IDM approach
Lee et al. (2018)	To suggest a new approach to evaluating BIM data in accordance with the diverse requirements of an MVD	Describes a method for confirming the quality of received data pertaining to a MVD
Lee et al. (2019)	To provide an in-depth discussion of the complexity and challenges of BIM data validation using a case study	Describes the mechanism and challenges of validating an information model against information requirements
Mondrup et al. (2014)	To propose a new approach for defining an IDM	Provides a description of the IDM process and the challenges and benefits associated with it
NATSPEC (2013)	To clarify misconceptions about the use of LOD and show the value of it as a project management tool	Gives definitions for different Levels of Developments. There are 5 levels: 100, 200, 300, 400, 500
NBS (2020)	To establish the expected levels of detail/information for model elements	Specifies levels of detail/information for model elements. A distinction is made between level of detail (graphical) and a level of information (alphanumerical)
Nøklebye et al. (2018)	To explore current approaches, experiences, and requirements for using maturity-based management in design	Compares maturity-level specifications with traditional approaches for design management
Tolmer et al. (2017)	To adapt LOD definition to meet BIM uses requirements and data modelling for linear infrastructures projects	Describes a methodology to redefine the LOD concepts and to describe how these could be used to complete the definition of BIM uses
Trani et al. (2015)	To identify and develop a BIM-based method to create a construction site information model	Describes a case study where a LOD framework was used to define information requirements for construction modelling
Tredal et al. (2015)	To review several existing LOD frameworks and propose a solution that combines LOD definitions with IDM	Proposes a framework with 7 levels of detail
Uusitalo et al. (2019)	To define a location-based design management process integrating the concept of LOD and Last Planner System	Integrates the LOD concept to the Last Planner System by establishing LOD-based milestones
van Berlo and Bomhof (2014)	To describe the research and development of the Dutch national standard for information levels of BIM	Describes a LOD framework which comprises 7 levels of detail
Wix and Karlshøj (2010)	To describe the Information Delivery Manual approach for defining information requirements	Provides a description and examples of the use of the IDM approach