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APPLICATION OF SEMANTIC WEB TECHNOLOGIES FOR THE ENHANCEMENT OF QUANTITY SURVEYING PRACTICES: CLASSIFICATION SYSTEMS AND TERMINOLOGY

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Abstract: *Building Information Modelling (BIM) technologies, as an advanced evolution of CAD, have improved the automation level of the cost estimation process and data accuracy. The evolution of these technologies has initiated the development of tools and applications intended to enhance productivity and cost certainty. However, there are still several limitations and difficulties, such as 2D-based documentation systems and lack of information exchange and interoperability, that the QS sector is facing while using existing technologies for cost estimation purposes. The aim of this paper is twofold. First, to comprehensively understand the state-of-the-art. This paper reviews the literature to identify limitations and challenges in using CAD applications in QS practices, focusing on the BIM context and the effective implementation of Information Technology (IT) and Information Management (IM). Second, the paper explores using Semantic Web technologies like Web Ontology Language (OWL) to create a database that can be applied to all building projects by utilising a unified data format and following a standard vocabulary based on New Rules of Measurements (NRM) practices. Although existing tools can initially address some of the challenges and limitations, there is limited scope for customisation, which is essential due to the diversity of clients, systems and digital models. Currently, cost information is documented in different data formats, databases, and applications, resulting in an ineffective and inefficient IM and fragmented IT implementation within most QS practices. The use of semantic Web technologies within the QS domain will improve the Level of Detail (LoD) and Level of Information (LoI) in the QS practices. It also provides an imperative baseline for developing the Cost Estimation Ontology (CEO).*

KEYWORDS: *Building Information Modelling (BIM), Computer-Aided Design (CAD), Quantity Surveying (QS), Semantic Web Technologies, Ontology*

1. Introduction

Digitisation within the construction industry can be defined as applying digital technologies to support and improve different aspects of the industry, such as data management, communication and collaboration, and project cost-effectiveness (Adesi *et al.*, 2018; Mahamadu *et al.*, 2020). With the emergence of advanced technologies, the construction industry is transforming towards digital practices (Tee & Kamal, 2021). It would appear that the Quantity Surveying (QS) sector is no different. The QS profession within the Architecture, Engineering and Construction (AEC) industry is to cost and manage cost-related activities requiring expertise in QS-related activities, such as measuring quantities of building elements, costing models, contractual administrations, and commercial management functions (Wong & Yew, 2017; Mahamadu *et al.*, 2020). One of the main Quantity Surveyors (QSs) responsibilities is to provide strategies for a clear vision of the cost-related aspects of building projects from inception onwards.

Paper-based measurement, cost estimation, and communication procedures as the traditional method have been widely adopted by QSs within the construction industry. The paper-based approach can be considered a time-consuming, error-prone, and unsecured procedure, requiring physical space for storing documents and perhaps resulting in a more complicated auditing process (Ismail *et al.*, 2016). Like many other professions within the AEC industry, the QS profession is also an evolving sector that requires improvements in the professional services needed to achieve the industry's ever-changing conditions (Gilchrist *et al.*, 2021). Hence, applying new technologies within the QS domain has gained notable interest in potentially moving from traditional paper-based information management toward a more semi-automated or automated procedure. Several studies have shown how new technologies and tools are used to improve QS practices with varying success (Wu, Wood, *et al.*, 2014; Alhasan *et al.*, 2017; Adesi *et al.*, 2018).

The emergence of Building Information Modelling (BIM) as a well-known term in the AEC industry has remarkably changed how the construction industry operates. BIM models as digital resources and virtual representations of physical and functional characteristics of a building project are fast becoming the comprehensive information source in different sectors of the AEC industry, e.g. O&M-related information in the Facilities Management (FM) domain and cost estimation-related data in the QS profession (Ismail *et al.*, 2016; Sadeghineko *et al.*, 2018b). The application of BIM can provide a feasible solution to some of the limitations and challenges related to the manual processes of quantification and cost estimations (Liu *et al.*, 2016). In contrast to the traditional 2D approaches, BIM-enabled projects provide QSs considerable involvement and collaboration in the pre-design and design phases (Ismail *et al.*, 2017). In this regard, studies have been undertaken to propose frameworks for integrating BIM and QS practices, such as 5D BIM, to improve the quantification and cost estimate processes, reduce the time spent manually creating costing-related documents, generate accurate data, and control costs throughout the construction process (Mayouf *et al.*, 2019; Gilchrist *et al.*, 2021). The use of BIM improves project productivity and performance and their corresponding deliverables, including QS inputs and outputs. A successful construction project can be determined by its performance in delivering the project with appropriate quality and cost within the scheduled time. Figure 1 depicts the general process of BIM applications within the QS activities.

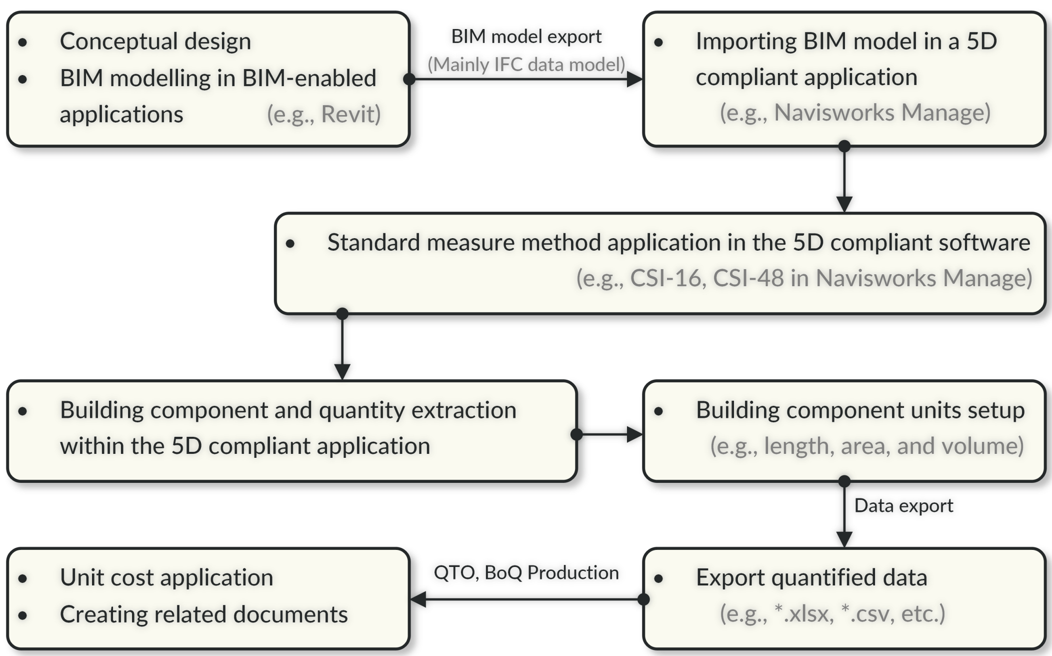

Fig. 1: QS BIM application general process.

Although the adoption of BIM-driven technologies and tools provides some solutions to the challenges and limitations, some sectors within the construction industry still suffer from the lack of information exchange and interoperability offered by such technologies. Hence, Semantic Web technologies, tools, and applications have gained popularity and interest in the AEC industry to potentially address some of the challenges. Semantic Web is a set of technologies and standards providing frameworks for storing, sharing, and reusing data on the Web (Sadeghineko & Kumar, 2021). Researchers and experts have widely employed these technologies to tackle challenges and limitations related to existing information exchange standards and tools with varying success (Sadeghineko & Kumar, 2020b). Examples of some uses are the stand-alone ontologies developed for IFC (ifcOWL) (Pauwels & Terkaj, 2016), COBie (COBieOWL) (Farias *et al.*, 2015) and ifcJSON (ifc JavaScript Object Notation) (Afsari *et al.*, 2017), mainly focusing on creating and sharing web-based data from an existing dataset. Moreover, the concept of Web-based ontologies has also been adopted in the QS practices to facilitate and improve the exchange of cost-related information between BIM-driven applications for various purposes with little success, such as quantification, cost estimation, and BoQ (Niknam & Karshenas, 2015; Abanda *et al.*, 2017; Wu *et al.*, 2020).

2. Research Approach

Research problem: Currently, in real-world projects, cost information is documented in different data formats, databases, and applications (Babatunde *et al.*, 2019; Mayouf *et al.*, 2019; Wu, Ginige, *et al.*, 2014), resulting in inefficient Information Management (IM) and fragmented Information Technology (IT) implementation within most construction practices (Kim & Park, 2016; Rasmussen *et al.*, 2020). Adopting advanced IT and IM technologies and standards for creating more structured cost information with an appropriate Level of Detail (LoD) and Level of Information (LoI) could lead to more enhanced and efficient quantifications, cost estimation, and Bill of Quantities (BoQ).

Research aim and objectives: The research presented in this paper aims to comprehensively understand the state-of-the-art through reviewing the literature to identify limitations and challenges in using CAD applications in QS practices, focusing on the BIM context and the effective implementation of IT and IM by using Semantic Web technologies. The research objectives for this ongoing research are as follows, with only the first three objectives discussed in this paper.

1. To investigate the use of BIM applications and Semantic Web technologies and standards within the AEC domain, in particular, the QS profession;
2. To explore existing Semantic Web-based ontologies within this domain and QS-related terminology by investigating data classification systems;
3. To create a common vocabulary and terminology database for the QS profession. NRM documents are adopted as the primary database for identifying standard vocabulary/terminology fit for QS practices;
4. To analyse methodologies developed for generating Semantic Web-based ontologies within diverse industries and domains;
5. To create a methodology that suits the construction industry and can be utilised to generate sector-specific ontologies, e.g., the Cost Estimation Ontology (CEO) in this research;
6. To investigate and evaluate BIM-enabled applications and their capabilities for integrating Semantic Web-based datasets with the BIM-driven models;
7. To integrate the CEO ontology with BIM models for live IT and IM, including the cost-related data;

3. The Role of the Quantity Surveyor

The QS profession is generally concerned with the cost control and management of construction projects to attain a high level of quality and value within the scope of project specifications and requirements. One of the main QSs responsibilities is to provide advice for employing an appropriate strategy for a clear vision of the cost-related aspects of building projects from inception onwards. QSs are involved in a wide range of imperative activities, such as quantification and costing, contract practices & administrations, procurement & tendering, design economics, cost planning, construction technology and environmental services, and sustainability (Wu, Wood, *et al.*, 2014; Babatunde *et al.*, 2018; Gilchrist *et al.*, 2021; Tee & Kamal, 2021). The QSs activities are generally distributed into four key project phases: 1) inception, 2) pre-contract, pre-construction or design, 3) post-contract or construction, and 4) post-construction or Operating and Maintenance (O&M) (Wong & Yew, 2017; Gilchrist *et al.*, 2021). The level of information available to QSs relies on the project phase. For example, the inception stage may include a brief description of the proposed project or even an idea of the project, and it might also include some 2D primary drawings. Different cost estimation approaches are employed in the costing process depending on the project phase, such as conceptual estimate, also known as Rough Order of Magnitude (ROM) estimate, schematic design estimate, detailed estimate, and definitive estimate (Iqbal *et al.*, 2013; Vigneault *et al.*, 2020). Figure 2 briefly illustrates potential project phases, available information level, cost estimation types, costing techniques, and some common uses of outputs.

However, like many other professions within the AEC industry, the QS profession is also an evolving sector that requires improvements in the professional services needed to achieve the industry's ever-changing conditions (Gilchrist *et al.*, 2021). The QS traditional practices – still practised by some of the QSs and, in particular, Small and Medium-sized Enterprises (SMEs) – were concerned with manually measuring or surveying quantities (quantification process) for proposed construction works using 2D drawings and paper-based documents (Moses *et al.*, 2020). Approximate cost estimates were prepared using a single costing method followed by the client's acceptance and the design process's commencement. However, with the introduction of technological advances, such as Computer-Aided Design (CAD) technologies, to the QS profession, the scope of QSs roles has extensively evolved into a more comprehensive and effective practice (Cheung *et al.*, 2012; Babatunde *et al.*, 2019). In terms of CAD technologies utilised in the construction industry, the Autodesk AutoCAD application could be a good example that generates 2D drawings used for measurements and quantification processes.

Nevertheless, one of the key limitations of 2D-based documentation systems is that information required to implement an effective and efficient cost estimate is distributed among different documents in diverse formats (Vigneault *et al.*, 2020; Gilchrist *et al.*, 2021). Processing these data may result in errors that may cause flaws in other aspects of building projects, such as delays in delivering a project. It is well-established that some of the limitations of 2D documentation systems can be rectified by integrating more advanced processes and corresponding technologies, such as Building Information Modelling (BIM) processes (Liu *et al.*, 2016; Vigneault *et al.*, 2020; Tee & Kamal, 2021).

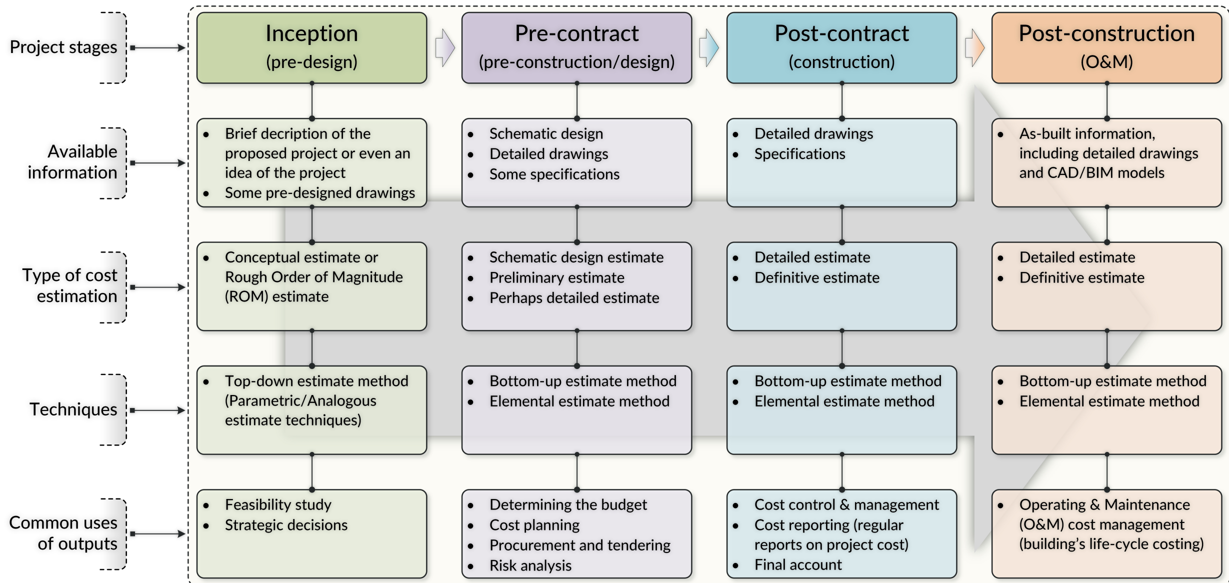

Fig. 2: General description of project stages, available information, costing methods, and common outputs.

4. BIM applications in the QS domain

Building Information Modelling (BIM) is a well-known term in the AEC industry, and its emergence has remarkably changed how the construction industry operates. BIM as a process is more than generating 3D models of buildings. It provides the opportunity to drive efficiency and effectiveness to the IT and IM of building projects (Sadeghineko *et al.*, 2018a). Accordingly, Building Information Models (BIMs), typically known as three-dimensional parametric models, are fast becoming the comprehensive information source in different sectors of the AEC industry, e.g. O&M-related information in the Facilities Management (FM) domain and cost estimation-related data in the QS profession (Ismail *et al.*, 2016; Sadeghineko *et al.*, 2018b). BIM models as digital resources and virtual representations of physical and functional characteristics of a building project are considered imperative parts of a BIM process. The use of BIM processes in a construction project enables a shared source of information among the project team, forming a reliable platform for the decision-making process throughout the entire life-cycle of a building project (Wu, Wood, *et al.*, 2014; Sadeghineko & Kumar, 2021).

Concerning the QS practices, the application of BIM can provide a feasible solution to some of the limitations related to the manual processes of quantification and cost estimations (Liu *et al.*, 2016). It is well established that the application of BIM within the QS domain is more efficient than the manual cost estimation process, leading to cost reduction due to the modelling accuracy of BIM-enabled applications, thus resulting in precise quantification and Quantity TakeOff (QTO) and overall project performance improvement (Abanda *et al.*, 2015; Choi *et al.*, 2015; Adesi *et al.*, 2018; Gilchrist *et al.*, 2021). Moreover, BIM-enabled projects provide QSs with substantial involvement and collaboration in the pre-design and design phases compared to the traditional 2D approach (Ismail *et al.*, 2017), depending on the BIM model Level of Detail (LoD) (Moses *et al.*, 2020). BIM models with appropriate information allow more accurate cost estimation than traditional methods throughout the project life-cycle from pre-design to post-construction phases. In this regard, several studies have been carried out proposing different approaches for integrating BIM applications and QS practices to improve the quantification and cost estimate processes, reduce the time spent on creating costing-related documents manually, generate accurate data, and control costs throughout the construction process effectively (Mayouf *et al.*, 2019; Gilchrist *et al.*, 2021).

The study carried out by Choi *et al.* (2015) proposed a QTO procedure by developing a QTO prototype system focusing on BIM models to enhance the schematic cost estimation at the early design stage (pre-design phase). The approach focuses on pre-designed reinforced concrete and steel framework components generated in Autodesk Revit as a BIM-driven application. The associated measurement codes are manually combined with the model through the project parameter feature of Revit. The prototype system is then developed based on the connection between the data properties, such as area and volume, extracted from the BIM models (concrete and steel frame components) and their corresponding unit costs. The schematic cost estimation is then carried out based on the information extracted from databases.

Some other studies have recently been carried out investigating the concept of 5D BIM, with 4D being the time and 5D the cost (Aragó *et al.*, 2021; Kim & Park, 2016). It is highlighted that a successful implementation of 5D BIM processes can be a feasible solution to some of the challenges involved in QTO, cost estimation, and Bill of Quantities (BoQ) processes of QS. However, its implementation within the industry, specifically the QS domain, relies on different elements, such as the quality of the model, the level of automation for taking off quantities, lack of compatibility between BIM-enabled applications and the store, reuse and sharing process of cost data, lack of formalised and digitised classification systems, appropriate technological integration between interoperability tools, and professionals skills (Smith, 2014; Plebankiewicz *et al.*, 2015; Kim & Park, 2016; Moses *et al.*, 2020). An example of a 5D BIM approach could be the work undertaken by Moses *et al.* (2020) concerning the development of a BIM-based framework for facilitating the 5D BIM implementation for the 5D costing purposes from a contractor perspective. The framework intends to facilitate the adoption of 5D BIM costing processes within three levels. Strategic – concerning decision-making based on the project brief, objectives, requirements, defined quality, timeline, and 5D cost performance. Operational – concerning a more collaborative cost management process through a virtual environment like the 5D BIM process. Technological – concerning the use of BIM-driven tools and technologies for digitalisation and automation of 5D cost estimate.

Industry Foundation Classes (IFC) is one of the industry standards widely adopted by experts when using BIM-enabled applications (Abanda *et al.*, 2015; Moses *et al.*, 2020; Sadeghineko & Kumar, 2020a). As a data exchange standard in the building industry, the IFC data model was developed by buildingSMART. It is the most well-known and widely used set of standards for exchanging information about a building among diverse IFC-compliant BIM applications. Moreover, the main idea behind the development of the IFC is to facilitate communication between BIM-driven applications (Sadeghineko & Kumar, 2020b). After almost two decades of IFC development, the current stable version of IFC (IFC 4 ADD2 TC1 Official version at the time of writing this paper) has made considerable progress, with more than 700 classes, thousands of attributes, and a dense network of relationships among its classes which makes it more complicated for end-users within the industry (Sadeghineko & Kumar, 2020a). However, Abanda *et al.* (2017) state that understanding the IFC data model and the rules of measurements is a key player in understanding the cost estimation process. Although the IFC data model has some limitations and implications representing all kinds of data embedded in a BIM model (Cheung *et al.*, 2012; Sadeghineko & Kumar, 2020a), it is the only practical, de facto, and open-source tool widely adopted within the AEC industry and is capable of representing the geometrical data about building objects which is critical for the QTO procedure.

Lawrence *et al.* (2014) proposed a prototype system that uses the ifcXML format of the BIM models as the input data. The MasterFormat classification system presents the cost estimate data in the proposed system. Project mappings are manually created from the cost estimate data and models by experts familiar with costing processes and BIM modelling procedures. The approach implementation is based on designed queries (queries are machine-readable statements designed to compute sets of values) run against the building design and extracted views. The query types, including aggregated quantities, proxies, and spatial queries, are structured to extract information from the design and views. The retrieved values are then utilised to manually produce the QTO, cost estimation, and BoQ documents. The IFC and ifcXML formats are used in the proposed approach to retrieve data types. However, as mentioned previously, the IFC data model has certain limitations for representing all kinds of data, mostly non-geometrical data. It can also not fully and properly exchange information between two different BIM-enabled applications locally and globally, although it is designed to be a universal data exchange standard (Kim & Park, 2016; Sadeghineko & Kumar, 2020a).

Although the literature suggests that the adoption of BIM is notably gaining interest within the QS domain, with substantial research carried out around a considerable range of topics, there are still challenges and limitations that require addressing to improve the efficiency and effectiveness of the QS profession. Some of the current challenges requiring further investigations include the Level of Development/Detail (LoD) and Level of Information (LoI) embedded in BIM models, such as geometrical and non-geometrical data; local and global measurement coding standards; lack of interoperability and incorporation protocols and standards in terms of storing, sharing, and reusing the data; and IT and IM standards, tools and technologies.

Concerning the use of BIM processes in a building project, one of the key challenges within the QS industry is the lack of effective integration of standardised measurement coding systems and BIM-enabled environments (Kim & Park, 2016; Moses *et al.*, 2020). It leads to the limited adoption of BIM processes and related technologies within the QS domain, resulting in inconsistent modelling standards and quantified data inaccuracy (Smith, 2016). It is also critical to note that BIM and cost estimation approaches use different representations of data and different sets of vocabularies related to building components and their corresponding cost data (Lawrence *et al.*, 2014). Hence, a standardised approach of integrating measurement standard databases with BIM-driven applications could be a feasible solution to the current limitations and challenges within the QS practices in terms of quantification and costing processes. Moreover, adopting advanced IT and IM-related technologies and standards for creating a more structured cost information output with an appropriate LoD and LoI fit for quantification parameters and digital measurement uses could lead to more enhanced and efficient cost estimation, QTO, and BoQ hence improving the project implementation from inception onwards. The QS profession will also benefit from using such technologies and standards, providing more reliable information delivery and checks, more coordinated semantically enriched information, alignment between standards and BIM, more efficient design process, increased cost data reliability, and effective O&M of building assets.

5. Semantic Web standards and technologies within the AEC industry

Semantic Web, as a set of technologies and standards, provides a suitable framework for storing, sharing, and reusing information on the Web. In the past years, Semantic Web technologies have gained growing popularity and interest in different industries, including the AEC industry. It is well-established that the application of Semantic Web technologies and standards, like Resource Description Framework (RDF) and Web Ontology Language (OWL), enhances the level of data quality and distribution and facilitates information exchange and interoperability (Sadeghineko & Kumar, 2021). Hence, studies have been undertaken using Semantic Web technologies and standards to address challenges and limitations related to existing information exchange standards and tools with varying success (Sadeghineko & Kumar, 2020b).

Some of the examples of these are the ontology for IFC, also known as ifc Web Ontology Language (ifcOWL) (Pauwels & Terkaj, 2016), an ontology for COBie (COBieOWL) (Farias *et al.*, 2015) and ifcJSON (ifc JavaScript Object Notation) (Afsari *et al.*, 2017). The main idea behind developing such schemas is to use existing information about a building and convert it into OWL ontologies, predominantly used to store and share the information on the Web. However, Semantic Web technologies can be used to enhance the database structure and increase the accessibility of data. Structuring databases based on web-based principles could be more efficient and effective in data management and manipulation (Sadeghineko & Kumar, 2021). While some studies focus on using Semantic Web technologies and standards to improve existing data exchange tools, others focus on developing Web-based ontologies to describe construction-related information.

Contrary to the proposed and developed Web-based schemas, other studies focus on developing Web Ontologies to represent structured Web data, which can also be used as Linked Data (LD) or Linked Open Data (LOD). Currently, communication between diverse applications is predominantly through diverse file formats with an implicit relationship between the data (Sadeghineko & Kumar, 2020b). However, the Semantic Web concept can be a feasible solution to some limitations that hamper appropriate communication between diverse data sources within the AEC industry, including the QS domain. The main idea behind Web-based data is to use Semantic Web technologies, standards, and applications to combine data distributed in different data formats and enhance data interoperability, reasoning and querying with an appropriate LoD in terms of vocabulary and terminology.

Moreover, Web-based ontologies are Web-centric datasets that provide a mechanism for gathering heterogeneous data formats and presenting them in a homogeneous format. Semantic Web standards like RDF and OWL are utilised as the main structure, i.e. any type and format of data can be combined with other ontologies from other domains as long as they use the same fundamentals (Sadeghineko & Kumar, 2020b). Nevertheless, studies have recently been carried out proposing and developing minimal Web ontologies, such as Building Topology Ontology (BOT), Ontology for Managing Geometry (OMG), and Building Product Ontology (BPO), for describing building data on the Web or as LD/LOD. The BOT, OMG, and BPO ontologies are developed by World Wide Web Consortium (W3C) Linked Building Data Community Group (W3C LBDCG) for storing and sharing data on the Web. BOT is a modular building ontology developed for expressing the topology of a building (e.g. Site, Building, Space and Building Element) (Rasmussen *et al.*, 2020). OMG has been developed to facilitate the reuse of linked geometry descriptions of an object on the Web (Wagner *et al.*, 2019). BPO is a minimal ontology designed to describe non-geometrical data, predominantly assembly structures, relationships and connections between product components, properties and property values related to their corresponding building products and elements (Wagner & Rüppel, 2019).

One of the many advantages of Web-based ontologies is that they can be extended with other ontologies (i.e., multiple ontologies can be combined to create an extended ontology) structured based on Semantic Web standards. Moreover, the main idea behind developing such minimal ontologies is to employ these ontologies and extend other ontologies if required. An example of utilising minimal ontologies to extend the base ontology could be the study by Sadeghineko and Kumar (2020b) and Sadeghineko and Kumar (2021). The proposed approach focused on using different existing ontologies to extend the base ontology (sbim) for facilitating the information exchange for 3D retrofit building assets. The vocabulary used in existing ontologies is used as the primary terminology, and new vocabulary are appended to the base ontology where required.

The concept of Web-based ontologies has also been used within the QS domain to facilitate and improve the exchange of cost-related information between BIM-driven applications for quantification, cost estimation, and BoQ purposes (Niknam & Karshenas, 2015; Abanda *et al.*, 2017; Wu *et al.*, 2020) with little success in contrast to other sectors within the construction industry. The work carried out by Abanda *et al.* (2017) focuses on structuring an ontology for measurement methods, NRM in particular, that is later used in BIM-enabled applications to facilitate the costing process and improve the cost estimation inaccuracies in a 5D BIM environment. Web-based ontology features make the data machine-readable, reducing human intervention and improving data quality (Sadeghineko & Kumar, 2020a). The Protégé OWL editor is used to generate the ontology for NRM manually. SQWRL (Semantic Query-Enhanced Web Rule Language) is employed to extract certain information from the ontology. SQWRL is a query language providing an array of operators that allows users to construct and run queries against OWL ontologies (O'Connor & Das, 2009).

According to Abanda *et al.* (2017), the main idea behind creating an ontology version of NRM is twofold. First, reasoning over the building items using the SQWRL, and second, using the ontology for QTO. The created ontology is converted into XML (eXtensible Markup Language) o be utilised in Autodesk Navisworks Manage software. The cost-related data is then manually generated in the software. However, the main idea behind creating Web-based ontologies is to store, share, and reuse data on the Web, which is not trackable in the proposed approach, i.e., the proposed method can be considered a local procedure rather than a Web-based approach. Another simple approach for integrating NRM code with BIM is to combine the NRM code with the model through the shared parameters feature of Autodesk Revit. The code can then be imported into Navisworks Manage software with the model and used to manually generate cost-related data. Nevertheless, there are also other studies aiming to address some of the challenges by using Semantic Web technologies and standards with varying success, such as the work carried out by Staub-french *et al.* (2003) proposed an ontology for supporting construction cost estimation; Lee *et al.* (2015) created an ontological interface of construction work items within a BIM-enabled environment; and Niknam and Karshenas (2015) proposed an approach for integrating distributed sources of data for cost estimating purposes.

6. Semantic Web-based terminology

One of the imperative outcomes from the extensive literature review carried out for this ongoing research which can be one of the common challenges in the construction industry without considering the sector and domain, is that datasets (databases) are produced in different data formats, making the data manipulation, interlink and management processes inefficient. Regarding the QS profession, although integrating new and advanced technologies provides few solutions to the challenges and limitations within the QS industry, most standard systems are still text-based and stored in diverse formats like XML (Abanda *et al.*, 2015). They also require regular and manual editing, reducing data reliability and accuracy during the project life cycle. The use of diverse data formats also directly impacts data sharing, long-term access to data, and data preservation (Martínez-Rojas *et al.*, 2016; Sadeghineko & Kumar, 2020a, 2021). Hence, using a single standard format could be a feasible solution to some of the challenges involved in IT and IM aspects of construction projects, including the QS domain.

The ongoing research reported in this paper aims to use Semantic Web technologies, standards, and applications to create a detailed and comprehensive dataset that can be linked to BIM models providing live and interlinked data in terms of project cost management. It can be utilised in the QS practices for different purposes, such as detailed Work Breakdown Structure (WBS), quantification, costing, tendering, Cost Value Reconciliation (CVR), and future commercial management. The general workflow of the research process for digital data and cost management framework can be classified into three key phases, viz. 1) Terminology identification, 2) Web-based dataset creation, and 3) BIM integration (Figure 3). However, the focus of this paper is to initiate the identification of an appropriate terminology that can be applied to building projects locally and globally (Phase 1 in Figure 3).

One of the most pivotal and challenging steps for creating ontologies for QS activities is to adopt a common vocabulary. With regard to QS practices, there are several classification systems and resources that can be considered when identifying the terminology. Examples of these classification systems include New Rules of Measurement (NRM), NBS Uniclass, Uniformat, and MasterFormat (Phase 1.1 in Figure 3). It is important to investigate these classification systems to identify and structure a comprehensive dataset that can be used in most QS activities locally and globally. The NRM system has been employed as the primary dataset to structure the initial vocabulary based on groups, elements, sub-elements, and components. NRM is developed by the Royal Institution of Chartered Surveyors (RICS), comprising three documents (volumes), viz. NRM1, NRM2, and NRM3.

- NRM1: Order of cost estimating and elemental cost planning for capital building works;
- NRM2: Detailed measurement for building works;
- NRM3: Order of cost estimating and cost planning for building maintenance works;

NRM generally consists of 14 group elements from which the first 7 groups cover the building works, starting from group element 0. The remaining groups focus on existing buildings, external works, preliminaries, etc. The building works group elements are initially used to create the primary terminology consisting of five levels. This research uses similar expressions to the NRM documents to develop the ontological levels. Level 1 is the main group element. Levels 2 and 3 focus on the sub-categories of group elements, and Levels 4 and 5 contain more detailed vocabulary describing details about components and their user-defined additional information (Figure 4).

The next step of Phase 1.1 (Figure 3) is to identify similarities and differences between the NRM as the primary dataset and other existing classification systems, such as National Building Specification (NBS) Uniclass 2015, Construction Specifications Institute (CSI) UniFormat and MasterFormat, to construct a common vocabulary database that includes most of the vocabulary shared between candidate documents. In addition to the Uniclass tables, the NBS Chorus content database has also been used in this research to access more detailed elements, systems, and products for enhancing the vocabulary identification process. Figure 5 describes an example of a comparison between NRM, Uniclass, UniFormat, and MasterFormat, focusing on some roof structure components as a superstructure group element in NRM documents. The NRM and Uniclass classification systems are designed for the UK construction industry. They are structured differently in terms of levels and how specifications are described in the database. The CSI UniFormat and MasterFormat are designed for US-based construction works. UniFormat covers up to three levels of divisions (i.e., specifications) and elements are general in character in this system. MasterFormat provides a more detailed description level, which can be mapped to the UniFormat's general specifications. The MasterFormat detailed descriptions are mainly presented in Levels 4 & 5 (Figure 5).

As shown in Figure 5, green texts are vocabularies that occur in almost all documents and can be categorised as common vocabulary and utilised in the Cost Estimation Ontology (CEO) in Phase 2 (Figure 3) to construct the ontology classes, sub-classes, individuals, type and data properties by adopting an appropriate and practical methodology. Moreover, some identified vocabularies can be considered synonym vocabularies. For example, the word 'pitched' occurs in the 'Pitched Roof' expression in the NRM and Uniclass databases, and 'slope' is used in the MasterFormat system (red texts in Figure 5). These types of synonyms can be dealt with at the ontology development phase by including additional layers of interpretation that capture data semantics.

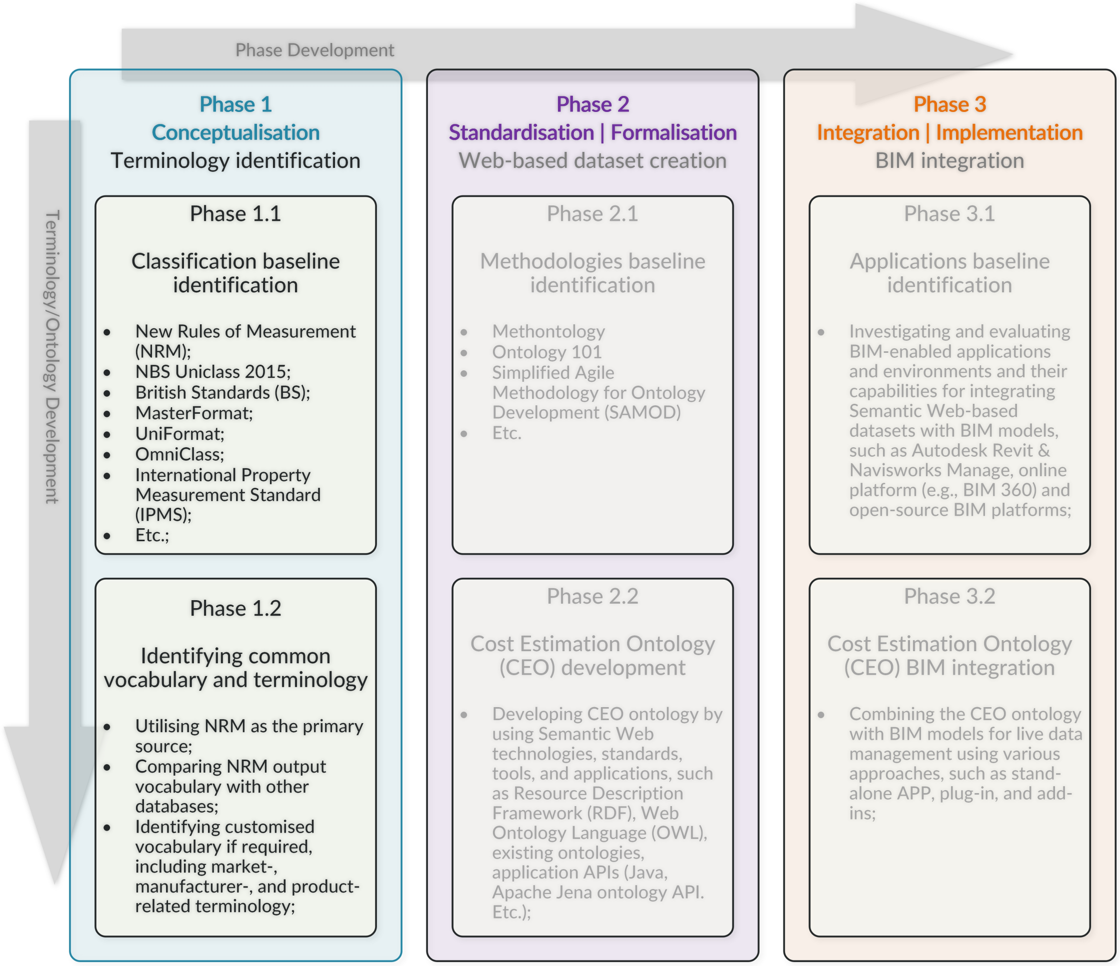

Fig. 3: Research workflow.

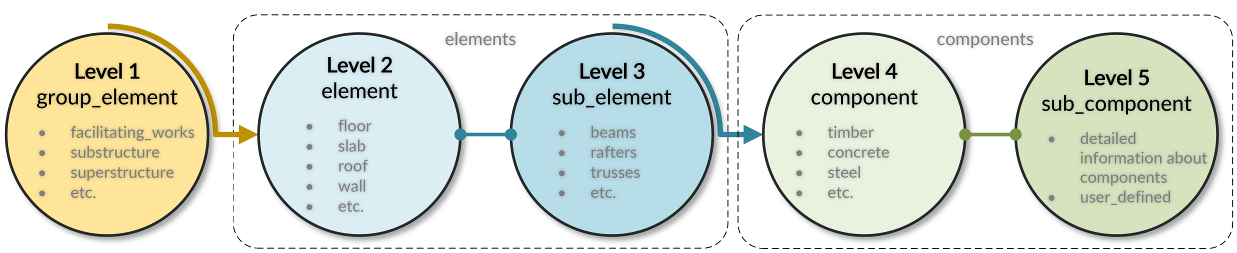

Fig. 4: Primary terminology levels.

7. Conclusions and Further Research

The research presented in this paper focused on first reviewing the literature to identify the challenges and limitations in CAD applications within the QS profession concerning the BIM context and the effective implementation of IT and IM-related technologies. Second, the existing classification systems and corresponding terminology were explored to identify a common vocabulary that the QS profession can adopt throughout the building project phases. Semantic Web technologies within the AEC industry, including the QS domain, were also explored to identify existing ontologies and their pros and cons to establish an appropriate development approach for creating the CEO ontology. Using a common terminology database created based on existing classification systems will improve the LoD and LoI required in the QS

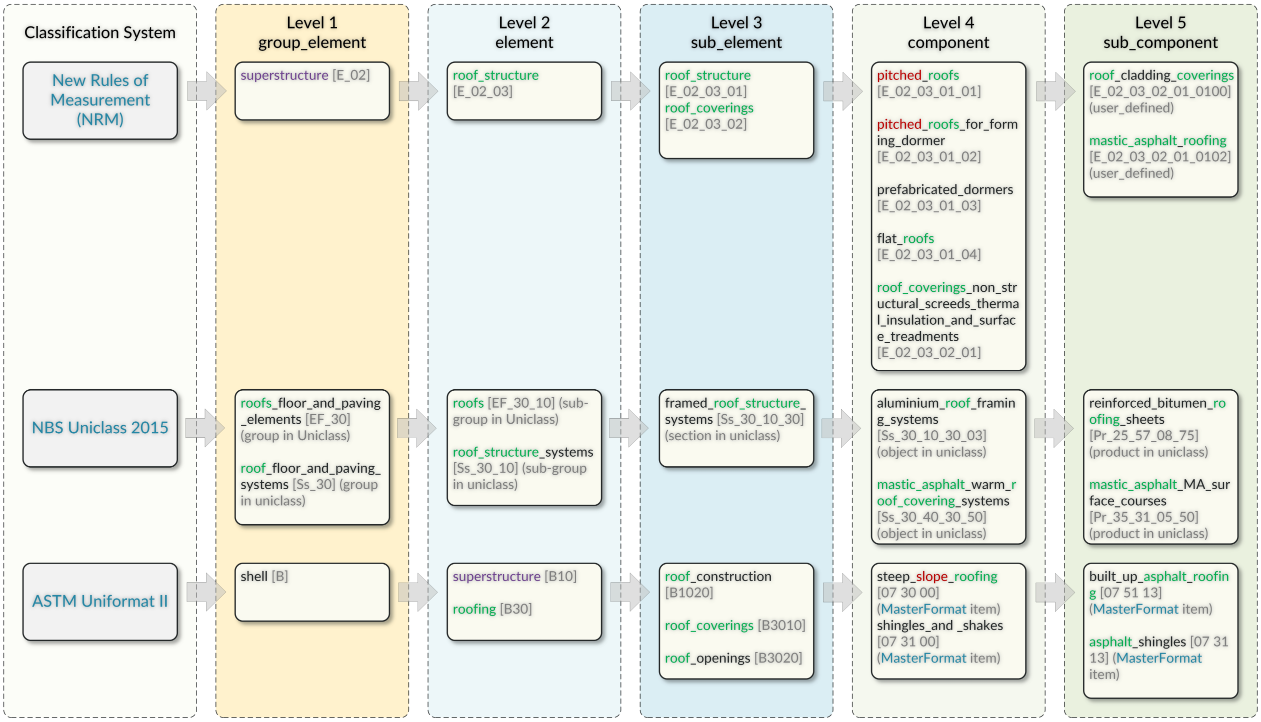

Fig. 5: An example of similarity and dissimilarity identification between classification systems.

profession. It also provides an imperative baseline for developing the CEO ontology.

One of the challenges in creating a common vocabulary database is the differences between existing classification databases, such as synonyms, terms and expressions that appear in only one database, and user-defined data (e.g., market-based and product-specific vocabularies). However, the Semantic Web provides a wide range of technologies and tools that can be used to address most of these challenges. For example, additional layers of interpretation will provide feasible solutions to rectify current challenges and limitations and improve the LoD and LoI of the CEO ontology. Nevertheless, the future steps of this research are to identify an appropriate and practical methodology for developing the CEO ontology in Phase 2 and implementing the BIM-based integration in Phase 3. Furthermore, one of the important steps of this research is to use the 'measurement rules for components' section in the NRM documents and similar sections in other databases to include datatype constraints and additive property constraints in the CEO ontology by adopting web-based constraint languages, such as Shapes Constraint Language (SHACL) and Shape Expressions (ShEx). This additional functionality produces a more efficient and functional cost estimate procedure. Consequently, it can improve the QS output accuracy and the building project performance.

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