Employment of Semantic Web Technologies for Capturing Comprehensive Parametric Building Models

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Abstract

Building Information Modelling is a well-known acronym in the construction industry. BIM process is more than modelling buildings, and it provides the opportunity to drive efficiency and effectiveness to the information management of build projects. Accordingly, Building Information Models (BIMs), typically known as semantic three-dimensional parametric models, are fast becoming the comprehensive information source in Architecture, Engineering and Construction (AEC), and Facility Management (FM). The use of BIM in existing buildings has been hampered by the challenges and limitations surrounding the available technologies. The most popular and commonly used approach for generating models is to manually generate 3D artefacts utilizing point measurements extracted from range-based technologies (typically 3D laser scanning). In the recent past, several studies have been carried out to make the retro t BIM development process as effective and efficient as possible by developing different methods for mapping 3D models using Point Cloud Data (PCD) as the main source of information. However, an appropriate fully generated parametric model is still some way away. In this paper, we review the-state-of-the-art to address the research gap and challenges involved in generating parametric models before outlining the proposal of our approach. In this research, we employ Semantic Web technologies to capture parametric models. Elements are first recognized in PCD, and corresponding geometric information extracted from PCD are then tagged with Universally Unique Identifiers (UUIDs). Tags are then linked with the generated Resource Description Framework (RDF) data for each element. The core and challenging part of this research is the standardization process where RDF as a serialization is translated to Industry Foundation Classes (IFC) as a data model. The generated IFC format is then utilized to capture corresponding models. The primary results are very promising and should be of interest to the modelling of all kinds of building components, particularly historical building information modelling (HBIM).

Keywords

Building information modelling • Semantic web technologies • Resource description framework

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I. Mutis and T. Hartmann (eds.), *Advances in Informatics and Computing in Civil and Construction Engineering*,
https://doi.org/10.1007/978-3-030-00220-6_14

14.1 Introduction

Building Information Models, typically known as semantic three-dimensional parametric models, are fast becoming the comprehensive information source in Architecture, Engineering and Construction (AEC), Facility Management (FM), and other associated domains [1]. The use of BIM process in build projects improves different aspects of an asset during its life-cycle, such as the decision-making process and the precision of the design during the planning process, data management, productivity, energy efficiency, sustainability, and health and safety of construction [1–4]. A semantic-rich parametric model contains two types of information, including the geometric representation of an object (geometric data) and the non-geometric information that needs to be added to the object for further use during the building's life-cycle. The use of semantic-rich parametric models has lately gained a lot of momentum in new build project for exchanging the information throughout a buildings life-cycle from the inception onwards [1, 5]. However, its use in existing assets, particularly in Historical Environments, has been hampered by the challenges and limitations surrounding the available technologies for developing retro t models. Practically, after the termination of new build projects, models captured from the initial design of a building do not necessarily coordinate with the as—built dimensions due to varying updates introduced to the asset during the construction period [6]. In a different manner, in unique conditions, such as existing assets and historic buildings, the facility may not have a proper 3D model, and the only accessible data are 2D drawings and corresponding documents. Accordingly, in the past years or so, several studies have been carried out proposing automated or semi-automated approaches for projecting BIMs utilizing 3D point measurements, typically known as Point Cloud Data (PCD). The workflow of generating BIMs using PCD can be categorized into two general processes consisting of Scan-and-BIMs and Scan-to-BIMs. The Scan-and-BIMs process involves approaches in which the as—designed 3D model is available and discrepancies, which occur between initial designs and as—is conditions, are identified by matching the datasets [7]. On the other hand, Scan-to-BIMs process is applied where the existing asset does not have a 3D model and PCD is therefore used as the main source of information for capturing BIMs [5, 8].

Historic Building Information Modelling (HBIM) has lately gained significant interest in heritage domain concerning the development of a suitable BIM frame-work for modelling historical monuments [26, 32, 33]. The suitability of HBIM framework relies on the model representation quality [27], reliability of generated geometries [9], and more importantly, required asset information embedded in models. A detailed and semantic representation of HBIM can be useful for addressing an appropriate Level of Detail (LoD) in advancing the HBIM framework. In order to collect the data from an existing asset, varying technologies are available for gathering required data in the form of images or point measurements, typically known as image-based or range-based methods [10]. Photogrammetry and Videogrammetry are considered as the commonly used data collection techniques in the image-based domain [1, 11, 12]. On the other hand, 3D Laser Scanning, as a range-based technique, is an accurate, popular, and most commonly adopted technology for extracting data from an existing building in the form of PCD [1, 6, 11, 13]. One of the challenges involved in generating reliable models from point measurements extracted from laser scanner is to record and analyze the information embedded in PCDs. The process is currently carried out manually which is a time-consuming, tedious, and error-prone owing to the human intervention [2, 14]. Although some progress has been recently made in generating parametric models from PCDs, a proper full-blown parametric model is still some way away.

In this paper, challenges and limitations involved in generating parametric models from PCD are addressed by reviewing state-of-the-art before presenting our approach. We use Semantic Web technologies, such as Resource Description Framework (RDF) in our approach to capture BIMs and manipulate the meta-data within the models. Figure 14.1 illustrates the workflow of proposed approach classified in four general steps consisting of (1) Data aggregation, (2) Data processing, (3) Data standardization, and (4) BIM capture. The first step involves extracting the information from an existing asset in the form of PCD and using corresponding 2D drawings and documents to append required information to the final result. In the data processing step, building components are recognized in the PCD, and the extracted geometric information for each element is tagged with a UUID (Universally Unique Identifier) or GUID (Global Unique Identifier). The unique Identifiers are used later to link the RDF data generated for each element to the corresponding data extracted from PCD in order to create linked data. In the third step, the SPARQL (SPARQL Protocol And RDF Query Language) is then used to extract the information required for the RDF-to-IFC translation process. The translated IFC is then used in the final step to generate the corresponding model by importing IFC into any BIM software that supports IFC format. The results of the proposed approach in this ongoing research are promising and should be of interest to the modelling of all kinds of assets, in particular, Historical Building Information Modelling (HBIM).

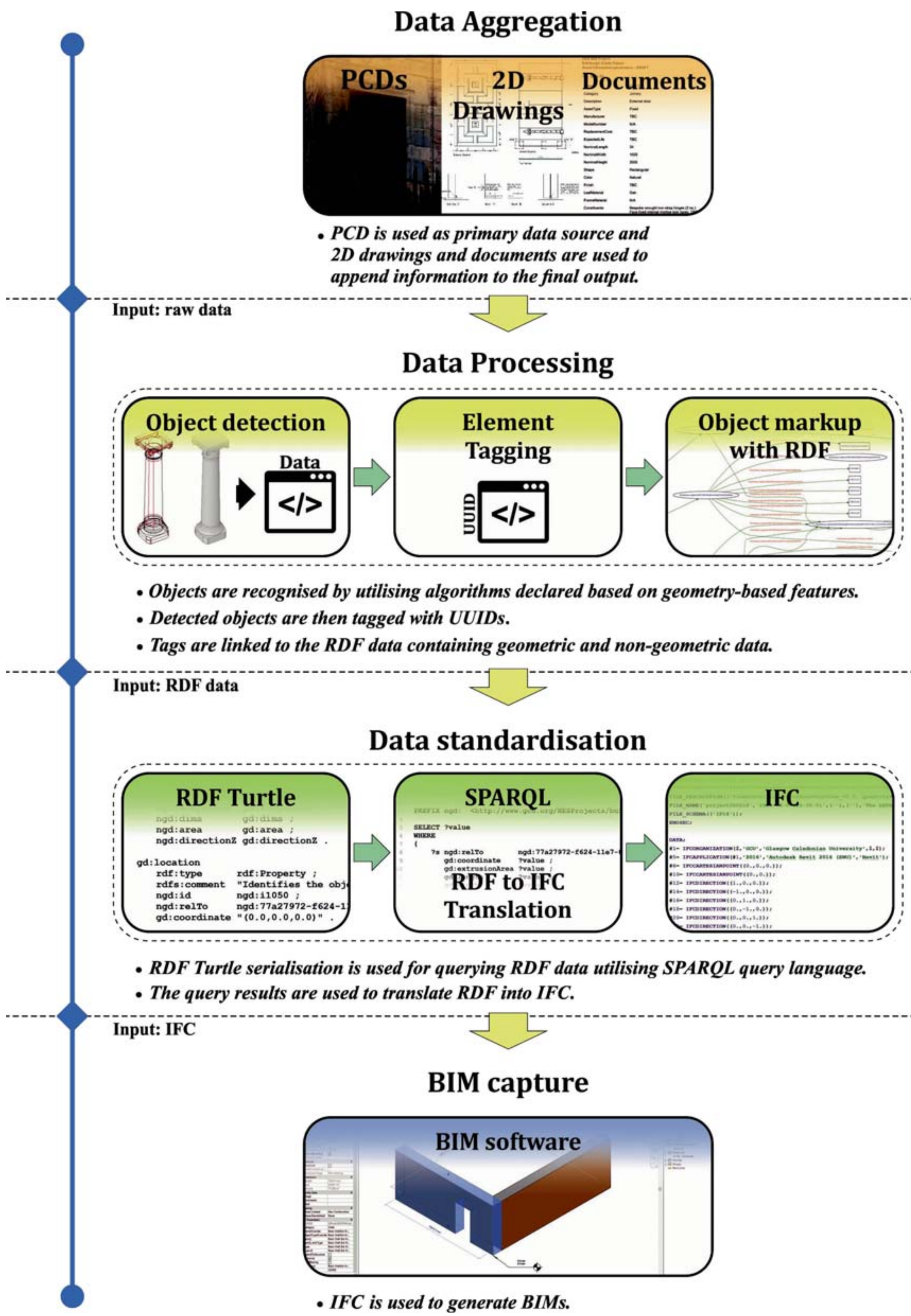

Fig. 14.1 The workflow classification of proposed approach [30]

14.2 Related Work

In the past years, several studies have been conducted to declare automated and semi-automated approaches for generating parametric models by using PCD as the main source of information. Proposed approaches are classified into two directions, including Scan-and-BIMs and Scan-to-BIMs. In the case of the availability of the CAD model (3D model), which represents the as—design condition of an asset, the process of generating BIMs is implemented through Scan-and-BIMs process where datasets are matched and compared together for the discrepancies identification and the BIM capture process. The approach proposed in Gao et al. [3] represents different algorithms for generating BIMs based on the Scan-and-BIMs process. In contrast, an existing building may not have a 3D model, and 2D drawings and documents are the only available information. In this case, the process of generating BIMs is performed through Scan-to-BIMs approach using PCD as the primary data source [8]. In this case, geometric features embedded in PCD, such as lines, boundaries, geometric primitives, and so forth are used to generate building components. The work proposed in Zhang et al. [8] is based on Scan-to-BIMs process and focuses on detecting planar patches (surfaces) of building elements using PCD as the main data source. The relationship between points and lines (shape boundaries) as geometric features are employed for the identification of object surfaces. Similar approaches—e.g. the work presented in Xiong et al. [15], and Adan and Huber [16]—have been proposed to recognize interior and exterior building elements like walls, floors, ceilings, and openings using different types of geometric spatial characteristics, such as connectivity, relative distance, and contextual relationship between points and corresponding elements.

According to the heritage environments, an accurate representation of 3D parametric models affects the performance of restoration, conservation, retrofitting, building analyses, and facility management processes [5, 17, 18]. Historical buildings in contrast to the new build projects contain complex building components, and commercial BIM software does not support such geometric complexity as they are designed to model new build projects, and are limited to irregular shapes occurring in HBIM [5]. The approach proposed in Barazzetti et al. [17] focuses on the reconstruction of an existing building in a historical environment using NURBS (Non-Uniform Rational Base-Spline) characteristics to identify discontinuity lines and corresponding surfaces for reconstructing building elements accordingly. In contrary, other methods are also proposed that concentrate on using predefined libraries of building elements in order to capture parametric models [19]. A semi-automated approach is proposed in Dore and Murphy [5] to capture building components using rule-based algorithms. More information regarding approaches developed based on libraries, and architectural ontologies can be found in Quattrini et al. [9], and Murphy et al. [19].

14.3 Parametric Modelling Using Semantic Web Technologies

14.3.1 Challenges and Limitations

In the past years or so, several studies have been carried out to make the process of generating BIMs (typically known as parametric models) as efficient and effective as possible. However, a single approach may not be applicable for different objects and environments. The level of required information embedded in generated models, which is an important part of BIM process, is one of the challenges involved in capturing BIMs. Information related to a semantic-rich model can be categorized into two general classifications, including geometric data and non-geometric data [6, 20]. Geometric data can be extracted and calculated using PCD, such as Cartesian Points, dimensions, and locations. However, non-geometric data like material, color, finishing specification, security rating, and load-bearing capacity—which cannot be extracted from PCD—needs to be appended to the final model separately to generate a full-blown parametric model. Another challenge that can be addressed is the management and manipulation of large-scale information that is needed to be included in final results. Moreover, building components generated for separate projects may share similar information, particularly in historic environments. In current practice, the information is appended to elements individually due to the lack of information interoperability among detected elements. In addition to that, required asset information is currently stored in different types of databases, such as 3D model and paper-based documents, which makes the data accessibility and management laborious. Edinburgh Castle BIM project illustrated in Fig. 14.2 carried out by Historic Environment Scotland (HES) as a case study in this research could be a good example for mapping BIMs from PCD, and for adding required asset information to the final model manually. One of the challenges involved in HES BIM projects is the management of large-scale information that needs to be added to the model. Currently, the information is stored in varying data formats (e.g. 2D Drawings, 3D CAD

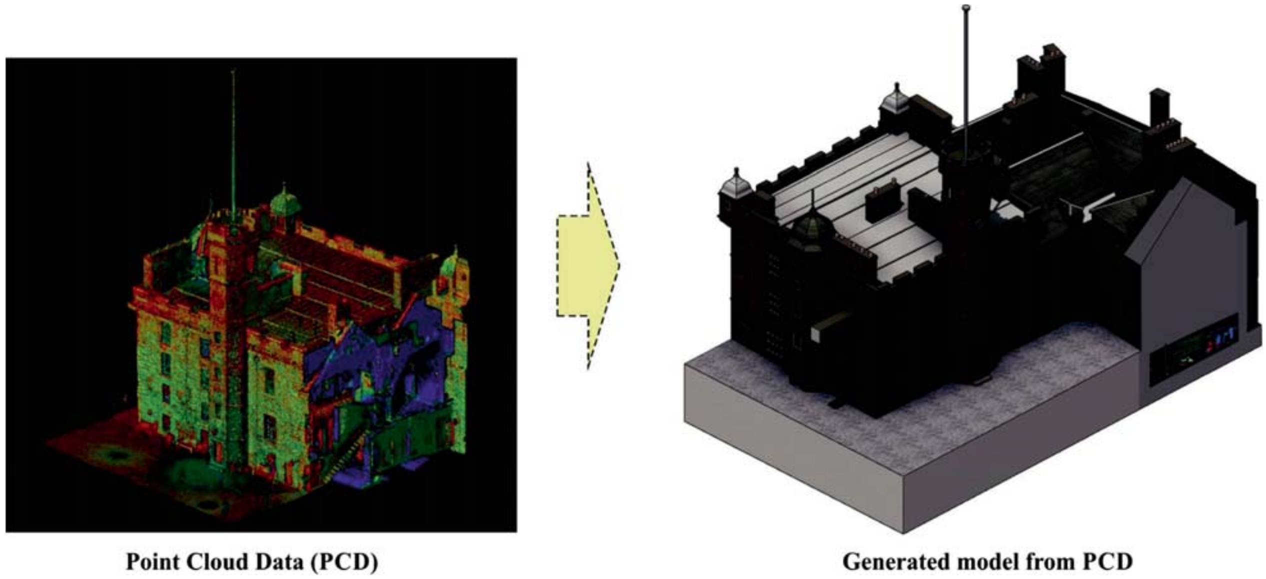

Fig. 14.2 Edinburgh Castle parametric model generated from PCDs [30]

Model, Documents, PDF, Excel etc.) which makes it difficult to access and manipulate the data associated with corresponding building components in the model.

14.3.2 RDF as a Semantic Web Standard and Technology

The use of Semantic Web technologies has lately gained interest and popularity in different domains, including the AEC. In McGibbney and Kumar [21] Semantic Web technologies are used to create a model for the legislation in AEC domain. The project carried out by Quattrini et al. [22] uses Semantic Web technologies for storing and representing information on the web. In this paper, we take advantage of Semantic Web standards and technologies—which provide a suitable framework for storing, sharing, and reusing the information on the web [23]—to attain a proper solution to the challenges and limitations in generating parametric models, particularly handling the large-scale data. RDF, as the most popular and commonly used Semantic Web technology on the web for the description and interchange of the large-scale information [24], is used in this project to append required asset information to the generated parametric models. RDF data in contrast to other databases (DBs) like Hierarchical DBs (e.g. IFC data model) does not have a concept of root or hierarchy. This feature enables RDF to connect resources without hierarchical relationships between them [25]. RDF is structured based on simple statements containing subjects (URI resources), predicates (URI properties), and objects (URI resources or literal resources). Figure 14.3 shows the relationship between nodes (subject, predicate, and object) in an RDF data graph and the TURTLE version for the same graph. The simplicity and flexibility characteristics of RDF data add the advantage to our approach to manipulate and manage the metadata required in parametric models in an unconstrained manner.

14.3.3 Data Aggregation and Processing

As demonstrated in Fig. 14.1, the workflow of our approach consists of four general steps. Data aggregation as the first step involves the collection of required data consisting of PCD as the primary source and corresponding 2D drawings and documents for enhancing the information required to be added to the model. In data processing step, building geometries are recognized utilizing the geometric features embedded in PCD. As mentioned in Sect. 14.2, in the past years or so, several approaches have been proposed for detecting building geometries in PCD with varying degree of success. In our approach, the information (the geometric data) related to detected elements is tagged by unique Identifiers like UUIDs or GUIDs before marking up elements. The markup process consists of two steps. RDF data is first generated for each identified element

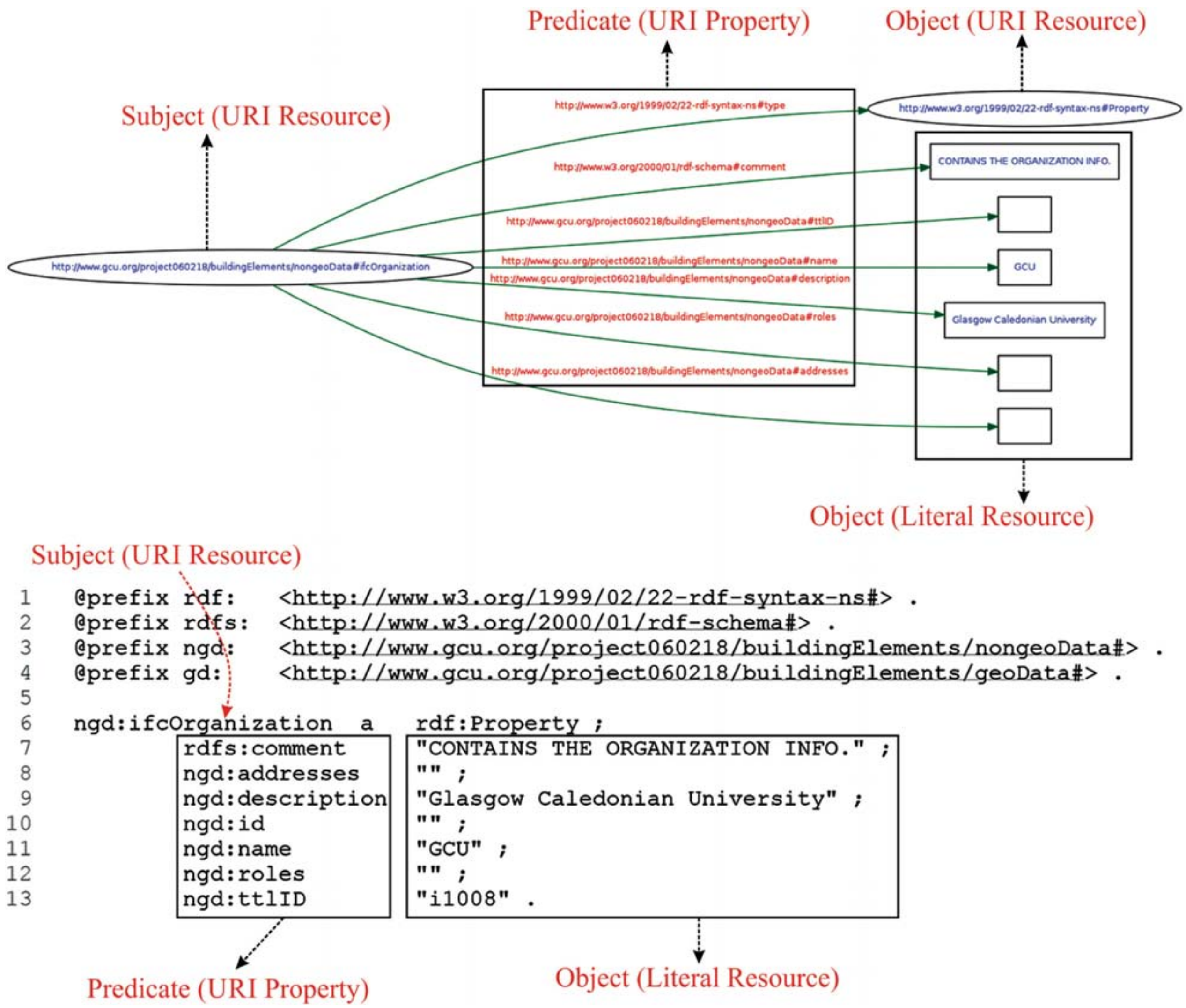

Fig. 14.3 (Top) RDF data graph, (Bottom) RDF Turtle for the same graph

separately as sub-graphs containing both geometric data (gd) and non-geometric data (ngd). Sub-graphs are then linked to the corresponding unique Identifier which links RDF to detected elements. The advantage of creating separate RDF is that the information stored in one sub-graph can be shared among different projects that contain the same information and the final corresponding RDF graph can be generated by merging the sub-graphs (Fig. 14.4). Figure 14.5 shows an RDF Turtle model generated for a wall consisting of asset information required by HES to be included in the final model and stored as linked data.

14.3.4 Data Standardization and BIM Capture

The core and challenging part of this project is the data standardization process where RDF data as a serialization needs to be translated into IFC as a data model. The translation process consists of two steps, including the extraction of required information from the generated RDF data and the generation of IFC using the extracted data. IFC is a standard and commonly used data model for the data exchange within the build projects in the construction industry. RDF model consists

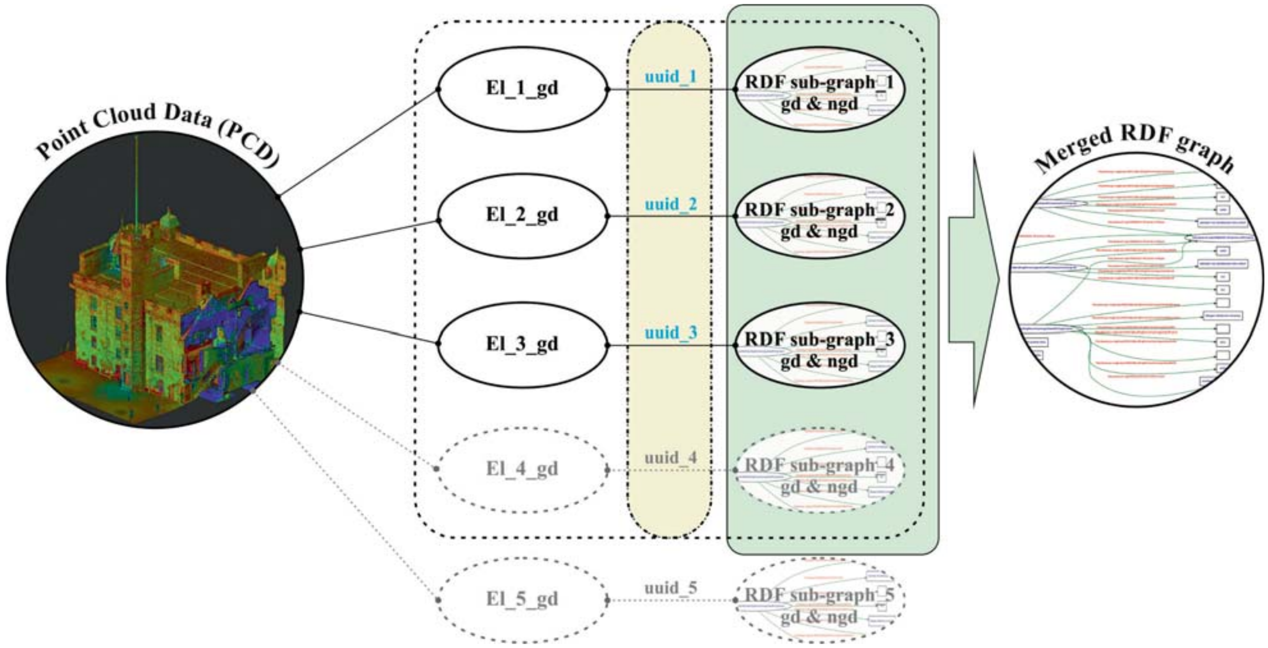

Fig. 14.4 Element mark-up process using RDF

of different types of serializations, such as RDF/XML, N3, N-Triple, and Turtle. The Turtle version of RDF as linked data is used in our approach to structure constant models based on the IFC requirements for generating parametric models. The reason for using RDF as linked data is that IFC data model has some limitations and it cannot represent some of the required asset information due to the constant structure of IFC [1, 2, 28]. In addition to that, the data for an object is represented in different locations in the IFC file, and this makes it difficult to reuse the data for other similar elements in different projects owing to the hierarchical structure of IFC data model [1, 29]. However, the use of RDF as linked data provides the opportunity to store the information and reuse it for similar objects in different projects [31]. RDF data is then generated for building elements based on a constant structure which is useful for future use in other projects if required. The other reason for using turtle format is that SPARQL query language has borrowed its structure from turtle which makes it more compatible with RDF turtle [23].

The SPARQL query language is then employed to retrieve and manipulate data that is stored in the form of RDF data. SPARQL can be used for querying either a simple RDF model (a sub-graph) or a merged model structured from several sub-graphs. An SPARQL query example is shown in Fig. 14.6 querying the sub-graph providing information regarding the organization (e.g., name, description, Identifier, etc.). The RDF model is then translated into IFC STEP by applying the information extracted from the model (query results) using SPARQL. IFC STEP entities are then generated based on the IFC requirements and the pulled data. For example, as shown in Fig. 14.5, the information related to the area of walls ShapeBase, which represented as ngd:wall 1 (subject) and gd:area (predicate) in turtle graph), is used as a planar surface to create the IfcExtrusionAreaSolid for IfcWall entity in IFC format. In the same RDF data, the ngd:pcdReference property with a UUID value is used to link the RDF Turtle to the geometric data extracted from PCD. The UUIDs are also used to represent the connection between different elements (e.g. two walls, wall opening etc.). Figure 14.7 illustrates an example of using extracted data from RDF utilizing SPARQL query for generating corresponding IFC elements. The parametric model is then generated by importing the IFC into any BIM software that supports IFC formats.

```
# filename: wall_1.ttl

@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#> .
@prefix gd: <http://www.gcu.com/projectNum/buildingElements/geoData#> .
@prefix ngd: <http://www.gcu.com/projectNum/buildingElements/nongeoData#> .

ngd:wall_1
    rdfs:comment    "Identifies the geo and non-geo data of a wall." ;
    ngd:pcdReference    ngd:77a27972-f624-11e7-8c3f-9a214cf093ae ;
    ngd:name    "Name" ;
    ngd:idNumber    ngd:HES-ID-Number ;
    ngd:category    "Wall" ;
    ngd:function    "Ext" ;
    ngd:objectType    "Function-Category-WallThickness:TagNumber(77a27972)" ;
    ngd:constituents    "HES-Constituents" ;
    ngd:classification    "HES-Classification" ;
    ngd:drawingReference    "The reference to the drawing related to the wall_1" ;
    ngd:material    "Material" ;
    gd:location    "The centre point of object base extracted from PCD";
    gd:length    "The length of the wall extracted from PCD" ;
    gd:width    "The width of the wall extracted from PCD" ;
    gd:height    "The height of the wall extracted from PCD" ;
    gd:area    "The area of the wall base extracted from PCD" ;
    gd:volume    "The volume of the wall calculated from data extracted from PCD" ;
    gd:weight    "Weight of the object calculated from the volume and material" ;
    ngd:colour    "The colour of the object (RGB)" ;
    ngd:contactPerson    "The responsible person contact detail" ;
    gd:fireRating    "FireRating value based on the object material" ;
    gd:acousticRating    "AcousticRating value based on the object material" ;
    gd:loadBearingCapacity    "Load Bearing Capacity value" .
```

Fig. 14.5 RDF Turtle data generated for walls based on the HES required asset information

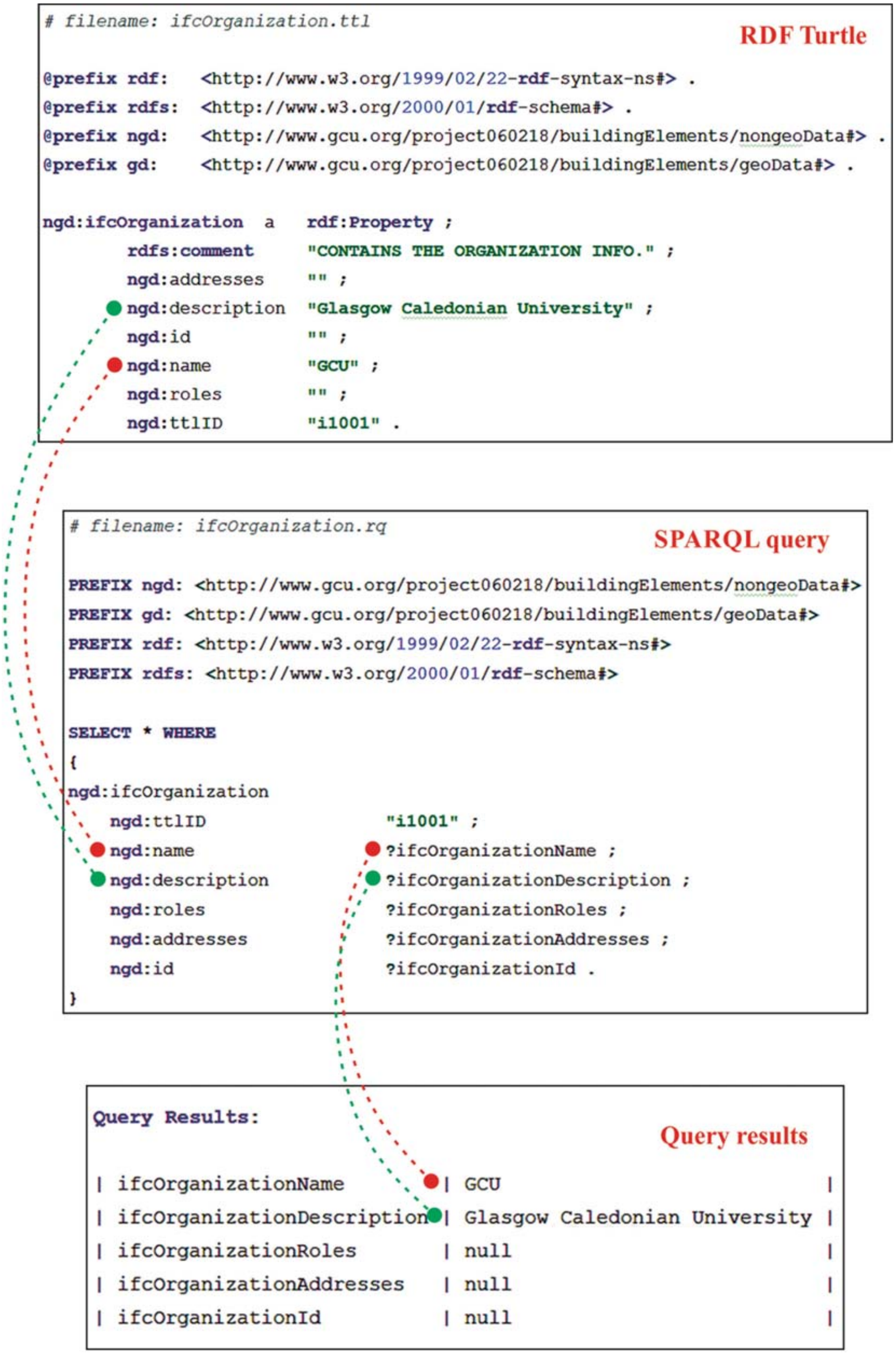

Fig. 14.6 Element markup process using RDF

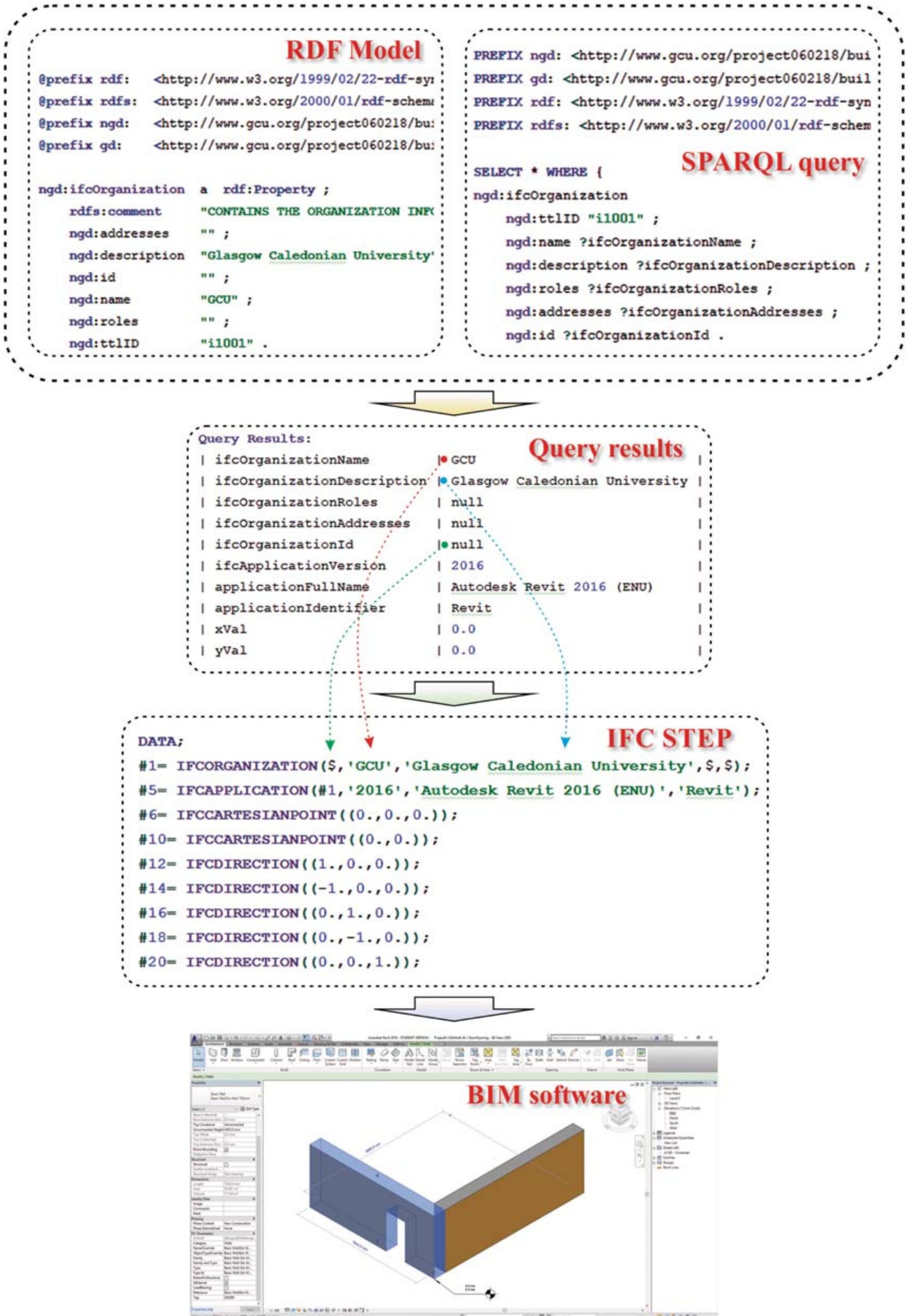

Fig. 14.7 RDF-to-IFC translation (Data standardization) and BIM capture

14.4 Conclusions

In this paper, challenges and limitations involved in generating parametric models for retro t assets, particularly historical environments, are addressed to perform a suitable framework for capturing BIMs and managing the large-scale information that needs to be appended to the model for further use during the buildings life-cycle. Several studies have been recently carried out using PCD as the main data source by declaring varying types of algorithm to identify building elements in PCD. Although some progress has been lately made to capture BIMs, a full-blown parametric model is still some way away. The fact is that a semantic-rich parametric model contains two types of information, geometric data and non-geometric data. In current practice, the identified elements, which are considered as parametric models, encompass only geometric data extracted from PCD and are represented as geometric primitives. Accordingly, non-geometric data which is required for the future use in a facility's lifespan (Facility Management), such as material, color, finish, fire rating, acoustic rating, accessibility performance, security rating, load-bearing capacity, etc., need to be added to the detected element during the BIM capture process.

According to the HES BIM projects as a case study in this project, one of the challenges is that some of the required asset information are individually added to each building component during the manual generation of the model using PCD, which is error-prone, time-consuming and laborious. The remaining information that cannot be added to the model, owing to the commercial BIM software limitations, are represented and stored in different file formats, such as documents, Excel spreadsheets, PDFs, and images. Hence, we use the concept of RDF as a Semantic Web Technology to store, share, and reuse information related to generated building objects, as a linked data, throughout the process of generating semantic parametric models. The proposed approach in this paper is currently implemented semi-automatically. The generation of RDF data for building elements is implemented manually due to the limitation of existing standard format for the data extracted from PCD. However, the process of RDF-to-IFC translation is carried out automatically by declaring constant RDF data and SPARQL queries for each category (e.g. walls, doors, windows, etc.) based on the HES BIM project requirements. The future work of this project is to implement the entire process automatically by generating RDF data based on the information captured from PCD and to structure effective, efficient, and flexible RDF data that can be utilized for all building elements and varying environments.

Acknowledgements Authors would like to express their gratitude to Dr. Vajira Premadasa of Historic Environment Scotland (HES) for providing assistance and support in the research presented in this paper.

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