# The Heterogeneity of BIM Objects in Different Construction Contexts

Jing WANG[1], Weisheng LU[2], Diandian LIU[3], and Fan XUE[4]

[1] PhD Candidate, Department of Real Estate and Construction, Faculty of Architecture, The University of Hong Kong, Hong Kong; e-mail: jingww@connect.hku.hk

[2] Associate Professor, Department of Real Estate and Construction, Faculty of Architecture, The University of Hong Kong, Hong Kong; e-mail: wilsonlu@hku.hk

[3] PhD Candidate, Department of Real Estate and Construction, Faculty of Architecture, The University of Hong Kong, Hong Kong; e-mail: liudd@connect.hku.hk

[4] Research Assistant Professor, Department of Real Estate and Construction, Faculty of Architecture, The University of Hong Kong, Hong Kong; e-mail: xuef@hku.hk

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## ABSTRACT

Building Information Modelling (BIM) objects are the primary 'building blocks' that form a building information model to store, organize and visualize project information. 'One size does not fit all'; BIM objects, along with their associated information, vary significantly from one construction context to another. In parallel with the deepening of BIM globalization is the increasing emphasis of "BIM localization", whereby designers desire a context-specific BIM object library that is in accord with the local building specifications and construction needs. Prevailing practice is to manually make the BIM objects and organize them in a library. This practice, however, could be inefficient, tedious and error-prone, particularly when the task is to deal with millions of objects in real-life projects. This study aims to explore the heterogeneity of BIM objects, with a view to facilitating the design of such context-specific BIM libraries using automatic or semi-automatic approaches. It first identifies the critical parameters that distinguish a general BIM object. Taking these parameters as the comparison criteria, the study further explores the variations of BIM objects in different construction contexts and the underlying factors leading to the variations. With such parameters identified, it is able to use the computational power to build up the BIM objects library (e.g. from other sources) for a specific construction context. The study outcomes could enable efficient BIM design and promote BIM implementation in real-life projects. The study could also contribute to the existing knowledge of BIM objects and offer significant implications to soft-landing BIM-based building project delivery.

**Keywords:** BIM objects, heterogeneity, object parameters, Industry Foundation Classes, contextual attributes.

## INTRODUCTION

It has been widely acknowledged that Building Information Modelling (BIM) is revolutionizing the landscape of building design and information management in the global architecture, engineering, and construction (AEC) industry (Eastman et al. 2011; Hardin and McCool 2015; Chen et al. 2017). Unlike traditional modelling methods, BIM, from a layman's perspective, is to assemble various BIM objects together to digitally represent the physical or functional characteristics of a facility. BIM objects stand at the central position in BIM design and subsequent BIM-based project delivery. BIM objects are not only the 'building blocks' to compose a BIM model; more importantly, they store, organize and visualize substantial building information into their geometry and non-geometry parameters (Lee et al. 2006; Pratt 2004; Eastman et al. 2011). In a sense, the BIM objects can be deemed as carriers of domain knowledge and expertise on building design and project delivery, as their parameters are modified according to engineering and project requirements (Belsky et al. 2016; Gao et al. 2017).

Considerable efforts have been paid to exploring the potential of BIM objects in enhancing efficient BIM utilization and promotion. For example, the Industry Foundation Classes (IFC) schema standardizes the representation of BIM objects and their parameters for data exchange between different BIM applications (buildingSMART 2016). Lu et al. (2017) proposed a conceptual model to efficiently develop an open-access BIM object library, with the aim to facilitate BIM design by organizing the existing BIM resources and making them available to BIM users. Ali and Mohamed (2017) depicted a method to group BIM objects by trade (e.g. structural, mechanical etc.), making it possible for different stakeholders to get the necessary information for professional analyses. Besides, several voluntary organizations, working together with some material suppliers, have started to develop online BIM objects libraries in view of the inadequacy of the elementary and scarce of BIM objects provided by BIM vendors. Popular BIM object libraries include *BIMobject*, *MagiCAD*, *The National BIM Library* in the UK, *Product spec* - the national library of products in New Zealand, and so on. Despite the joint efforts, soft-landing of these ideas has been hindered in practice due to the lacking consideration of the influence that local environment will exert on BIM objects.

One size does not fit all; BIM objects, along with their associated information, vary significantly from one construction context to another. This could be crucial to local BIM implementation to a substantial extent (Sebastian and Berlo 2010). BIM objects are intrinsically clusters of information of corresponding building and construction projects (Lu et al. 2017), which vary significantly as their locations changing. For example, every construction context has their own building codes, specifications, and engineering requirements, which requires a unique set of context-specific BIM objects with parameters in line with the local requirements. The culture difference will also influence the construction practice, and consequently the information stored in BIM objects (Xiao and Boyd 2007). Therefore, when utilizing BIM objects in practice, huge manual efforts are necessary to tailor the BIM objects to the local building specifications and construction needs. This could be inefficient, tedious and error-prone, particularly when it comes to dealing with millions of objects in a complex, real-life project.

This paper aims to explore the heterogeneity of BIM objects in different construction contexts, which is a critical and foremost step to develop a context-specific BIM object library using automatic or semi-automatic approaches. By *heterogeneity*, we mean the variation of BIM object parameters in different construction contexts, specifically, how and why BIM objects vary in different countries. The remainder of the paper starts with a review of IFC documents and literature to identify the critical BIM object parameters and their representations in IFC documents. Based on the outcomes, the methodology of the paper is presented in the following section. The variations of identified BIM object parameters in different construction contexts are shown in Section 4, followed by a discussion summarizing the underlying contextual attributes leading to the variations, and the concluding remarks in the last section.

## LITERATURE REVIEW

### *IFC Schema – the Description of BIM Object Information*

The Industry Foundation Classes (IFC) is a widely-adopted data exchange schema that facilitates BIM interoperability in the AEC industry (Eastman, et al. 2011). Developed by buildingSMART, IFC defines the information of BIM objects using an EXPRESS based entity-relationship model, which consists of more than 600 entities organized into an object-based inheritance hierarchy (BuildingSMART 2016). Figure 1 illustrates parts of the IFC4 Add2 schema. IfcRoot is at the most abstract level, derived from which there are three fundamental entity types in an IFC model – IfcObjectDefinition captures semantically treated tangible object items (e.g. products, processes, resources, etc.), IfcPropertyDefinition defines the characteristics of both general object types and specific object occurrences, and IfcRelationship assigns property information to the corresponding BIM objects while specifying the relationships among objects. Today, IFC has been widely adopted as a general standard and supported by many BIM software vendors (Gao et al. 2017; Ali and Moahmed 2017).

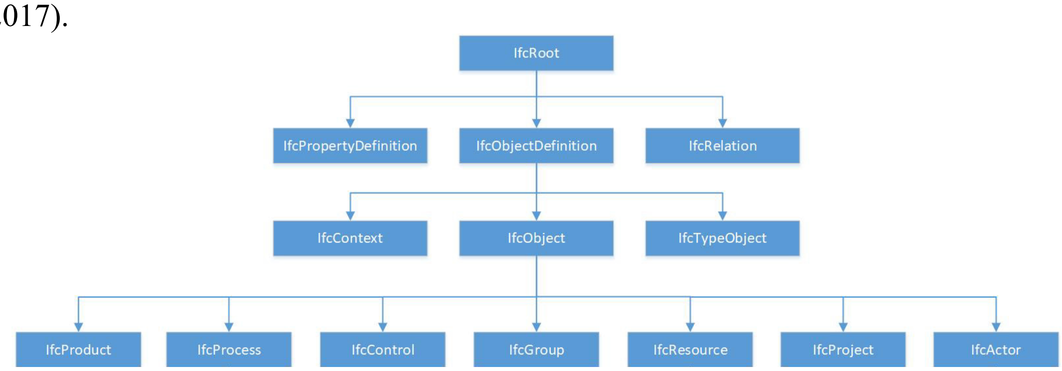

Figure 1. Parts of the IFC4 Add2 schema

*BIM Object Parameters*

Previous studies have explored BIM object parameters and their classifications in different application scenarios (Table 1). Although the classification criteria vary in the studies, they emphasize some parameters in common, such as identification, geometry, material, manufacturer, technical attributes, and information relating to project delivery. This is fundamental and essential to support BIM object utilization and consequently wider BIM adoptions.

However, despite the joint efforts of academia and industry, the influence of local contexts on BIM object parameters has never been studied systematically. It is not enough to simply identify the object parameter types for wider applications of BIM objects in practice. To do so requires a systematic study to figure out in what aspect, to what extent and how the local contexts will constrain and influence the BIM object parameters.

Table 1. The classification of BIM object parameters

| **Research/ industry** | **Application Scenario** | **Object Parameters** |
|---|---|---|
| Pratt (2004) | BIM object contents exchange | Functional type; Geometry;<br>Attributes; Relations between objects; Behavioural rules. |
| Belsky et al. (2016) | Semantic enrichment for BIM objects | Function; Geometry; Material; Identity; Aggregation relationships; Composition relationships. |
| Chen and Wu (2013) | Parametric BIM object modelling | Basic Object Data (*Identification, Classification, Geometry, Quantities, and Phasing*); Representation data (*Material*) |
| Open Geospatial Consortium (OGC, 2007) | Object data description in *CityGML* for virtual 3D city and landscape | Geometrical, Topological, Semantic, and Appearance properties. |
| Autodesk Revit (2017) | Modelling and professional analysis (e.g. thermal) | Identification (*number, name, type, description*); Classification (*OmniClass code and description*); Geometry; Material; Quantities; Manufacturer; Cost; Phasing; LEED, Thermal and Structural Properties, etc. |

| | | |
|---|---|---|
| RIBA (2014) | Object data description defined in *NBS BIM Object Standard* | Authorship, Identification (*name, Uniclass code, and product link*), Manufacturer, NBS description, and reference, etc. |
| NIBS (2012) | Information Collection via *Cobie* to improve handover to owner-operator | Authorship, Identification (*created by, category, Description, type, code*, etc.) Manufacturer, Warranty, Geometry, Material |
| CIBSE (2016) | Product description for manufacturer defined in *Product Data Templates(PDTs)* | Manufacturer, Construction, Application, Dimension, Performance, Electrical, Controls, Sustainability, Operations and Maintenance |

## METHODOLOGY

The primary aim of this paper is to explore the heterogeneity of BIM objects in different countries, or say, to figure out how and why BIM objects and their parameters vary in different construction contexts. There are three necessary steps to achieve the aim:

(1) To identify the critical parameters that define a BIM object;
(2) To summarize the features of the identified BIM object parameters in various construction contexts; and
(3) To analyze the contextual attributes that will influence BIM object heterogeneity.

Step (1) is particularly necessary given that there is a myriad of object parameters identified for different application scenarios. Based on the literature review presented in the previous chapter, we selected three types of critical BIM object parameters for heterogeneity analysis in this paper. They are,

- *Identification*: the name, classification, code, or other attributes for users to recognize individual objects;
- *Geometry & representation*: the physical characteristics and appearance of BIM objects, such as dimensions, materials, colours, etc; and
- *Behaviour*: the influence of BIM objects to the external systems, such as the function (e.g. structural, thermal, acoustic attributes), and information relating to project delivery (e.g. cost, manufacturer, construction).

For each identified parameter, the context-specific features are summarized and discussed in Step (2) and (3). This is based on a review of literature, standards, and industry reports, as well as the analysis of BIM objects from *bimobject*, one of the largest online BIM object libraries providing objects from manufacturers. We collected and analyzed the data of 102 fixed frame windows to identify context-specific features of BIM objects. The selected construction contexts are Hong Kong, China, the United

Kingdom, and the United States. They are in the leading position of BIM implementation and have their own sets of BIM standards, regulations and industry reference. Admittedly, the analysis of context-specific object features is not exhaustive, but it is an important step to unravel the general patterns of BIM object heterogeneity.

## THE BIM OBJECT HETEROGENEITY IN DIFFERENT CONTEXTS

### *Identification*

The *identification* parameters are essentials for BIM users to recognize individual BIM objects. The object name is one of the primary identifiers, which makes it possible to connect the BIM object with external information sources (e.g. technical specifications) and retrieve BIM object information efficiently (Goedert and Meadati 2008; Gandhi and Jupp 2014). The object name consists of several description segments (e.g. functions, types), which are ordered according to their importance perceived by the BIM designers (Chen et al. 2017). The perception of BIM designers can be influenced by several factors, including the knowledge, owners' requirements, the local building and construction industry, the culture, etc. Therefore, BIM object naming conventions could vary in different countries/regions. Table 2 is a summary of BIM object naming conventions of Hong Kong, China, the UK and the US. It is identified that the naming conventions vary in segment wording, selection, and ordering. The Hong Kong naming convention emphasizes the features of objects, the one of the UK focuses on the source of objects, while the US on the classification of objects. It should be noticed that the object naming in China doesn't show any distinct feature due to a lack of BIM object naming standard.

Another important identifier is the classification system, which describes BIM objects in a standardized way (Afsari and Eastman 2016). Various classification systems are adopted in different countries, presented in Figure 2. The percentage indicates how many percents of BIM objects (fixed frame windows from *bimobject*) are classified by the system. It is implied that Uniclass is the most popular classification system in Hong Kong, China, and the UK, while CSI MasterFormat, OmniClass and CSI UniFormat II gain more support in the US.

Table 2. The Summary of BIM object naming conventions

| Context | Specification | Published by | Naming Convention |
|---|---|---|---|
| Hong Kong | *BIM Library Components Reference* | Hong Kong Housing Authority (HKHA), 2010 | *<Author>_<Location>_ <Type>_<Features>_ <Series>_<Codes>* |
| China | / | / | / |
| The UK | *NBS BIM Object Standard* | Royal Institute of British Architects, 2014 | *<Role>_<Manufacturer>_ <Type> _<Subtype/Product code> _<Differenciator>* |

| | | | |
|---|---|---|---|
| The USA | *BIM Guidelines* | NYC Department of Design and Construction, 2012 | <Category>_<Type>_ <Subtype>_<Manufacturer> _<Description> |
| | *E/A Design Division*<br><br>*BIM Standard Manual* | The Port Authority of NY & NJ, 2012 | <Type>_<Subtype>_ <Manufacturer>_<Series/ Model>_<Description> |

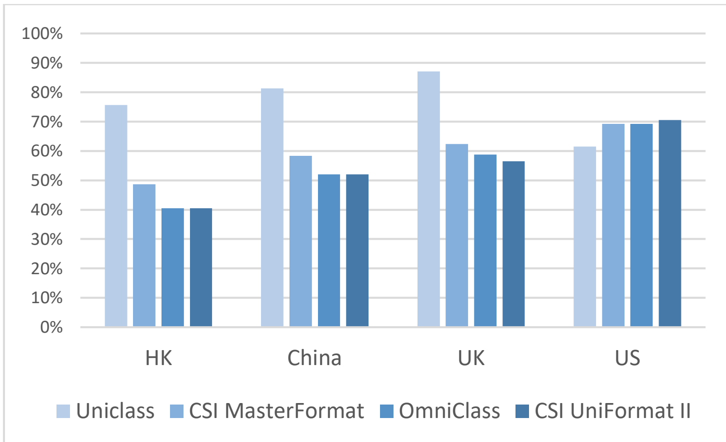


Figure 2. Classification systems in different construction contexts

### *Geometry & Representation*

The geometry and representation parameters, describing the physical features and appearance of BIM objects, are constrained by domain knowledge and expertise to meet the project requirements (Lee et al. 2004). It includes a broad range of contextual issues, such as building specifications, general architectural styles, aesthetics, available construction materials from the market, etc. In this regard, the parameters of geometry and representation will distinctively vary in different construction contexts. For example, the materials variation of fixed frame windows is presented in Figure 3, where the percentage indicates the proportion of BIM objects made from the materials. Glass and Aluminium, implied from the figure, are the most popular materials especially in Hong Kong and China. Glass is necessary for the lighting, while aluminium is chosen for its high performance in terms of affordability, design flexibility, durability, and energy saving. Thus, aluminium is often used for windows of high-rise buildings that are particularly common in HK. It is also suggested that a larger portion of windows is made from wood in the UK, while a wider variety of materials adopted in the US, compared to the other three countries.

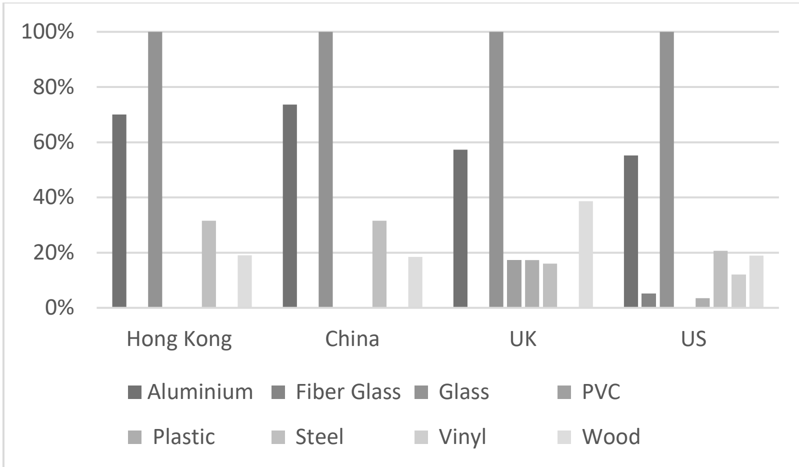


Figure 3. Materials in different construction contexts

### *Behaviour*

The behaviour parameter indicates the reaction of BIM objects to the external stimulates (Lee et al. 2004), or say, the influence that BIM objects exert on the external system. One of the illustrators is the function parameter of BIM objects, such as the structural, thermal, acoustic attributes. In IFC files, these parameters are usually defined in a form of *<Attributes>_<Values>_<Units>* in *IfcProperty*. The *Value* could be single, listed, enumerated or bounded in different unit systems with design specifications and domain expertise embedded. Thus, a value might vary significantly in different contexts. For example, the distributed imposed loadings of floor objects are 2.0 kPa, 2.0 kPa, 1.5 kPa for domestic buildings in Hong Kong, China, and the UK respectively. Comparatively, in the US, the floor loading is presented as a list value in both imperial unit system and international unit system (Figure 4).

| Residential | psf (kpa) |
|---|---|
| One- and two-family dwellings | |
| Uninhabitable attics without storage | 10 (0.48)[l] |
| Uninhabitable attics with storage | 20 (0.96)[m] |
| Habitable attics and sleeping areas | 30 (1.44) |
| All other areas except stairs | 40 (1.92) |
| All other residential occupancies | |
| Private rooms and corridors serving them | 40 (1.92) |
| Public rooms[a] and corridors serving them | 100 (4.79) |

**Figure 4. The floor distributed imposed loading attributes used in the US (sources: *Minimum Design Loads for Buildings and Other Structures*)**

## DISCUSSION

BIM objects are the primary "building blocks" that store, organize and visualize project information in the BIM environment. Project information distinguishes BIM objects from any other forms of product representation, and BIM objects vary in different construction contexts as the project information changes.

The BIM object variation, or say, its heterogeneity in different construction contexts could be classified into two categories – the variation of the information itself, and the way of information presentation and organization. The former one goes beyond the environment of BIM and is largely determined by the domain expertise. This includes context-specific project knowledge and experience. For example, the object parameters of *geometry, representation, and behaviour* are numerically or textually constrained by factors such the local resources, industry specifications, building features, project delivery methods and even the cultures. This is one of the reasons why wood materials are more widely used for construction in the European countries such as the UK rather than in Hong Kong.

The object *identification* parameter, comparatively, depends more on the standardization of information presentation and organization in BIM environment. It varies textually in different countries, as building departments are trying to publish their own BIM standards in line with local requirements to promote BIM implementation.

Four contextual attributes are summarized in this study to account for the BIM object heterogeneity. They are:

- *Local resources,* such as materials, manpower, machinery, technology, finance, space, etc.
- *Regulations and policies,* which standardize information representation and organization in BIM objects, and set minimum requirements to constrain the object contents.
- *Architectural features*, mainly influencing the *geometry and representation* parameters of BIM objects, as well as defining a unique set of BIM objects in different regions.
- *Culture*, which causes differences in people's thinking, learning and thus practice in construction (Xiao and Boyd 2007). It may directly influence individual patterns to determine the values of BIM object attributes or be embedded into other contextual features such as architectural features, regulations, and policies.

This study, by exploring the heterogeneity of BIM objects in different construction contexts, offers both practice significance and academic merits. Firstly, it is valuable to develop national BIM object libraries to enhance BIM design efficiency. By following the deliverables of the study, local project requirements can be analyzed, interpreted and understood much easier. This is important for library developers to enrich BIM object local semantics and provide a particular set of BIM objects in line with local BIM users' needs.  Besides, the study acts as an essential step towards developing BIM object ontology by identifying the critical BIM object parameters and their data representations in the model.

## CONCLUSIONS

As the most fundamental elements that stores building information in line with domain expertise and project requirements, the BIM object with rich local semantics is necessary for efficient BIM design and subsequent project delivery. Without a general understanding of how BIM object parameters change in different construction contexts, it is difficult to develop a library to organize these BIM objects for local BIM design, let alone promoting local BIM implementation to a substantial extent. This paper, by exploring BIM object heterogeneity in different construction contexts, has both academic merits and immediate practical significance. It identifies three BIM object parameters that are critical to defining a BIM object, namely *the identification, geometry and representation*, and *the behaviour*. This is an essential step to explore BIM knowledge, such as BIM object ontology and semantics, which are fundamental to support a wide range of BIM application towards an intelligent project delivery. Based on the identified parameters, the paper summarizes the variations of BIM object parameters in different contexts, and the underlying contextual attributes leading to these variations. The attempt is the fundamental research frontiers to explore general knowledge of BIM localization. Besides, this study offers significant implications to analyze the local requirements of BIM object information and its representation. This facilitates the development of a localized BIM object library by providing a particular set of BIM objects that meet the local users' needs, and therefore, enhance BIM design efficiency and local promotion.

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