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Ontological Classification for Heritage Computer Aided Design

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Abstract—Recent endeavors in Computer Aided Design (CAD) have enabled creating intelligent 3D models of building assets that allow high efficiency in constructing and operating/maintaining those assets. However, in order to support this, detailed specification, classification and codification of the individual building systems and their components must be created. This entails usage and embedding of specific construction classification systems with the CAD systems utilized. While many such systems exist for new builds, there is lack of classification systems for heritage buildings, which are unique in the characteristics of their components that cannot be covered by current classification systems. This paper presents part of an ongoing research to justify and create a new Ontological Classification system for Heritage assets that can be used in conjunction with CAD systems, specifically 3D intelligent authoring tools, to specify the special requirements of Heritage components. The paper will start with a comparative study to validate creation of an “Onto-Classification” system as opposed to other systems like thesauri, taxonomies etc., including case study examples of them. This will be followed with examples of the new Onto-Classification system using a current existing Case study of Toson Palace in Egypt.

Keywords—Computer Aided Design, Classification, Heritage BIM, Ontology, Taxonomy, Thesaurus

I. INTRODUCTION

It is crucial within the Engineering and Construction industry to utilize classification systems to specify and codify the different components and systems within a building for purposes of ordering, constructing and maintenance. This becomes even more relevant when considering historical or heritage buildings, which belong to different architectural styles and historical eras, built in different unique methods and contain different building elements and components. The need to renovate, refurbish, and maintain them dictates accurate recording of their constituent building elements and blocks and their detailed characteristics to be able to replace or conserve them in the optimum methods possible.

Current classification systems utilized for new buildings and assets include CI/SFB, C-AW, SFG20, Omniclass, Uniclass, NRM versions etc. However, Saleeb et al. [1] provide evidence for the lack of appropriate current classification systems for Heritage which lack dimensions required for classifying heritage components in terms of object types, hierarchy of tables/schedules, depth levels and appropriateness for different architectural styles and parametric geometries (e.g. origin, material, allowed stresses, proportions).

Saleeb et al. [1] concluded that the factors and dimensions lacking from current classification systems necessitate development of a new system for Heritage. Four main requirements for development were identified, in addition to further attributes essential for defining heritage components, which include both geometric and non-geometric information e.g. architectural style, geometric characteristics and ratio, condition, construction method, cultural value, material, color, reflectance characteristics.

Furthermore, the type of grouping proposed to classify the components was the Combinatory (faceted) grouping where classes of objects can be identified using multiple sets of attributes. A facet acts as a set of similar properties such as functions to enable categorizing objects accordingly. In a faceted classification, new objects can be continuously added [2]. This can be more suited for a heritage classification system as new found and unique objects may need to entered into the system constantly and which may be categorized using multiple attributes related to function, social value, environmental context etc., which are not conventional attributes in current classification systems. This is different from the current Direct (hierarchical) grouping where classes of objects are identified through a combination of properties; however, new objects cannot be accommodated without creating new revisions of the classification [3].

Due to this discrepancy in system requirements above, the next stage is to compare and contrast the current classification systems including thesauri, taxonomies and ontologies to determine the most appropriate system to use for Heritage assets, as detailed in the next section.

II. CLASSIFICATION VS. THESAURUS VS. TAXONOMY VS. ONTOLOGY

A. Analyzing Classifications and Thesauri

Is creating a Classification system sufficient for defining Heritage asset components? According to Miller [4], both Classification and Thesaurus schemes are tools used for indexing and retrieval of information, however there are a few differences between them.
1. Classification deals with organizing information mono-
hierarchically according and limited to a single aspect or
factor at a time. Every concept is dismembered and
included in some categories. However, a thesaurus in
principle is a poly-hierarchical system offering access to
information via multiple interrelated aspects – “a
vocabulary of a controlled indexing language” [5]. This
means that a term or its synonyms can appear in more
than one area showing interconnections between different
words. This is not a required function when classifying
building objects where every component just needs to be
uniquely identified and specified in an organized hierarchy of categories without showing how it is similar
to other terms or connected to other objects.

2. Thesauri record a set of terms (words or phrases)
covering some knowledge domain, with three types of
relationship - equivalence, hierarchical and associative
between them [6]. Classification systems do not necessarily exhibit the equivalence (synonymy) between
different terms or inter relations and associations between child components (mainly hierarchical parent
relationships). While displaying inter-relations is a
useful functionality, it is not required when codifying and
specifying different building components individually
for procurement and maintenance purposes. E.g. relationship between a volute and corniche is important
to know in certain contexts that study architectural and structural relationships, but is not necessarily conducive
to specifying the different objects individually for
monitoring or procuring.

3. A thesaurus is a classification based on natural-language
words rather than abstract categories, it does not form a
strict tree structure, and one term may have several
“parents” at the level above [6]. Thesauri are fundamentally linguistic, while classification schemes
organize conceptual categories. Thesauri find compact
words or phrases to describe objects. With classification
schemes, the goal is to have completely distinct
conceptual categories that are mutually exclusive and
jointly exhaustive. Classifications are generally further
organized in a structured manner than thesauri [7]. For
classifying building components, semantics and
meanings of the terms is not the main focus. However, a
strict tree hierarchy of components is crucial e.g. space \rightarrow system \rightarrow item.

4. Categorial analysis is based on categories constructed
beforehand but clusters are created during an analytical
process. Terms can be simultaneously included in several
categories but in one cluster only. Therefore, categorial
analysis can be deemed as a thesaurial method and cluster
analysis a classification method [8]. Clusters of terms
should be mutually exclusive, i.e., no term in one cluster
should appear in any other clusters without plausible
cause [9]. Having several parent classes for one item is
not useful as it would render codifying a particular component difficult. Mutual exclusivity of objects is
building assets is important to avoid confusion and non-
precision in procuring objects. As an example, a
“cornice” might be part of “columns” category or
“decorations” or “non-structural elements” category. However, when codifying a corniche, it might be
preferable to have it as part of one class only for
replacement or refurbishment techniques purposes.

5. While the same thesaurus term could be linked to more
than one class number, a preferred place is selected for
the concept in the schedules and a cross-reference made,
in the form of hierarchical or associative relationships
between the preferred and non-preferred location. The
expression of a “preferred place” is a classification-based
way of thinking. The relationships between preferred and
non-preferred terms are not hierarchical or associative
but only that of equivalence [10]. The link between lead-in
(pxref) and predominant terms is merely that of a
two-way many-to-many relationship. Rows or records in tables
have one or more key fields which guarantee their
uniqueness, and links between records in different tables
are represented by matching key fields. If this system is
used for classifying objects, this requires normalizing the
database so that each entity and relationship is stored
only once, thus avoiding the problems of redundancy and
possible inconsistency [6].

B. Analyzing Classifications and Taxonomies

Classification is "systematic arrangement in groups or
categories according to established criteria." The term is
comprehensive that incorporates any type of grouping according
to criteria. However, a Taxonomy is the process of giving names
to objects or groups of objects according to their positions in a
hierarchy e.g. orderly classification of plants and animals
according to their apparent natural relationships. The items are
defined according to their relationship with the other items in the
hierarchy [11]. With taxonomies, the hierarchical relationships
usually only groups items according to one or two
class numbers, a preferred place is selected for
the concept in the schedules and a cross
reference made, while thesauri offer
multiplied associations between
items themselves e.g. species, however with classifications,
criteria can be defined based on any external factors, which is
more relevant to classifying or organizing building components
based on many different external factors e.g. building discipline,
energy usage, structure, or in case of heritage, architectural era,
function, dimensions etc.

Taxonomies are also more concerned with providing
exhaustive lists while classification is not exhaustive. This is
useful to be able to add new building components to the
classification.

Taxonomies are based on providing a hierarchical
relationship map between a multitude of items while
classification usually only groups items according to one or two
attributes. The fundamental difference is that taxonomies
describe relationships between items while classification simply
groups the items [11]. This is beneficial for defining a clear
specification and codification of asset components.

C. Analyzing Taxonomies and Ontologies

An Ontology is concerned with highlighting the metadata of
associative relationships between objects. It specializes in
relationships and the intricacies between them. Taxonomy
identifies relationships between items and categories, but lacks
the complexity that ontology provides in terms of displaying the
metadata of those items that can ultimately change the
associations between them. Ontology is a collection of
numerous taxonomies that can be used to describe a domain of
knowledge along with the relationships among them [12].
As can be seen in figure 1, an ontology delves into describing the inter-relations between the different items of the networked hierarchy of elements, and not just define its presence. Applying metadata to the relationship itself is a very beneficial aspect provided by Ontology. This can be especially useful in Heritage even more so than creating new builds due to the historical, cultural, human and environmental contexts of the heritage asset. For example, connecting a type of window to a façade can have differing relationships based on the architectural period, location and cultural aspects (e.g. privacy considerations of that era). This means that a relationship could be conditional, temporary or seasonal.

This is inference, and is one of main features of ontology. Other Metadata for that relationship, such as date range, origin, material, allowed stresses, proportions, architectural style, geometric characteristics and ratio, condition, construction method, cultural value, colour, reflectance characteristics can be added.

Fig. 1. Example of a construction related ontology [12]

Thus, the relationships and associations are not absolute. The different ways a relationship can be described and how that relationship may have facets, like seasonality, demonstrates the intricacy of an ontology. It makes the relationship active or inactive, which then triggers other relationships. While a taxonomy is a defined, static entity, an ontology is dynamic [13]. This could be perceived as a fundamental difference between live history and context of a Heritage building that affects how its components are refurbished and maintained, as opposed to a new build.

In the realm of Product Information Management (PIM), which can be similar to classification of building components or products, objects are either linked or not. Ontologies can provide added layers to that relationship and take it outside of PIM. Ontology looks at a much larger universe. “There can be all kinds of taxonomies in an ontology, says Dino Eliopoulos, Managing Director at EIS, but the real difference is that an ontology attempts to describe and capture an entire subject area, with all of its complexity, whereas a taxonomy tries to simplify a complex collection of seemingly unrelated items into a linear, organization.” [13]

III. DERIVING A NEW ONTOLOGICAL CLASSIFICATION SYSTEM

Based on the analysis of the different classification schemes described previously, the authors propose the adoption of a merged system to classify Heritage buildings within the context of BIM, comprising of a Classification system in principle which is enriched by adding aspects of associated metadata of the different components to it, as utilized within Ontologies. Hence the term an “Onto-Classification” is coined within this research i.e. a merged classification and ontology scheme. A summarization for the reasons for this is that a scheme is required to be

1. Non-exhaustive - allowing addition of new elements to it as previously explained in the introduction chapter. This is an attribute of classification systems as opposed to taxonomies.
2. Non-semantic specific – focus is not on meaning of words and which terms can be synonymous with each other, which is an attribute of Thesauri
3. Doesn’t need associative relationships between child objects – the objective is clearly classifying the individual components of a building without complex parent and many to many relationships as used in thesauri.
4. Concepts for hierarchical categorization preferred to be according to general criterias and external characteristics not based on internal inherent characteristics as per taxonomies
5. Inclusion of metadata – as per ontologies hence a merge between classification and ontology schemes.

IV. CASE STUDY

An example of a current case study within this research is Toson Palace, Egypt. A full 3D point cloud scan was performed for the palace internally and externally. From this, the main existing architectural, structural and services heritage components within the palace were identified, and hence classified into 4 major ontological classes, each sub-divided into a further 4 levels of subclasses as follows:

Assembly Category

• Orientation
Table 1 below shows the different components aligned with the classes and subclasses (as populated from Toson Palace as an example case-study), with only an example of what is inside the 4th level of subclass “composition”. The full visualisation of all classes and sub classes was created using the open source software Protégé and can be seen in Figure 1 below as per the colour codes in the table.

As can be seen in Fig 2 below, the main 4 assembly classes in the centre are those proposed to divide up a Heritage asset’s components into – namely:

1. Structural components
2. Attached Architectural Components
3. Independent components
4. Cladding

This heritage classification system has opted to focus on the components only and their individual characteristics and categorisations and not allude to environmental hierarchy of space function such as in Uniclass systems (complex, entity, activity, space) due to the fact that in new builds this can be of high importance since the new buildings are in current usage as per their original design and might still need operational management related to that. However with heritage assets, the function of the building might have changed over time, or has just become an artefact, and there might not be any more connection with other buildings on the same site as per originally creating the asset due to demolition or change of environment, hence the focus is purely on the components themselves and their characteristics. These environmental aspects have been rather placed as data properties and not defining hierarchical classes.

Furthermore, the green subclasses in Fig 2 represent the orientation of the component whether vertical or horizontal. The next level of class hierarchy belongs to the system that the components fall under. This is followed by the component type in the next stage of class hierarchy (in orange) e.g. columns joists, sanitary fittings. The 5th final subclass category is the composition or material of the component to make it easier to replace.

This is part of the ontological classification system. The next step is to add

1. The data properties which describe the common attributes for instances of a class i.e. the relationship between instances and their data values. In this case of sub-class level 4 giving the opportunity to document all the different components with their different characteristics that are actually available onsite.
2. The object properties which describe the relationship between the instances of the different classes / sub classes and each other

The data properties that have been identified to be added to all instances of subclass level 4 “Composition” are:

- System
- Type
- Composition

- Code ID
- Architectural style
- Age
- Geometric ratio
- Origin
- Material name
- Allowed stresses / load bearing
- Construction method
- Condition (deterioration)
- Life expectancy
- Maintenance constraints
- Cultural Heritage value
- Reflectance
- Space function

These would aid in identifying the specific individual components within the different heritage sites and help create an international database to assist in locating substitute components, order / manufacture replacement objects or help in maintaining existing components.

The object properties defining relationships between the data properties and sub classes are yet to be defined within this ongoing research. These are paramount, as explained previously, as they could change the relationship and relevance between different components from one heritage asset to another hence affect the way these components are maintained.

As can be seen this system satisfies the 5 characteristics of ontologies and classifications, outlined previously, that satisfy a coding system for heritage components, in the following way:

1. Non-exhaustive - The system relies on defined class hierarchy as opposed to component hierarchy hence allowing non-exhaustive addition of components based on the type of heritage asset classified.
2. Non-semantic – The differentiation between the different components relies on a coding system not on names
3. Simple parent-child relationships – with no multiple inheritance in the components as achieved through the current created 4 levels of classes and sub classes
4. Hierarchical categorisation is according to general criteria not inherent within the components themselves

Inclusion of metadata – The ontological classification relies on addition of data properties and object properties between the individual components adding more depth and richness in information to the heritage components that is required for its maintenance that is not available in current new component classifications with generic setup.
Fig. 2. Graphical Representation of the Classes and Subclasses of the Heritage Ontological Classification
<table>
<thead>
<tr>
<th>Class 1 Assembly Category</th>
<th>Sub-Class2 Orientation</th>
<th>Sub-Class3 System</th>
<th>Sub-Class4 Type</th>
<th>Sub-Class5 Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structural components</td>
<td>Vertical Support</td>
<td>Columns</td>
<td>Egyptian</td>
<td>Concrete</td>
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<td></td>
<td></td>
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<td>Doric</td>
<td>Stone</td>
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<td>Ionic</td>
<td>Brick</td>
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<td>Corinthian</td>
<td>Timber</td>
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<td>Tuscan</td>
<td>Steel</td>
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<td>Islamic</td>
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<td>Load bearing walls</td>
<td>Interior wall</td>
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<td>Exterior wall</td>
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<td>Retaining wall</td>
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<td></td>
<td></td>
<td>Interior Stairs</td>
<td>Flying stairs</td>
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<td>Honorary stairs</td>
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<td>Spiral stairs</td>
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<td>Exterior Stairs</td>
<td>Flying stairs</td>
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<td>Spiral stairs</td>
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<td>Beams</td>
<td>Simple support beam</td>
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<td></td>
<td>Fixed beam</td>
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<td>Cantilever beam</td>
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<td>Continuous beam</td>
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<td>Joists</td>
<td>Single Joists</td>
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<td>Double Joists</td>
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<td>Arch</td>
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<td>Roofs</td>
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<td>Gable roof</td>
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<td>Hip roof</td>
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<td>Shed Roof</td>
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<td>Gambrel</td>
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<td>Attached Architectural Components</td>
<td>Vertically Attached</td>
<td>Pillar Components</td>
<td>Capital</td>
<td>Architrave</td>
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<td>Horizontally Attached</td>
<td>Ribbed Ceiling</td>
<td>Circular</td>
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<td>Rectangular</td>
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<td>Flat Decorated Ceiling</td>
<td>Trays</td>
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<td>Arches</td>
<td>Semi-circular</td>
<td>Semi-circular</td>
<td>Segmental</td>
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<td>Doors</td>
<td>Interior</td>
<td></td>
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<tr>
<td>Windows</td>
<td>Double Casement</td>
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<td>Casement</td>
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<th>Vertically Supported</th>
<th>Wall Ornaments</th>
<th>Paintings</th>
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<td>Corner</td>
<td>Adjustable</td>
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<td>Drainage System</td>
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<td>Panel</td>
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<td>Horizontal</td>
<td>Exterior</td>
<td>Roofing material</td>
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REFERENCES


