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Research paper

Taxonomizing Building Forms and Characteristics for Urban Scale Virtual Reality 3D Models

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Abstract

Virtual reality (VR) technology allows urban environments to be experienced through a full-scale digital immersion. However, as the virtual environment (VE) in VR is set to be in full-scale by default, what can be considered as adequate details for architectural operations in large VEs is therefore ambiguous. This paper aimed to taxonomize building forms and characteristics represented as level of details (LOD) in creating operational urban scale 3D models for VR. A total of *N*=96 respondents participated in a survey, in which they were requested to rank the building characteristics critical to be represented in an urban scale VE. A Principal Component Analysis (PCA) was then used to factorize these characteristics which resulted to 'geometric extrusion' and 'distinction'. These components were then used to define the taxonomy of urban scale 3D models for VR.

Keywords: *Use about five key words or phrases in alphabetical order, Separated by Semicolon*

1. Introduction

The renewed interest in making VR to be affordable to the masses has paved the way to the so-called 'second wave' of VR revolution, as their current hardware and software have improved rapidly (Stein, 2015; Halley-Prinable, 2013). New possibilities such as using VR in architectural operations are therefore ought to be researched for exploring their potentials. VR has already been used for urban planning and construction activities (Diao, Xu, Jia, & Liu, 2017), but to increase non-specialists' interest in VR, the current pipeline of model acquisitions via user input in architectural practice must also be observed. The notion of sufficient details for this process is still vague, therefore this paper attempted to contribute a proper taxonomy to define what is sufficient for a full-scale urban VE in VR.

2. Methodology

The discourse framework was set through literature reviews. A total of *N*=96 respondents participated in a survey, in which they were asked to rank the architectural characteristic items which they perceived as critical to be preserved in an urban scale VR 3D model, measured at an ordinal scale (Likert-type score) with scores ranging from 1 (highly unimportant) to 5 (highly important). The items were then factorized through a PCA in SPSS to reduce a larger set of variables into a smaller set of constructs.

3. Representations and scale

The operational use of models may vary depending on the scale and the LOD (Stavrić, 2013). For practical purposes, reducing the scale of models will typically increase the LOD and vice versa. There are no rules on dictating how salient a 3D building in a VE should be built. In the case of a full-scale VR 3D models, the concern of scale is silent thus the notion of details' adequacy becomes more apparent. Therefore, it is relevant to use architectural forms and characteristics to become the basis for our taxonomy.

4. Schematization of lod

LOD is a discipline within the interactive computer graphics bridging the complexity of 3D models and its performance by regulating several details used in the models (Luebke et al., 2002). Ideally, reducing the LOD in the sampling of the 3D objects will eventually reduce the rendering computation. This reduction often comes at the expense of the visual detail. The use of 3D graphics in regulating LOD is increased simply because it can be achieved now (Çöltekin, Lokka, & Zahner, 2016), but this overlooks the substantial essence of the 3D models itself, that the interest of achieving a pragmatic VE is ignored. This paper argues that architects may only need necessary visual information in their 3D models, thus it is always favorable to have the models schematized to a certain LOD, leaving only the necessary characteristics.

5. Previous taxonomies of urban scale 3d models

The Shiode (2001) model (Fig. 1) proposed a simple continuum consists of LOD taxonomies arranged from low to high geometric content. The complexity of the model corresponds to each stratum is increasing.

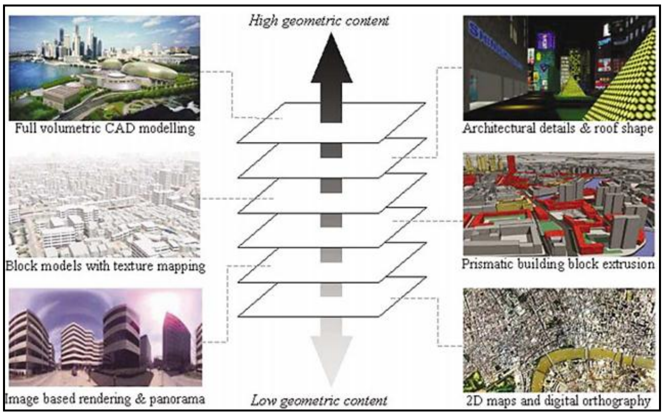

Fig 1: A taxonomy of urban scale 3D models by Shiode (2001).

Horne et al. (2013) suggested urban scale 3D models can be divided into 'low level' (presentation and evaluation) and 'advanced' model (real-time editing and analysis). Kobayashi (2006) categorized the quality classes as 'online quality', 'PC quality' (rendered for simulations) and 'movie quality' (static/ non-interactive). He added these models can be subdivided into 'street', 'block' and 'city' level, as summarized in Table 1.

Table 1: Taxonomies by Horne et al. (2013) and Kobayashi (2006)

Authors	*Approach*	*LOD in VEs*
(Horne et al., 2013)	Operational	Low level (evaluation) Advance level (real-time editing)
(Kobayashi, 2006)	Visual quality & level of viewing the model	• Online quality • PC quality • Movie quality • Sub categories: • City level • Block level • Street level

Another taxonomy is derived from the Open Geospatial Consortium (2012) which has been focusing on buildings as illustrated in Fig. 2. It describes the instances increase in geometric and semantic complexity through LOD 0 (footprints and optional roof edge polygons) to LOD 4 (complete model with indoor features) (Biljecki, Ledoux, & Stoter, 2016).

Fig 2: A taxonomy of urban scale 3D models by Open Geospatial Consortium (2012) (Biljecki, Ledoux, & Stoter, 2016).

Although Shiode's (2001) taxonomy may be applicable to 3D models in general, in the case of VR, it somewhat disregards full-scale immersion and the level of viewing. The taxonomy proposed by Kobayashi (2006) has included visual quality and level of viewing, with the street level being a practical way of viewing an urban scale VE in VR. But this taxonomy alongside with Horne et al. (2013) model are too universal to be regarded as useful for a specific domain such as architecture. The Open Geospatial Consortium (2012) taxonomy, though is hierarchical and clearly differentiate both geometry and semantics of buildings, is too linear. It does not satisfy what can be considered as 'sufficient' for an architectural operation in VR. Thus, we propose a taxonomy that is more 'fluid' for acclimatizing architects' pipeline of 3D modelling. The taxonomy is modelled for an urban scale VR 3D model that is regarded as 'low level' with 'PC visual quality' and to be viewed from the 'street level' as these are the attributes commonly associated with VR simulation. 3D models with 'architectural details and roof shape' and with 'prismatic building block extrusions' are considered as the extreme ends of our continuum as to allow future redefinitions. Additionally, the dichotomous qualities of these two levels are more apparent and therefore would be more explicitly demonstrated in our taxonomy, as predefined in Fig. 3.

Fig 3: The predefined taxonomy for urban scale 3D models for this study.

6. Building form and characteristics

People use buildings' characteristics as cues to remember in an urban environment which are represented in buildings' form, style, façade, ornamentation and roof form (Zadeh & Sulaiman, 2010). Appleyard (1969) particularly defined building form by the movements around buildings, clarity of contour, size, shape complexity, surface color and texture, maintenance quality, and signage (Gary W. Evans et al., 1982). Table 2 summarizes the building form components that are possible to be replicated in 3D models.

Table 2: Building form components as described by Appleyard (1969).

Building form component	*Description*
Clarity of contour	The boundary sharpness that makes a building stand out from its ground.
Size	Height/ bulk of a building as perceived from its approach view.
Shape complexity	Simple shape allows faster perception while complexity attracts attention.
Surface colour and texture	A salient characteristic of a building can be of the brightness, coarseness and complexity of surface.
Signage	Verbal signs to attract attention.

As building visibility and symbolic significance are related to human interactions with the buildings and therefore are not physically replicable in 3D models, this paper therefore excluded them. From this, the form and characteristics components are then derived into items for the questionnaire. Some related components are incorporated into a single item based on a logical judgment. Some items are separated as they have been consistently used as parameters in previous taxonomies. The 9 items are then established, with the objective of getting the respondents to rank them based on their importance. The items, in no particular order, are presented as such:

Table 3. Building form components interpreted as questionnaire items.

Architectural Detail Components	*Source description*
Color/ texture	Derived from building form components by Appleyard (1969)
Shape/ form	
Text/ signage/ symbol	
Size/ volume	
Orientation	
Height	
Roof profile	Derived from the Open Geospatial Consortium (2012) taxonomy (Biljecki, Ledoux, & Stoter, 2016).
Façade component	
Facade details	

7. Results

A PCA was run in SPSS using the data from the nine items in the questionnaire. The result has led to the retention of only 2 components, as shown in Table 4.

Table 4: Pattern matrix.

	Components		
	1	*2*	
Colour	0.854		Geometric Extrusion
Shape	0.812		
Roof	0.746		
Text	0.733		
Size	0.629		
Orientation		0.858	Distinction
Height		0.759	
Façade component		0.642	
Façade detail		0.533	

Strong loadings consistent with the architectural details of '**geometric extrusion**' items on Component 1 and '**distinction**' items on Component 2. The subjective decision is proposing that 'geometric extrusion' is regarded to be components affected by volumetric suppression and extrusion, including active modifications on its surfaces which define a building's form and characteristic. The items fall under 'distinction' are regarded as the components contributing to the enrichment of the forms and characteristics itself, a quality that may be used to extend the buildings' semantics even further. These two components are therefore selected to be the main units to define the parameter for our taxonomy.

8. Proposed taxonomy

In Table 5, the units of 'geometric extrusion' and 'distinction' are given dichotomous levels (high and low), as per the intention of this paper to establish a more 'fluid' taxonomy rather than a linear one.

Table 5: The Parameters of Taxonomy

Items	*Factorized components*	*Parameters description*
Façade detailing Façade component Size/ volume Height Roof profile	Geometric extrusion	• Low geometric extrusion ○ Low geometric content ○ Prismatic block extrusion. • High geometric extrusion

		○ High geometric content ○ Details with profiles
Color/ texture Text/ signage/ symbol Shape/ form Orientation	Distinction	• Low distinction ○ Monochrome ○ Rough information • High distinction ○ Color and texture ○ Granular information

To extend the definition of the predefined taxonomy established earlier, this paper then proposes the parameters to be the strata separator (Fig. 4). The parameters do naturally agree with the extreme ends in the predefined taxonomy.

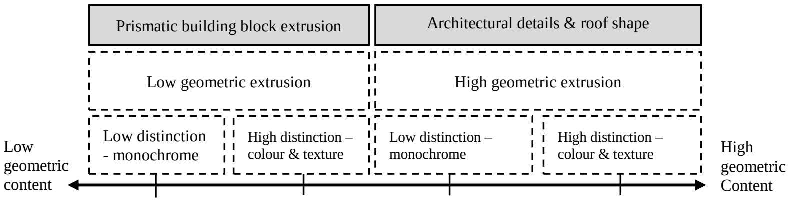

Fig 4: The proposed taxonomy for urban scale 3D models in VR.

Fig. 5 illustrates the overlapping of the parameters (low and high) ascribed to the 'geometric extrusion' and 'distinction' components. The dichotomous levels of 2 different components naturally contribute to the birth of 4 different VEs with different LODs.

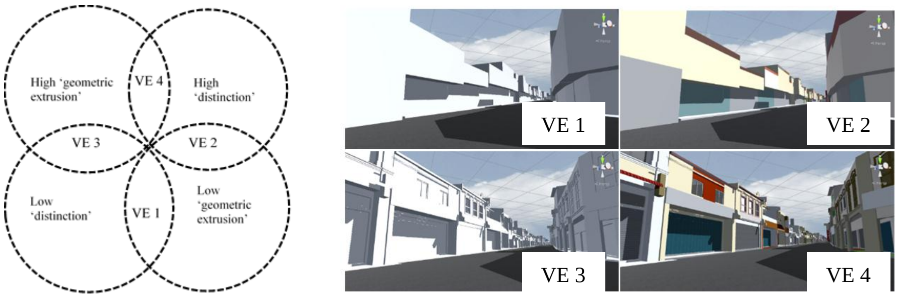

Fig 5: VEs prescribed to the components' attributes with proposed samples.

9. Discussion and conclusion

As 3D modelling pipelines among architects are often performed through user input, there should be no dictating rules in the procedure. Instead, the unique way this taxonomy could work is due to its flexibility. An architect may find a specific operational dimension of a VE, which corresponds with the best parameters. VE 1, for instance, may be used for elementary assessment of an urban environment. Thus, the architect would produce an urban scale VE with low 'geometric extrusion' and 'low distinction' for that matter. Despite there are 4 main VEs that can be regarded as direct derivations from the taxonomy, they are not necessarily confined within the suggested parameters. In this case, our proposed taxonomy acts more as a basis rather than a rule, which open-endedness would accommodate architects' 3D modelling pipelines. The building forms and characteristics are saturated into the components of 'geometric extrusion' and 'distinction', therefore the taxonomy is more fluid and less restrictive to be used as a basic guide for architects to build 3D models for VR.

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