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An Assessment of Visual Variables for the Cartographic Design of 3D Informal Settlement Models

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Abstract. Visual variables were originally proposed for hard copy maps printed in black and white by Bertin in 1980s. However, we can now generate various digital geovisualization products that are inherently different from printed maps, such as interactive 3D city models. Additional visual variables have been proposed for some of these new geovisualizations, however the discussion is still on-going. In this paper, we contribute to this discussion by investigating the relevance of a subset of visual variables for planning informal settlement upgrades in 3D geovisualizations, and specifically how these variables contribute to the selectiveness of objects. The variables were systematically evaluated against specific requirements for planning upgrades which were compiled using expert knowledge. We observe that evaluated visual variables, except *colour* and *texture*, are not directly transferrable. Furthermore, we propose that; in an interactive 3D setting, visual variables *position*, *orientation* and *motion* should not be only considered in relation to the objects in a 3D environment, but also in relation to the camera, and the concept of Level of Detail (LoD) should replace *shape*. The results contribute towards building design principles of 3D informal settlement models for planning upgrades.

Keywords: visual variables; 3D models; informal settlements; planning

1. Introduction

Informal settlements (also known as squatter camps, shantytowns or slums) are densely populated illegal or unauthorised settlements characterised by rapid and unstructured expansion and improvised dwellings made from scrap material (City of Tshwane 2012, Huchzermeyer & Karam 2006, Mason et al. 1997). The settlements are traditionally located along the borders of urban areas, close to the social and economic hubs. As informal settlements are considered to be illegal or unauthorised, they lack secure tenure, basic service delivery (e.g. access to water, electricity and waste removal) and infrastructure (e.g. roads and storm water drainage) (City of Tshwane 2014, Paar & Rekittke 2011, Richards et al. 2006, Sliuzas 2003). In South Africa, informal settlements arise due to biased planning, housing backlog and the search for work and a better quality of life (City of Tshwane 2014, Richards et al. 2006).

The South African government has prioritised the upgrading of informal settlements to ensure that all citizens have adequate housing and access to basic services (National Planning Commission 2012). Planning informal settlement upgrading is part of the urban planning process and could integrate geovisualization to *understand* the current environment, and to *communicate* planned developments. Maps and aerial photography have successfully been used in the past to gather information from the local community (Mason et al. 1997, Paar & Rekittke 2011, Sliuzas 2003). However, recent research suggests that three-dimensional (3D) geovisualizations are a viable alternative for collecting and exploring information virtually. Especially when used in conjunction with site visits, 3D geovisualizations have successfully been utilized in other application fields, such as forensic science and anthropology (Agosto et al. 2008, Gibson & Howard 2000, Gruen 2008, Koller et al. 2009).

When using 3D informal settlement models for urban design, users should be able to extract information from the model, such as distance from a water distribution point or sunlight exposure for placement of solar geysers. This type of information can be visualized in 3D models using graphical aspects (in other words, visual variables) such as façade *colour*, *texture* or *size* of the object (Döllner et al. 2006). Information needs to be simplified and abstracted when visualized using visual variables (Wood et al. 2005).

In this paper, our goal is to assess the relevance of a subset of visual variables for 3D geovisualizations of informal settlements for urban planning. The assessment is based on whether visual variables can be *selective* (see Table 2 for Bertin's definition of this term) in the context of visualising 3D informal settlements for the purposes of planning upgrades.

The results will contribute towards obtaining design principles for 3D informal settlement models in the context of urban planning. The focus of this paper is on 3D models, i.e. accurate and mathematically correct 3D digital representations of an area (Chen 2011); rather than 3D maps, i.e. a generalised representation of a specific area using symbolization to illustrate physical features (Häberling et al. 2008). The remainder of the paper is structured as follows: Section 2 provides an overview of visual variables; Sections 3 and 4 describe the informal settlement upgrading process in South Africa, as well as geovisualization requirements; Section 5 presents the results of the assessment of the visual variables; and lastly, Section 6 offers conclusions.

2. Visual Variables

Bertin (1983) pioneered the concept of visual variables for designing data graphics for print on white paper under normal reading conditions, listing seven variables: *position, size, shape, value, colour, orientation* and *texture*. At the time, Bertin (1983) did not see the usefulness of dynamic maps and argued that motion would dominate the graphic and disturb the effectiveness of the cartographic message. However, through the years, visual variables were extended for interactive displays, most prominently by DiBase et al. (1992) and MacEachren (1995) who introduced six new visual variables: *movement, duration, frequency, order, rate of change,* and *synchronisation*. Another decade later, Carpendale (2003) also argued that *motion* should be considered a visual variable for information visualization on computational displays. Furthermore, Slocum et al. (2009) proposed *perspective height* which is important for 3D models. Information visualization introduced *sketchiness* as a visual variable that has been found quite effective in visualizing uncertainty (Wood et al. 2012, Boukhelifa et al. 2012). In a recent paper, Halik (2012) provides a complete chronological breakdown of static visual variables and identifies the following static visual variables that are most frequently used in literature: *size, shape, lightness/value, orientation, texture, location (position), hue, saturation/intensity* and *arrangement*.

Visual variables have been adapted successfully in various application fields, such as visualizing interactive information, 3D cadastre and 3D maps, and evaluated (Köbben & Yaman 1996, Fosse et al. 2005, Döllner et al. 2006, Yi et al. 2007, Heer & Robertson 2007, Halik 2012, Wang et al. 2012, van Oosterom 2013, Walker et al. 2013, Brychtova & Coltekin 2014).

Table 1 provides descriptions of the visual variables considered in this paper. Note that the term *mark* refers to points, lines, and areas (or

polygons) in 2D maps, and for 3D models, Carpendale (2003) proposed surfaces and volumes as marks.

When choosing which visual variable to modify, it is important to understand how it will affect the user's ability to perform a specific task (Carpendale 2003). Visual variable characteristics were developed to classify the variables according to their practicality (Halik 2012). Table 2 provides an overview of the characteristics.

Visual variable	Description
1. Position	Position is considered the most versatile visual variable and is important for representing geovisualizations (the exact position of objects in a geovisualization). On a 2D computational display, two positional variables X and Y are used, and on a 3D display, three variables X, Y and Z.
2. Size	A mark's size can be changed in length, area or volume. However, when modifying the size of a mark, altering the meaning should be avoided.
3. Shape	Varying the outline, not the size, can change a mark's shape. The shape can be associated with a specific meaning (i.e. a red cross denotes a medical facility). The link between shape and meaning can be cultural, and is commonly stated on the legend of a map.
4. Value	A shift in the value of a mark is attained by changes in lightness or darkness (range of shades in grey).
5. Colour	Changing a mark's colour involves adjustments in the hue without affecting the value. On computational displays, changes in saturation and transparency are included in this visual variable.
6. Orientation	The orientation of a point has an infinite number of different orientations, and orientation of a line or area is altered by the angle of the pattern. In 3D environments, the orientation of the camera (viewing angle) is included.
7. Texture	This visual variable refers to grain, pattern and texture. With advancements in technology a wide variety of grains, patterns and textures are available to display characteristics of various materials.
8. Motion	Motion was impossible with printed graphics. With computational displays, motion is possible; however, this has not been researched comprehensively. Motion has various aspects to consider, such as direction, speed, flicker, frequency, and rhythm.

Table 1. Subset of visual variables considered in this paper (Carpendale 2003, Haerberling 2002, Wang et al. 2012)

In addition to the visual variables listed in Table 1, various other aspects should be considered for interactive 3D models: e.g. *camera setting, lighting and illumination, shading and shadows, and atmospheric and environmental effects* (Haeberling 2002). However, these aspects are not considered in this paper, as they are beyond the scope of our case study. These variables are important to consider for a sense-of-place experience (e.g. virtual reality experiences, gaming) but for our urban planning context with a specific purpose (informal settlement upgrades in South Africa), we start with the most basic visual variables.

Characteristics	Description
1. Selective	A visual variable is selective if a mark can be changed in only this variable and easily differentiated afterwards.
2. Associative	A visual variable is associative if several marks that are related can be grouped according to a change in only this visual variable.
3. Quantitative	A visual variable is quantitative if the relationship between two marks can be expressed as a numerical value.
4. Order	A visual variable is ordered if marks can be ordered and if changes in this visual variable express the ordering.

Table 2. Characteristics of visual variables (Bertin 1983, Carpendale 2003, Halik 2012, Wang et al. 2012)

3. Upgrading Informal Settlements in South Africa as a Use Case

One of the main aims of the South African National Development Plan (NDP) is to improve the standard of living of all South Africans. The NDP highlights adequate housing, and access to clean water, sanitation and electricity as key elements for achieving a minimum standard of living (National Planning Commission 2012). According to the Municipal Systems Act of 2000, each district municipality shall develop Integrated Development Plans (IDP) spanning five years. The IDP informs and guides all development activities within the region. The City of Tshwane IDP aims to provide *sustainable service infrastructure and human settlement management* (strategic objective 1), and as part of this outcome 3 aims to *develop quality infrastructure to support liveable communities* (City of Tshwane 2013). For the financial year 2014/15, the City of Tshwane aims to formalize seven informal settlements; proclaim eight identified settlements; and, increase the number of households in informal settlements that have access to rudimentary water, sanitation and waste removal services.

Figure 1 presents an overview of the process to be followed when an informal settlement is upgraded. It also indicates the level of services available at each stage of upgrading. Geovisualization can be useful to *understand* the initial or current situation (Level 1) and to *communicate* planned developments for subsequent levels.

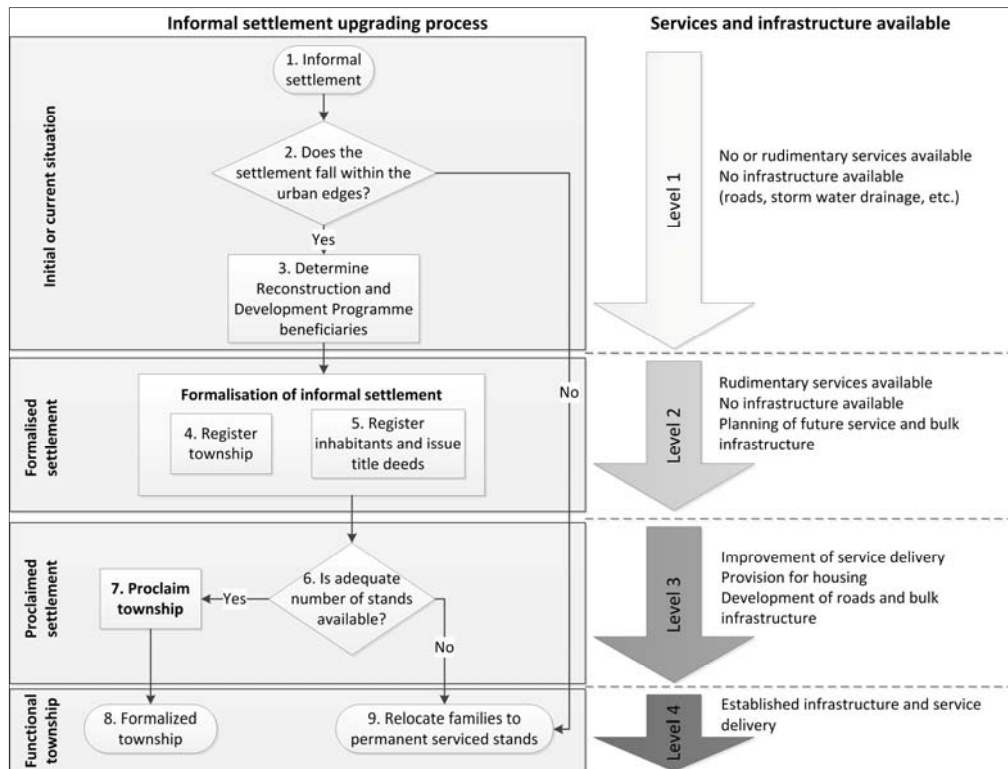


Figure 1. Informal settlement upgrading process

4. Requirements for 3D Informal Settlement Models

In this context, formalisation refers to the legal processes required to create townships (township establishment) with formal service delivery through which residents obtain security of tenure. This normally includes the development of top structures, such as houses through government funded programmes. For the formalisation of an informal settlement, the principal planning task is identifying (or distinguishing) individual stands (also known as land parcels) and allocating addresses (including street names).

The following are key considerations when deciding to do in-situ upgrading or to relocate the settlement during formalisation (City of Tshwane 2012,

City of Tshwane 2014, Housing Development Agency 2011): *can the settlement be integrated into the adjacent communities? Is adequate access to the city and main economic hubs possible? Is the area of a stand large enough for the number of individuals, accommodating changing requirements over time, e.g. single to multiple households?*

Therefore, the following are essential requirements for a 3D informal settlement model:

1. **Representation of the terrain of the stands:** Understanding the terrain of the environment is important for determining if the settlement is located on a suitable terrain. For example, harsh terrains like rocky or mountainous areas should be avoided.
2. **Representation of the boundaries of a stand:** The extents of stands in informal settlements are not well defined, as the area is typically very densely occupied. It is important that the stakeholders can identify the bounds of a stand in a 3D model. During the *formalisation of the informal settlement* (Figure 1) it is required to identify the boundaries of the stands and to determine if the stands satisfy predetermined specifications.
3. **Representation of spatial patterns among stands:** The spatial patterns among stands within an informal settlement and adjacent community are important to plan how the informal community can be integrated with the surrounding city for the *formalisation of the informal settlement*. The spatial patterns provide insight into the distribution of the stands in the settlement and can assist in planning upgrades to ensure lower density and improved infrastructure.
4. **Representation of spatial relationships between stands and other physical objects:** The relationship between the stands and other objects such as water tanks or footpaths is vital to answer some of the key considerations mentioned above.
5. **Representation of the impact of new infrastructure:** Service delivery infrastructure is important for enhancing the quality of life of the inhabitants. However, not always positively; e.g. high voltage electricity transmission lines would affect the height of new structures and nearby vegetation. Refer to the *functional township* in Figure 1.
6. **Display of additional information:** Information, such as addresses, is important in informal settlements for the *planning of future service delivery and bulk infrastructure* (refer to Figure 1 Level 2). Additional information, such as the size of a stand or distance from water distribution points, can be displayed on labels.

5. Evaluation of Visual Variables for the Requirements of Informal Settlement Upgrading

We evaluate the relevance of a subset of visual variables for interactive 3D informal settlement models considering only the selective characteristic as an exercise to systematically study the transferability of visual variables in this context. In this manuscript, “3D geovisualization” refers to an abstraction of real world objects on 2D displays with 3D perspective views. The following visual variables are included in the study: *position, size, shape, value, colour, orientation, texture, and motion* (Table 1 provides a short description of each variable). Note that for this exercise, we only considered expert users, and a non-exhaustive list of geovisualization requirements. The requirements were collected through a literature review and expert knowledge, and only the primary requirements are discussed (refer to Section 4). The requirements consider 3D objects and text labels.

Table 3 provides a summary of our assessment (refer to Annex 1 for examples of each visual variable). We phrased a question for each requirement and visual variable; for example, *can position be used to enhance the selectiveness of a stand's boundary?*

Visual variable	Position	Size	Shape	Value	Colour	Orientation	Texture	Motion
Requirement								
1. Representation of the terrain of the stands	No	Limited	No	Limited	Yes	Limited*	Yes	Limited
2. Representation of the boundaries of a stand	Limited*	No	Yes, but changes are rather in LoD than shape	Limited	Yes	Limited*	Yes	Yes
3. Representation of spatial patterns among stands	Limited*	Yes	Yes, but changes are rather in LoD than shape	Limited	Yes	Limited*	Yes	Yes
4. Representation of spatial relationships between stands and other physical objects	Limited*	Yes	Yes, but changes is rather in LoD than shape	Limited	Yes	Limited*	Yes	Yes

5. Representing the impact of new infrastructure	Limited*	Yes	Yes, but changes are rather in LoD than shape	Limited	Yes	Limited*	Yes	Yes
6. Display of additional information	Yes	Yes	No	Limited	Yes	Limited*	No	Yes
* Limited, only appropriate for the camera.								

Table 3. Relevance of visual variables for the requirements of informal settlement upgrades (selective)

Informal settlement upgrade planning requires accurate models, i.e. existing objects should be shown in their correct positions. This does not necessarily mean that the model shall be georeferenced, but that all objects representing existing features (e.g. shelters) and planned developments (e.g. tar roads or water distribution points) should be placed in their correct relative position. Thus **position** is not applicable as a visual variable for the requirements relating to objects, as changing the X, Y or Z positional parameter of the object will alter the accuracy of the model. However, the position of labels displaying additional information can be altered as needed to ensure that the information is optimally placed and legible.

The position of the camera is applicable for all requirements as it can enhance the selectiveness of the desired objects. For example, by focussing on new developments, such as a (proposed) bridge to connect the settlement to the local community, when entering the 3D environment, we expect that the user will immediately notice them. However, changes in the camera position might alter or distort perspective. These distortions can make an object (e.g. a shelter) appear larger or leaning to one side (e.g. would make the shelter seem structurally unsound).

A change in **size** is not suitable for most requirements. For example, size is not suitable for representing the terrain or boundary as changes might alter the meaning. For example, the boundary of a stand cannot be extruded to make it more visible, as this extrusion would alter the meaning of the boundary (the boundary might be interpreted as a wall). However, altering the size of an object depending on the distance from a specific location or object (e.g. proportionally reducing the size of shelters according to the distance from a water distribution point) could be quite effective.

We found that **shape** was not appropriate for 3D models. Instead we propose *level of detail (LoD)* to be considered. Changing an object's physical shape may change the meaning of the object. For example, changing the shape of a shelter (generally a cuboid) to a sphere would not

contribute to the informal settlement upgrading requirements. However, LoD is a method of modifying the shape of the objects in subtle ways by adding or removing detail, while keeping the global shape recognisable (Coltekin & Reichenbacher 2011). A high LoD is often associated with higher realism, and considered to be useful for showing new developments or upgrades in the environment by planners. Additional housing to be developed can be shown in a higher LoD. This would contribute to the selectiveness the objects.

Modifying the colour **value** refers to changes in lightness or darkness, but was found to be of limited relevance for the requirements. Modern 3D models are generated in self-illuminating environments and typically there is no light source or shadow. Colour value would only be effective for certain views, such as static overviews. Self-illuminating environments pose a challenge because as the user navigates through the environment, the lightness of objects changes, and then value is not an optimal visual variable to employ for selectiveness. An example of changes in colour value could be for planning the addition of solar geysers; i.e. shelters with high sun exposure would appear lighter than those with a lower sun exposure.

Variations in colour, texture, and LoD contribute to the realism of the 3D environment. Changes in **colour** and **texture** were found to be the most relevant visual variables for the requirements. Various colours or textures can be used to highlight certain aspects and to ensure selectiveness. However, selecting the optimal colour or texture for informal settlement upgrading remains an issue that needs to be investigated further.

Orientation was found not to be relevant for any requirement, as altering the orientation of an object in the 3D environment would change the meaning and accuracy of the model. However, changing the orientation of the camera to focus on the aspect that needs to be distinguished would potentially assist in the selectiveness of certain objects

The use of **motion** in 3D environments still needs further research, but motion is essentially the principal attention grabber of all visual variables. Carpendale (2003) stated that it is then fundamentally selective. However, spinning a house around in a city model might not be an optimal choice, but rather a flickering object would immediately get the attention of the user (used with caution). Thus motion was found to be relevant for all requirements. The motion of the camera can also be included, for example, the user's attention would be drawn to a specific development corridor. Motion should be cautiously used, and the viewer should be able to deactivate it at any time.

6. Conclusion

In this paper, we present results from an expert assessment of the relevance of a subset of visual variables for 3D interactive geovisualizations of informal settlements for urban planning. Our goal was to evaluate the selectiveness of the visual variables for specific geovisualization requirements of planning upgrades in informal settlements.

Various researchers have expanded on Bertin's (1983) visual variables and there are many interesting suggestions for interactive displays. However, in the scope of this paper, we only considered the following variables: *position, size, shape, value, colour, orientation, texture, and motion*.

Position in the traditional sense is not easily utilized as a visual variable, as we cannot move the physical position of a river, for example. However, *the position of the camera* is very important in a 3D environment as the placement may enhance the selectiveness or distort the perspective. Not only should the camera position be considered as an additional aspect of position as a visual variable, but also the *camera orientation* and *camera motion*. *Motion* is an integral part of interactive 3D geovisualizations, and can be of great use as an attention grabber. Nevertheless, motion can limit the visual variable *value*. Due to motion and self-illumination of environments, value needs to be used with care as dynamic light sources and self-illumination might influence how the value is displayed. As a result of this qualitative evaluation, *colour* and *texture* emerge as the most powerful variables, because these two were found to be appropriate for all requirements. Optimal colour and texture need to be further investigated. We suggest that *shape* is replaced with LoD, as it is commonly used in computer graphics to add or eliminate detail from 3D objects (Luebke 2002). More detailed objects are considered to be more selective, as they (potentially) capture the attention of users more easily in an environment where most objects will have lower LoDs. The vice versa would also apply, thus a lower LoD objects in a high detailed environment.

In this study, we conducted a conceptual exercise by rethinking the visual variables for 3D in a very specific context of urban planning. We argue that such studies are useful in expanding the cartographic knowledge beyond its usual audience and application domains. With this manuscript, we provided new observations and suggestions which may be applicable for 3D geovisualizations in general. As next steps, we plan to evaluate the other characteristics (associative, quantitative and order) of visual variables, as well as additional visual variables to establish the most useful visual variables for 3D geovisualizations of informal settlements. Following this,

we plan to evaluate the proposed visual variables with user studies to complete our top-down expert evaluation with empirical observations.

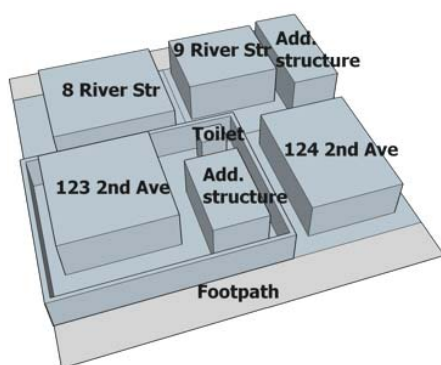
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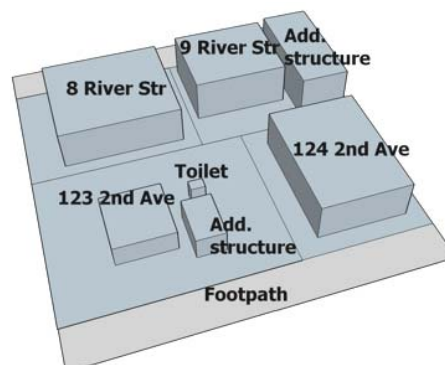
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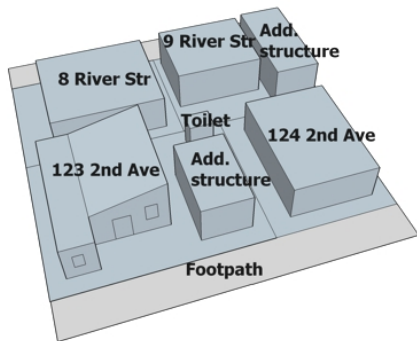
Annex 1



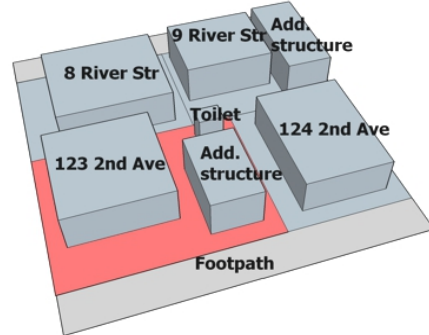
I) Change in the **size** of the boundary



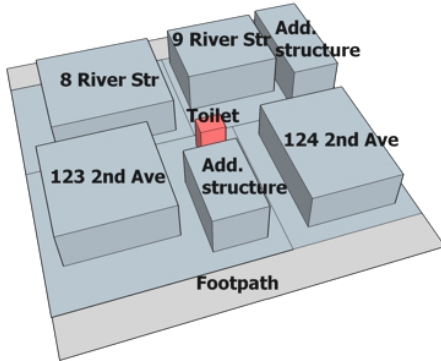
II) Modifying the **size** of shelters



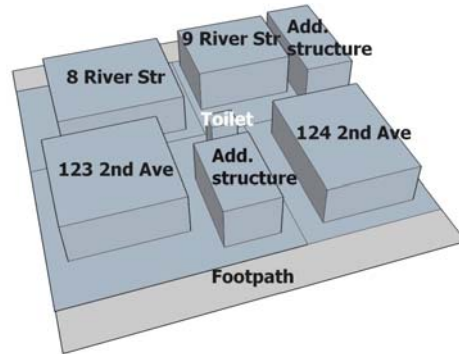
III) Altering the **shape** (higher LoD)



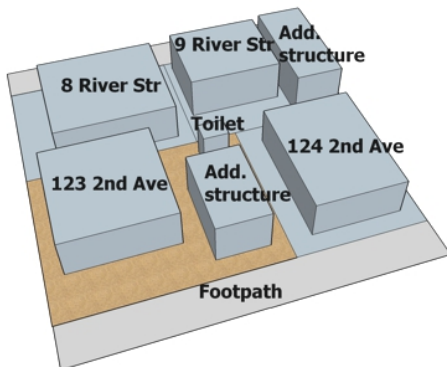
IV) Highlighting through changes in **colour**.



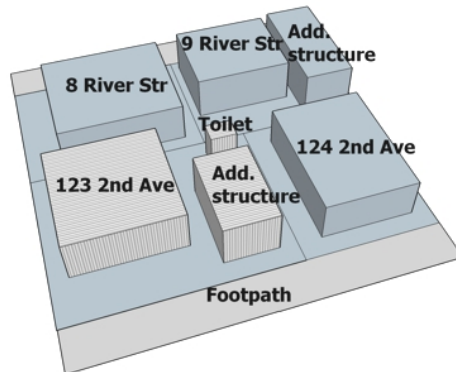
V) Highlighting a structure through a change in **colour**.



VI) Enhancing label's selectiveness with a **colour** changes.



VII) Depicts a change in **texture**



VIII) Depicts a change in **texture**

Figure 2. Selected examples from the evaluation discussed. For illustration purposes, the shelters are represented by basic geometry and boundaries as a line on the terrain.