Simulating Virtual Construction Scenes on OpenStreetMap

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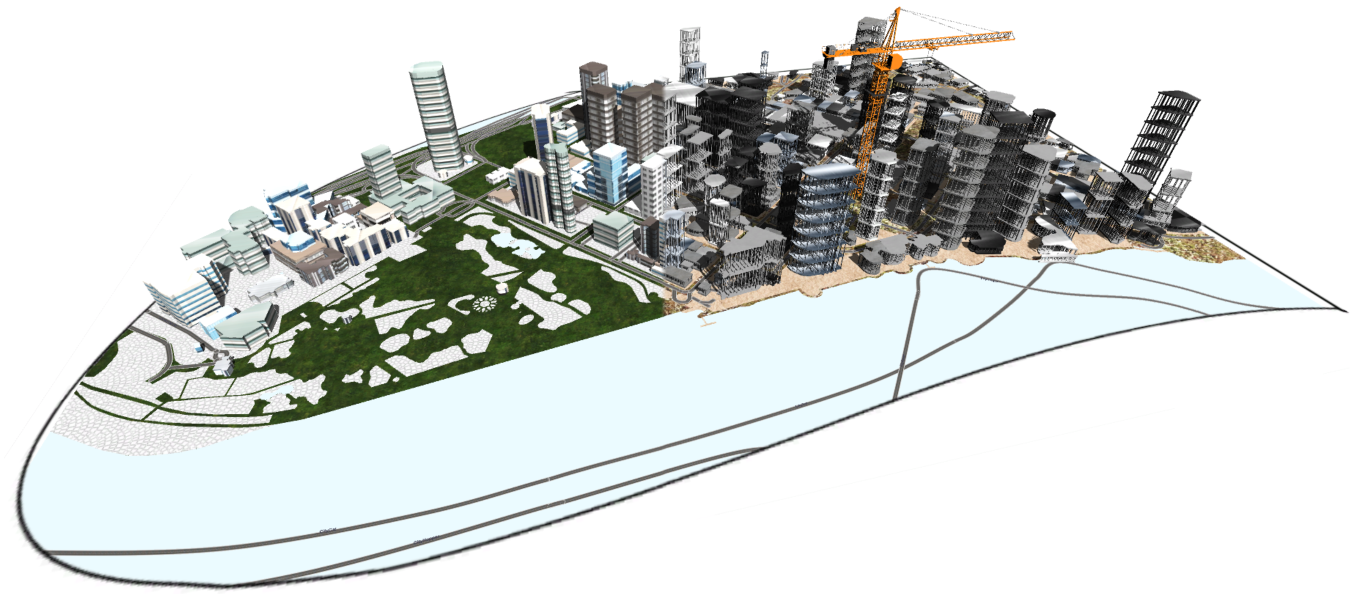

Figure 1: This figure shows an example that a virtual construction scene being simulated on OpenStreetMap. The original virtual world created with OpenStreetMap data (left half-figure) is automatically converted into a virtual construction scene (right half-figure) using our approach.

ABSTRACT

Nowadays, as more advanced technologies in Virtual Reality (VR) are emerging, virtual training become an important branch of modern construction training programs. However, manually creating virtual construction scenes is time-consuming and effort-demanding for VR developers. Given this observation, we devise a novel procedural modeling approach for simulating virtual construction scenes on OpenStreetMap (OSM) without demanding too much manual effort. According to a series of numerical studies, we demonstrate that, through our proposed approach, parameterized realistic construction sites can be automatically generated in virtual reality given arbitrary location coordinates in the real world with OpenStreetMap data.

CCS CONCEPTS

• **Computing methodologies** → **Rendering**; **Interactive simulation**; **Virtual reality**.

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KEYWORDS

construction training, virtual reality, procedural modeling

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1 INTRODUCTION

As Virtual Reality (VR) technologies are widely employed in various kinds of applications such as gaming, teaching, and training, realistic virtual content generation is necessary for creating VR programs. Manually creating virtual content typically requires a large amount of time and effort from the VR program developers. Therefore, procedural modeling approaches that can generate virtual content using computer programs are becoming more and more popular within both the VR industry and the VR academy. To the best of our knowledge, the most popular applications of procedural modeling on virtual content generations are those developed for interior scene synthesis [30], urban layout synthesis [6], and terrain landscape synthesis [23]. Generally speaking, interior scene synthesis is taking the advantage of the optimization approach from human heuristics to automatically place the virtual furniture

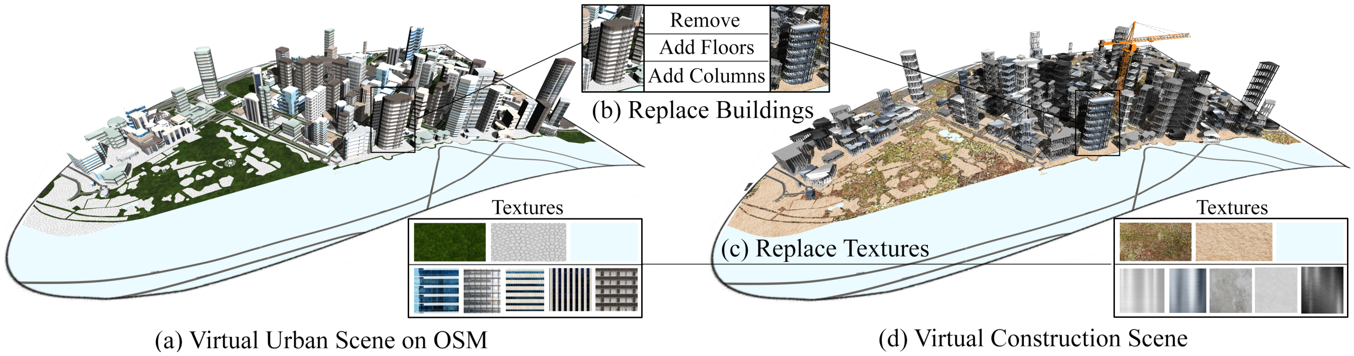


Figure 2: Overview.

and virtual objects in the given arbitrary interior room layouts to result in reasonable and realistic interior designs. Different from interior scene synthesis, urban layout synthesis is applied on arbitrary terrain as input for generating the urban structures that can match well with such input terrain. Urban layout synthesis is particularly important for urban-scale virtual scene generations and for computer-aided urban planning. Different from the previous two, terrain landscape synthesis is considering even more high-level content synthesis that considers the whole terrain as output. Terrain landscape synthesis is typically achieved through mathematical formulas and recursive equations to generate the geometry that looks like a specific type of landscape. Theoretically, after combining existing procedural modeling approaches, all types of realistic virtual content can be synthesized within the virtual world automatically without too much manual effort from the designers. However, in reality, there are still lots of open problems on how to apply these procedural modeling approaches to a specific type of virtual scene generation, and it is mostly dependent on the specific feature and requirements of such type of scene.

At the same time, as one promising research area, virtual training is an important branch of modern construction training programs. In order to maximize the profit margin and minimize the cost overrun during a construction project, construction workers must be trained through effective training programs. Recently, researchers have developed lots of effective training programs using VR environments for virtual construction training programs. Most of those works claimed a positive conclusion that realistic virtual training programs are effective for workers' construction training. On one hand, a common feature of these successful works is there are immersive virtual construction scenes embedded in these VR training programs, all of these immersive environments are built up manually by the VR developers. On the other hand, manually creating virtual construction scenes is time-consuming and effort-demanding for VR developers. One possible way to avoid such efforts is to take advantage of those procedural modeling techniques as pointed out earlier. However, to the best of our knowledge, no existing work has been focusing on procedural generation for virtual construction scenes so far. Therefore, it remains an open problem to devise an effective procedural modeling approach to simulate realistic construction scenes in virtual reality.

Given this observation, we devise a novel approach for simulating virtual construction scenes on OpenStreetMap (OSM) [4] using procedural modeling techniques. Through our proposed approach, parameterized realistic construction sites can be automatically generated in virtual reality given arbitrary location coordinates in the real world through OpenStreetMap data. The advantage of using OpenStreetMap data is the synthesized virtual world can be exactly matched with the real world. In this way, different virtual construction scenes can be automatically generated given different locations coordinates in the real world and the virtual experiences can be as immersive as real-world experience. Through our approach, trainees can be trained in any place in the virtual world created with OSM and there is no constraint on locations. Our approach can facilitate the training program designers significantly so that there will be no need to manually create any virtual construction scene that looks like any place in the real world. Contributions of our work include:

- We propose a novel research topic about how to simulate the virtual construction scenes using procedural methods.
- We propose and implement a novel approach for simulating the virtual construction scenes on OpenStreetMap.
- We demonstrate and validate the results of our approach through different parameter settings and location settings.

2 RELATED WORK

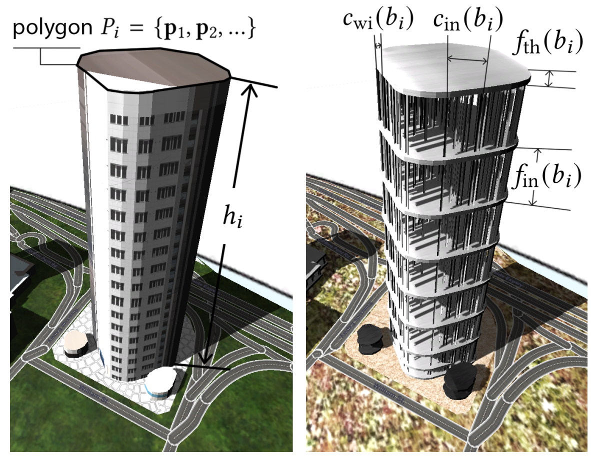
Virtual Construction Training. Since recent years, Virtual Reality (VR) technologies have been widely used in construction engineering education and training [27]. In 2005, Yaoyuenyong et al. [29] developed a virtual construction negotiation game as an interactive learning tool for project management negotiation skill training. In 2006, Xie et al. [28] developed a virtual reality safety-training system for construction workers. In 2011, Rezazadeh et al. [20] devised a novel approach to increase trainees' operation performance in virtual construction crane training system by devising an effective human-machine interface. In 2013, Sacks et al. [21] developed effective training programs for construction safety training using immersive virtual reality. in 2018, Lu et al. [9] examined the priming effects on safety decisions in a virtual construction simulator. In 2020, Terentyeva et al. [25] examined the potential of the virtual construction site as a tool of knowledge management on technological processes of construction production. At the same year, Jeelani et al. [5] developed stereo-panoramic environments for construction safety training in virtual reality. However, all of these mentioned related works are built on immersive virtual construction scenes within the VR training programs which are manually created by the VR developers and researchers.

Urban Procedural Modeling. Procedural modeling approaches have been well studied for high-quality realistic urban reconstruction since decades ago. In 2001, Parish et al. [18] proposed a novel system using a procedural approach based on L-systems to model cities automatically. In 2006, Lechner et al. [8] described a method for procedurally generating typical patterns of urban land use using agent-based simulation. During the same year, Muller et al. [14] presented the technical approach of procedural modeling of buildings. In 2007, Kelly et al. [7] developed an interactive system for procedural city generation called *Citygen*. In 2009, Haegler et al. [3] proposed the approach for procedural modeling for digital cultural heritage. During the same year, Teoh et al. [24] introduced a generalized procedural modeling approach to generate East Asian architecture. In 2012, Vanegas et al. [26] introduced the inverse procedural modeling approach for interactive urban design. In 2015, Saldana et al. [22] proposed an integrated approach to model the ancient cities and buildings procedurally. In 2016, Nishida et al. [17] devised an interactive sketching interface for urban procedural modeling. In 2017, Lyu et al. [10] introduced an urban simulation system to generate urban layouts with population, road network, and land-use layers. Later, Edelsbrunner et al. [1] proposed the procedural models of architecture with round geometry. In 2018, Nishida et al. [16] proposed a novel procedural modeling approach for creating a building from a single image. In 2019, Martin et al. [11] propose a generic graph-rewriting technique to transform input rulesets into new ones for building procedural modeling. In 2020, Mustafa et al. [15] devised an approach for procedural generation of flood-sensitive urban layouts. Most recently, in 2021, Ghorbanian et al. [2] employed the procedural modeling techniques as analytical tools for 3D Survey in urban design assessment. However, all of these mentioned works show that the attempt in simulating the virtual construction sites using procedural modeling techniques has not been receiving any attention in the research community.

This left an open opportunity for us to explore the methods that can be devised for simulating immersive virtual construction scenes using procedural modeling approaches. Given the fact that OpenStreetMap (OSM) [4] can be used to achieve realistic street layout generation [13] that can match virtuality with reality [12, 19], we devised our procedural modeling approach upon OSM data. Due to the high accuracy between the virtual map on OSM and the real-world map, the generated urban layout is realistic. So, given this foundation, we further devised a procedural modeling approach to convert the geometry of an arbitrary building on OSM into a new geometry that is representing the construction structure of unfinished buildings on the construction site to simulate the virtual construction scene on any place in the real world.

3 TECHNICAL APPROACH

Overview. Figure 2 shows the overview of our technical approach for simulating virtual construction scenes on OpenStreetMap (OSM). First, given the synthesized urban scene constructed from the OSM data as shown in (a) as input, in this example, the location center is set near the Museum of Brisbane, in Queensland, Australia. Then, after replacing the original buildings on OSM into the building frames as shown in (b) through three procedural modeling steps including (i) removing the original buildings, (ii) adding the floors of the building, and (iii) adding the columns of the building, the geometry of the buildings in the construction scene is synthesized. Finally, by replacing the texture package from the urban scene into the construction scene as shown in (c), the result of a virtual construction scene is synthesized as shown in (d).



(a) Building geometry. (b) Building frame.

Figure 3: Building representation.

Building Geometry. As one important step to simulate the construction sites, understanding the default mathematical representation of the building geometry that is defined in OSM data is a prerequisite. As OSM data is collected from all over the world using an abstract approximation of the geometries of the building, the reconstructed virtual buildings that are similar to the real buildings have fewer geometric details so that the data used for storing the building information can be compressed. According to our observation of the OSM data structure, all buildings are represented with extruded polygons. In mathematics, for each building b_i in the building cluster $B = \{b_1, b_2, ...\}$ within a particular region on the OSM, b_i can be represented as a tuple $b_i = \{\mathbf{P}_i, h_i\}$, where $\mathbf{P}_i$ is a polygon in 2D space consists a group of 2D vertices that represent the shape of building b_i such that $\mathbf{P}_i = \{\mathbf{p}_1, \mathbf{p}_2, ...\}$ and h_i is building b_i's height. The advantage of this representation is any building can be reconstructed realistically by combining several building blocks with extruded polygons using Boolean OR ($\bigvee$) operations. In order to more accurately formulate the procedural model, let us define extrude operation along the y-axis as $\uparrow$, then the geometry of building $b_i = \mathbf{P}_i \uparrow h_i$ is represented as a polygon $\mathbf{P}_i$ extruded from the ground along the y-axis with a distance at h_i. Figure 3 (a) shows an example that illustrates the mathematical representation of building geometry.

Procedural Building Frame. Given the observations that the main difference between the ordinary urban scenes and the urban scenes under construction is the exposure of the building frames in the construction scenes. According to civil engineering's terms, building frames, or framing, is the construction process of fitting together the frame pieces to give structural support to a building. Framing materials are usually wood, engineered wood, or structural steel. In order to simulate the virtual construction scenes on OSM, we propose a generalized parametric procedural modeling approach

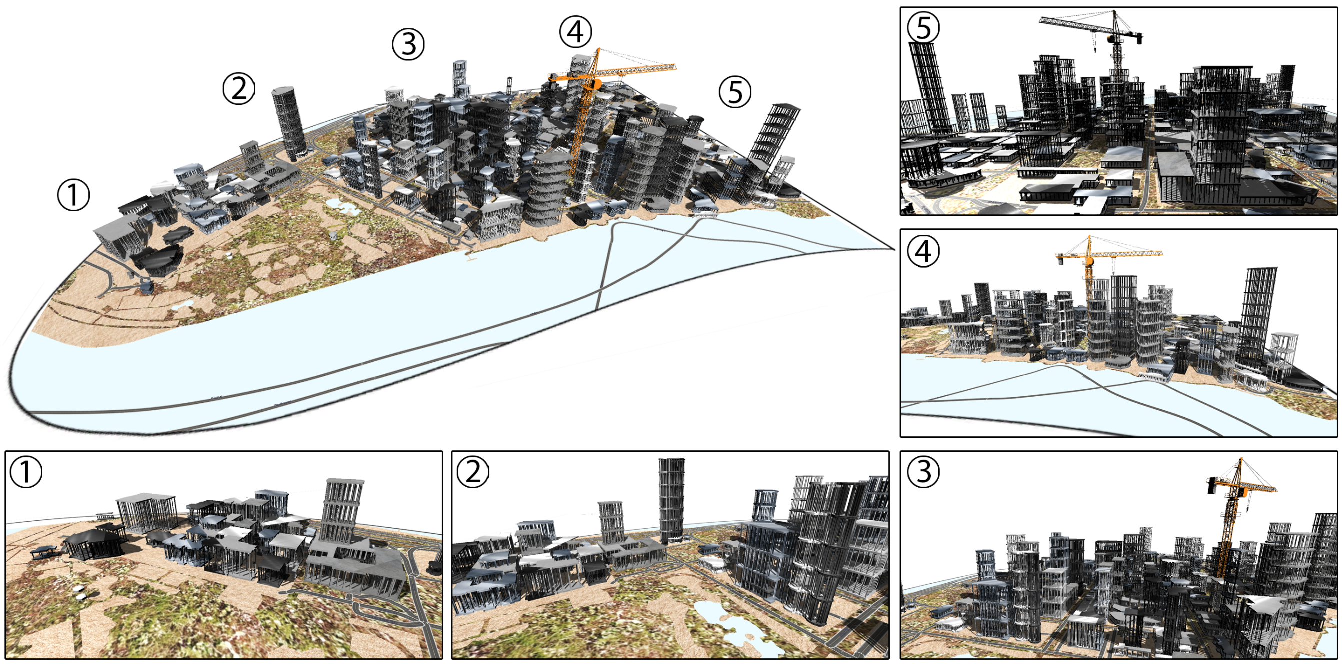


Figure 4: Details of synthesized virtual construction scene. In this figure, five different views are rendered from five different cameras placed in the virtual construction scene that is synthesized with our approach.

to formulate the building frame for arbitrary building geometry defined in the OSM as presented earlier. As shown in Figure 3 (b), parameters of our procedural building frame modeling approach include building b_i's floor interval $f_{\text{in}}(b_i)$, floor thickness $f_{\text{th}}(b_i)$, column interval $c_{\text{in}}(b_i)$, column thickness $c_{\text{th}}(b_i)$, column depth $c_{\text{de}}(b_i)$, and column width $c_{\text{wi}}(b_i)$. Then we construct each building frame by iteratively adding floors on horizontals (x-z planes) and adding columns along with vertical directions (y-axis). Number of floors are determined by building b_i's height h_i and floor interval $f_{\text{in}}(b_i)$. The minimum number of floors is one where there is supposed to be at least one ceiling. The geometry of each building floor can be calculated as $\mathbf{P}_i \uparrow f_{\text{th}}$ and they are placed uniformly along y-axis with same interval of $f_{\text{in}}(b_i)$. Similarly, the building frame columns are sampled along the building b_i's polygon $\mathbf{P}_i$ with uniform column interval of $c_{\text{in}}(b_i)$ between every edge (two adjacent vertices) in $\mathbf{P}_i$. Also, the minimum number of columns sampled on each edge is one. We simplify the column geometry by extruding a quad defined as $Q(\mathbf{p}, \mathbf{e}, \mathbf{d})$ where point $\mathbf{p}$ is sampled from one edge in the polygon $\mathbf{P}_i$, $\mathbf{e}$ is the direction of that edge, and $\mathbf{d}$ is the direction along which point $\mathbf{p}$ faces towards the center of polygon $\mathbf{P}_i$ denoted as $\mathbf{C}_i$. Then, $Q(\mathbf{p}, \mathbf{e}, \mathbf{d}) = \{\mathbf{p} + c_{\text{de}}(b_i)\mathbf{d}, \mathbf{p} + c_{\text{de}}(b_i)\mathbf{d} + c_{\text{wi}}(b_i)\mathbf{e}, \mathbf{p} + c_{\text{wi}}(b_i)\mathbf{e} + [c_{\text{de}}(b_i) + c_{\text{th}}(b_i)]\mathbf{d}, \mathbf{p} + [c_{\text{de}}(b_i) + c_{\text{th}}(b_i)]\mathbf{d}\}$. Then, columns in building frame for arbitrary building $b_i = \{\mathbf{P}_i, h_i\}$ can be represented as $c(b_i = \{\mathbf{P}_i, h_i\})$:

$$c(b_i) = \bigvee_{j=1}^{|\mathbf{P}_i|-1} \bigvee_{k=0}^{N-1} Q\left(\mathbf{P}_{i,j} + \frac{k\dot{\mathbf{P}}_{i,j}}{N-1}, \frac{\dot{\mathbf{P}}_{i,j}}{||\dot{\mathbf{P}}_{i,j}||}, \frac{\mathbf{C}_i - \mathbf{P}_{i,j}}{||\mathbf{C}_i - \mathbf{P}_{i,j}||}\right) \uparrow h_i,$$

where $\dot{\mathbf{P}}_{i,j} = \mathbf{P}_{i,j+1} - \mathbf{P}_{i,j}$ and number of columns $N = \left\lceil \frac{||\dot{\mathbf{P}}_{i,j}||}{c_{\text{in}}(b_i)} \right\rceil$.

4 EXPERIMENTAL RESULTS

Scene Details. Figure 4 shows the detailed experimental results of one virtual construction scene synthesized with our approach. By placing five different cameras at different places in the scene, five different perspectives of the scene are rendered. To generate such a scene, we implemented our proposed approach using Unity 3D with the 2019 version. We conducted the simulations with the hardware configurations containing Intel Core i5 CPU, 32GB DDR4 RAM, and NVIDIA GeForce GTX 1650 4GB GDDR6 Graphics Card. The building reconstruction is implemented with the OpenStreetMap APIs that are embedded in an open-source Unity Asset called GoMap. The location setting of this scene is the center of Brisbane, in Queensland, Australia where the latitude is -27.4700188 and the longitude is 153.0257349. The procedural modeling parameters settings are: floor interval $f_{\text{in}} = 20$, floor thickness $f_{\text{th}} = 2$, column interval $c_{\text{in}} = 5$, column thickness $c_{\text{th}} = 0.5$, column depth $c_{\text{de}} = 2$, and column width $c_{\text{wi}} = 1$. As shown in the results, these figures rendered from different points of view are realistic, immersive, and look like construction sites in the real world. However, it can be more immersive if more construction objects such as trucks, cranes, and excavators are included, this point will be emphasized in the future work subsection.

Changing Parameters. Figure 5 shows another group of experimental results. In this case, we test our approach with different parameter settings. While keeping the same location setting and other building frame settings, we demonstrate different simulation results with respect to two varying parameters: floor intervals (as specified in different columns) and the column intervals (as specified in different rows). As we can see, from the left top corner

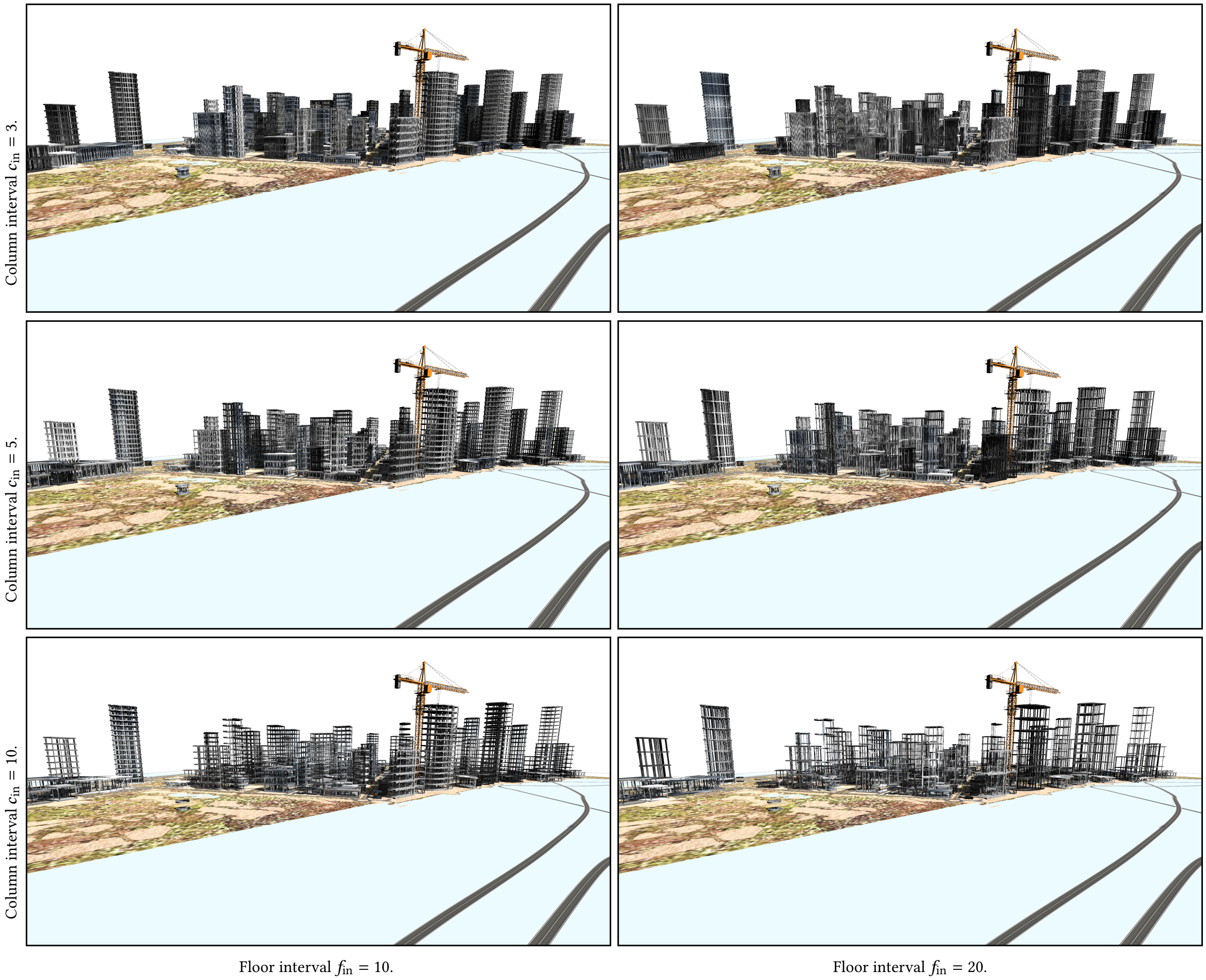


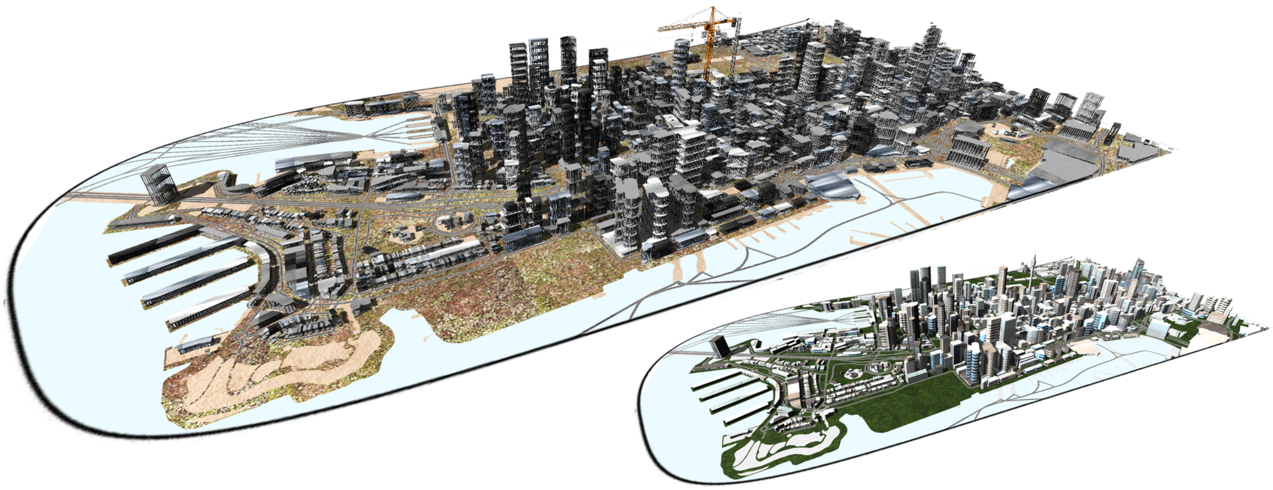
Figure 5: Changing parameters. This figure shows the construction scenes synthesized at the same place but with different parameter settings. Different rows show the synthesized construction scenes with different column intervals. Different columns show the synthesized construction scenes with different floor intervals.

to the right bottom corner, as the floor and column intervals increase, the building frame becomes more sparse. This result actually gives an illusion that the sparser building frames look more like unfinished construction work at the early stage while the denser building frames look more like the construction works that are close to completion. However, more details on completion degrees need to be addressed to achieve a more immersive environment. This point will be emphasized in the future work subsection.

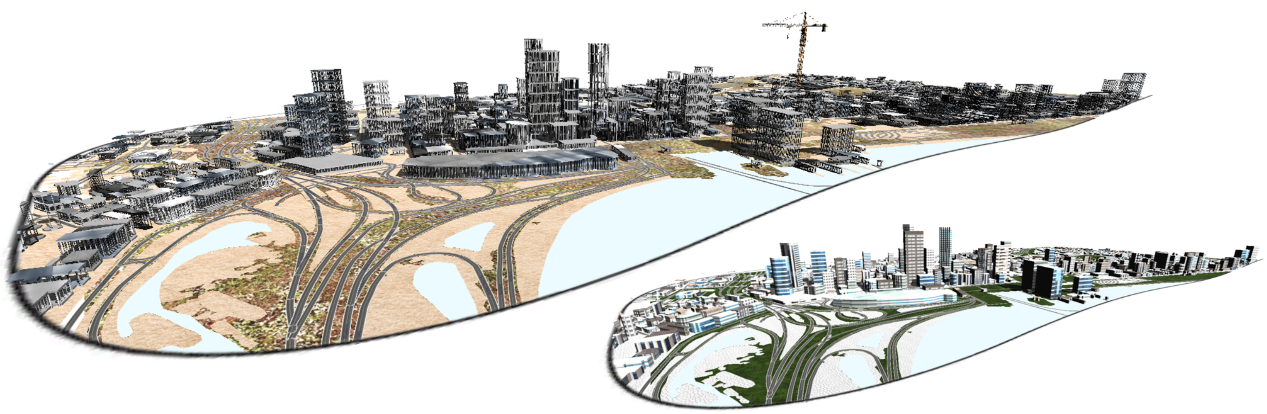
Different Places. We test our approach with different location settings. As shown in Figure 6, three different virtual construction sites are simulated in three different places in Australia, they are Sydney (a), Perth (b), Melbourne (c) respectively. Their corresponding location coordinates (latitude, longitude) are: (-33.86368, 151.20165), (-31.955695, 115.85557), (-37.82173, 144.96440) respectively. The building frame settings are the same as the settings in the subsection of **Scene Details**. As we can see from the results that our approach is robust enough to simulate realistic virtual construction scenes at different places given arbitrary location coordinates.

5 CONCLUSION

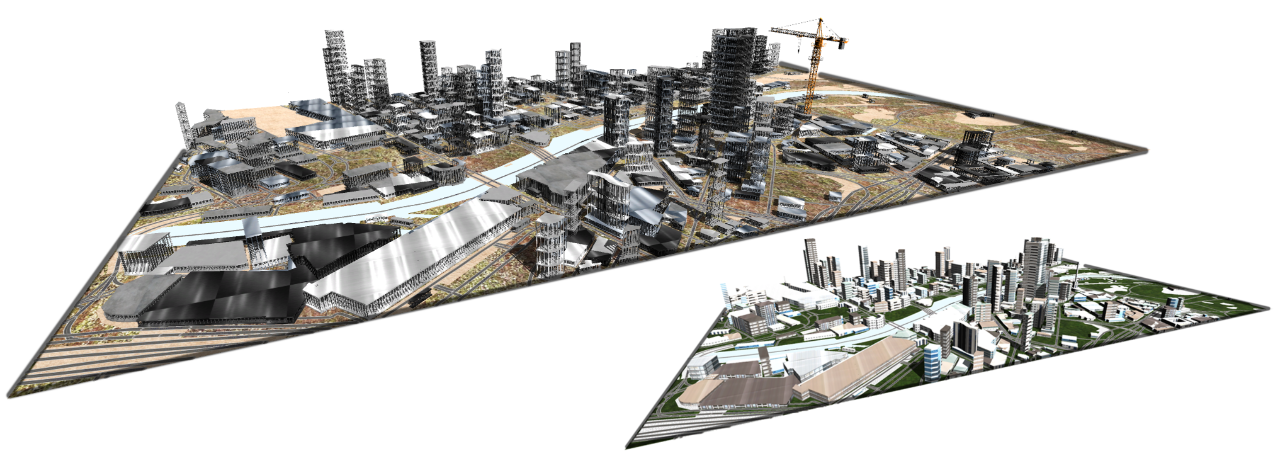
In this paper, we propose a novel research topic about how to simulate virtual construction scenes using a procedural modeling technique. By taking advantage of OpenStreetMap (OSM) data, we present and implement a novel procedural modeling approach for automatically simulating the virtual construction scenes at arbitrary places in the real world. During the procedural generation of virtual construction scenes, we have considered several important parameters of building frames which are the key features of



(a) Sydney, New South Wales, Australia.



(b) Perth, Western Australia, Australia.



(c) Melbourne, Victoria, Australia.

Figure 6: Experimental results of simulating virtual construction scenes at different places. For each row, the left top corner subplots the construction scenes synthesized with our approach, the right bottom corner subplots the urban scene reconstructed from the OpenStreetMap (OSM) data given a specific location setting.

construction scenes. Given the demonstration of several numerical experiments, we have tested the robustness of our approach in dealing with different building frames parameter settings and different location settings. All results show acceptable visual effects in simulating realistic virtual construction scenes on OpenStreetMap.

However, during the experimental process, we realize there are still some limitations within our proposed approach. For example, our approach can automatically synthesize realistic construction buildings using a procedural modeling approach on construction sites, although this can save the most part of time and effort for the VR developer, manually placing construction objects in the scene such as trucks, cranes, and excavators also takes some time. If this can be included and placed automatically in our future work, the generated virtual construction scenes can be even more impressive. However, this is another challenging research topic that can be regarded as a follow-up work of this paper. Besides, another limitation of our work is the lack of consideration of the unfinished degree. In our problem formulation, all building frames are exactly matching with the building's original geometry. However, in reality, there can be building frames that are partially matching with the final building. Again, this requires more effort in designing a random procedural model to simulate such phenomenon which can be considered to be another challenging follow-up work. We believe our work is a meaningful preliminary study along with this research direction and will inspire researchers for simulating more immersive virtual construction scenes.

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