CIM-enabled quantitative view assessment in architectural design and space planning

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Abstract

A view is among the critical criteria in an architectural design process. Presently, it is assessed by conventional site observation, labour-intensive data collection, and manual data analysis before designing a building mass, plan, façade, openings, and interior space. City Information Model (CIM), with its capabilities to store, visualize, and analyze a wealth of site-related information, has a great potential to support an automated view assessment. However, its realization is nascent, and it has not integrated with architectural space planning in either research or practice. This research, therefore, aims to develop a model through which CIM can be extended to assist view assessment in architectural space planning. By literature review, brainstorming, prototyping, and case study, this research corroborates that by harnessing the power of CIM, the conventional view evaluation can be transformed from qualitative to mix-used. It helps practitioners assess a view and design a space in a more precise and rapid manner. This research also provides the integrated model for view evaluation in architectural space planning with three stages to support the real-world practice. Future studies are recommended to develop the proposed model and integrate it with multiple criteria to advance the generative design.

Keywords –

Architectural design; Generative design; Space planning; View assessment; City information model; Deep learning.

1 Introduction

The characteristics of the view outside a window considerably influence the occupants' well-being (e.g., stress recovery), building comfort (e.g., sleeping quality), as well as working productivity [1-4]. In healthcare architecture, the preferred view, including green, water, and other natural scenes, can improve patients' satisfaction, shorten a hospitalization period, and ultimately enhance recovery after medical treatments [5]. Because of these significances, the building orientation, shape, form, envelope, space, openings, fixture, furniture, and decoration are usually designed to capture a great view and maximize its benefits to a project. In some building types, including hospitality and wellness architecture, a view is highly prioritized during design to achieve higher star ratings and improve clients' satisfaction. The gorgeous view must be well reserved for important spaces, e.g., bedroom, living, dining, and working areas, while service spaces, e.g., storage and mechanical rooms, are located in a place with a less impressive view or without a view. In Hong Kong, for example, the triangular bay window is used for the hotel space planning and façade design to capture the breathtaking view of the Victoria harbour (see Figure 1).

Figure 1. The architectural space planning and façade design to capture a preferred view [6]

In the current architectural design practice, the view is assessed manually before conceptual design, mass development, and space planning. The common ways include visiting a site, exploring surroundings, and using a camera or drone to capture photos in every level and direction (see Figure 2) [7-9]. Then, all photos are reviewed and analyzed manually by a design team using criteria, such as view types, content, distance, quality, and surroundings' future development [10]. Apparently, this view evaluation method is time-consuming, labour-intensive, and costly. The process highly depends on the designers' perception and perspective without automatic tools to help the determination process, while other design criteria, including climate and energy consumption, already have advanced computational tools to simulate and facilitate precise and rapid decision making. Furthermore, additional site visits or drone flights are sometimes required when vital information is not collected in the previous visit [7]. Therefore, this process urgently needs an effective tool for supporting view evaluation in architectural design practice.

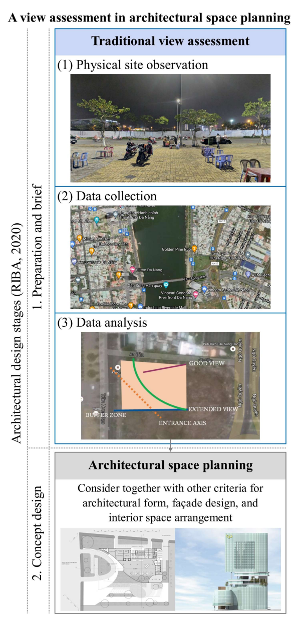

Figure 2. View assessment in architectural design

With the advancement of 3D reconstruction and remote sensing technology, the emerging city information modelling process has started to develop the City Information Model (CIM) and serve urban computing, simulation, analysis, and design [11]. CIM has been widely used in various intelligent applications due to its well-preserved geometry and digital reflection of the real world. The related location-based application covers a broad spectrum of fields such as navigations in transportation [12], disaster simulation in emergency response [13], utility and facility management in smart city construction [14], site design in urban planning and development [15], and big data analysis in urban computing [16]. Harnessing the power of CIM, studies in the field of architectural design have also presented numerous new findings, involving window design [17], solar estimation [18], and ventilation analysis [19].

Recently, an automated and accurate window view assessment has been further validated on CIM for urban-scale view evaluation [20]. CIM-based view assessment is also expected to help the architectural space planning and interior arrangement. However, this potential approach is rarely discussed in the previous literature. Moreover, the implementation process in real-world practice remains unclear. What is urgently needed is not only the program development but also the integration of CIM into the current design practice.

This research, therefore, aims to develop CIM to assist view assessment in architectural space planning. It is achieved by adopting a 5-step research method: empathizing the view evaluation in architectural design, defining the practice challenge, brainstorming the potential solution, developing a CIM-enabled quantitative view assessment model, and finally validating through the case study in Hong Kong.

2 Literature review

2.1 Architectural design

Architectural design is generally a highly creative and dynamic process to manage available resources, resolve difficulties in the built environment, and finally establish the environmental conditions for activities [21]. This process can be regarded as a Multi-Criteria Decision Making, since it copes with various factors in the complex social realms, such as users' requirements, site conditions, laws and regulations, functionality, feasibility, technologies, and aesthetics [22-24]. It has been demanded to mitigate more difficulties in the Architecture, Engineering, and Construction (AEC) industry, including manufacturing and assembly processes [25], sustainable building life cycle [26], and construction waste minimization [27]. According to the real-world case study, it is currently an arduous task, if not entirely impossible, for practitioners to understand, scrutinize, and reinterpret all factors before locating them into one design [28]. Assistive tools, such as CIM, Computer-aided design, Building Information Model, virtual reality, and design management software, are indeed required to help this intricate process [21, 28-29].

2.2 A view

In architecture, a view is a visual connection with the outside world, allowing occupants to keep in touch with ongoing activities, time, and seasonal changes [30]. It can be regarded as one of the basic human needs, since the view provides humans information about the environment for their feeling of safety [31-32]. The view is separated into three main layers with different purposes [30]. Firstly, the sky is a source of natural light and weather information. Secondly, the city or landscape part provides information related to the environmental condition and surroundings. Lastly, the ground is to observe or recognize ongoing activities outside.

Due to the significance of view in architecture, several view assessment measures have been proposed (see Table 1). The measures include, for example, the categories of view or information content received from exterior view [30]. Many studies agree that the view of nature, garden, and the well-landscaped area tends to be more preferred by occupants than the urban environment [2-3]. This view type can positively change the emotional state and increase occupants' satisfaction [1]. The content and composition of sky, land, ground, building, and city, also affect the view attractiveness. A wide view, containing more information, is more interesting than a close and narrow one [38]. Furthermore, the quality of view outside is influenced by the density of both internal space and surroundings [2]. Sometimes, the openings and outside world can also affect occupants negatively [30]. For instance, the window facing directly to other buildings or service facilities may be harmful to privacy.

Table 1. Examples of view assessment criteria

No	Criteria	References
1.	View type	[2-5, 30]
2.	View composition	[30]
3.	Density	[2]
4.	Distance and privacy	[2, 30, 33, 38]

The perception of beauty and satisfaction of view depends on not only the view itself but also how we design the frame to capture it [33]. The quality and impact of view also associate with the architectural mass and form, façade, interior space arrangement, and windows' type, size, and mullion [10]. Architecture must be well designed and crafted carefully to capture the best view outside. However, in reality, the view evaluation criteria must be balanced and weighed with other factors, e.g., functionality, feasibility, and laws and regulations. Each criterion requires a large amount of information to be collected and pondered together. It is still a herculean task for practitioners to handle this wealth of information from every design aspect at one time.

2.3 Simulation-based view assessment

The simulation method as a convenient and effective tool has been widely adopted in the architectural design field. For the simulation-based view assessment, previously, some methods were developed through projection [34], raytracing on hand-made models [35-36], or a fish-eye lens [34, 37]. However, they tend to rely on manual work and thus are time-consuming. Recently, a new technological window of opportunity opens for this study, consisting of high-quality 3D photo-realistic CIMs, mature 3D view capture APIs, and robust online computer vision tools. Utilization of existing 3D photo-realistic CIMs brings users effortless scenes of buildings and their neighbourhood environment, while making full use of the 3D view capture techniques and computer vision tools can help visualize and quantify the view photos with high automation and accuracy.

For instance, Li and Samuelson [18] effectively integrated the outside view assessment into the window frame design by using textured CIMs from Google Earth Studio. The simulated views were assessed by the criteria including window direction, openings' geometry, and human preference. Li et al. [20] classified the window views into two groups, natural and urban, for a city-scale view disparity assessment. Harnessing the power of deep transfer learning, the window views of nature were distilled automatically. Both studies show that the view photos generated from photo-realistic CIMs are similar to the ground truth photos in the real world, and the assessment results of views are accurate for decision-making. However, there exists a gap and method in connecting the automated view assessment method with the architectural space planning for more comprehensive judgment. Space planning concerning a view assessment may gain more momentum from these new technological breakthroughs in terms of efficiency and accuracy.

3 Research methods

This research comprises five stages to both constitute knowledge contributions and resolve real-world challenges (see Figure 3). It began with a comprehensive literature review to gain a holistic view of the current architectural design practice, view evaluation method, and CIM performance. Secondly, all information was analyzed, redefined, and discussed with practitioners to highlight critical challenges in the view assessment. It was followed by brainstorming to explore the potential solution in the third stage. This stage was to fabricate innovation in complex social conditions and bridge the gap between theoretical knowledge and design practice. In this research, the solutions were to identify view evaluation criteria for architectural design and develop a CIM-enabled view assessment model. The fourth stage was mainly about developing CIM as an assistive tool for assessing, visualizing, and facilitating the architectural design process, and aligning with the current practice. Finally, the proposed model was validated and improved through a case study implementation in Hong Kong SAR.

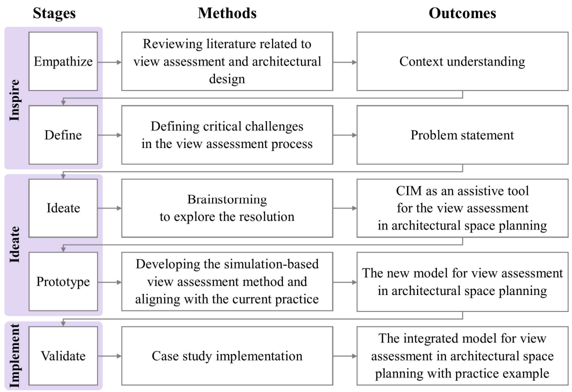

Figure 3. Research methods

4 The integrated model for view assessment

After reviewing the literature, redefining the real-world challenges, and brainstorming the potential solutions, the new view assessment model is generated (see Figure 4). It is the consolidation of simulation-based view assessment and traditional site observation and evaluation.

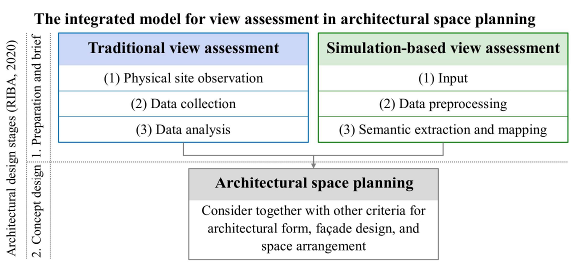

Figure 4. The integrated model for view assessment in architectural space planning

4.1 Traditional view assessment

At the beginning of the architectural design process, the design team visits a construction site to observe site-related factors. The collected qualitative data include, for example, surroundings, site terrain, wind direction, existing features or structures, traffic and transportation, noise, and view quality. Moreover, alternative data are also gathered for further analysis, discussion, and decision-making, such as maps, drawings, and pictures. In this stage, the team uses multiple tools to collect data of the site and surroundings, including a camera, drone, laser distance meter, surveying instruments, etc. The data is then analyzed manually by several methods, e.g., sketches and diagrams.

4.2 Simulation-based view assessment

Apart from physical site observation, the CIM and computational technology advancement can support the simulation-based view assessment and strengthen the design. Its realization comprises three main stages (see Figure 5).

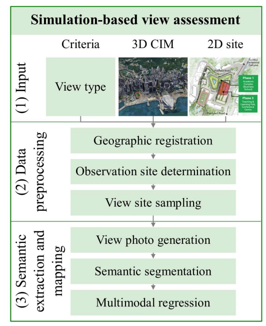

Figure 5. Workflow of simulation-based view assessment

4.2.1 Input

The process initiates with a 3D photo-realistic CIM and 2D site preparation, and critical criteria selection. The criteria should be well selected and prioritized depending on specific project conditions, such as users' requirements, building function, site location, and surroundings. This study searched through the scientific database and generated a list of view assessment criteria for practitioners to choose from (see Table 1).

4.2.2 Data processing

The data processing consists of three key steps: geographic registration, observation site determination, and view site sampling (see Figure 5). First, the 2D site and 3D photo-realistic CIM are registered on the 3D WGS-84 globes to identify the development area. Thereafter, considering the site settings such as shape and neighbourhood environmental characteristics, the users can determine the representative observation site. Then, to examine the view disparity quantitatively, the view site at eight directions from 0° to 360° are evenly sampled from different altitudes. A sample interval h (h=5m) is set here to simulate the view situation of different floors.

4.2.3 Semantic extraction and mapping

As the nature view is more preferred within the cityscape, view types, including nature and urban, are set as the judgment criterion to demonstrate the semantic extraction and mapping process. In this study, we extend Li's method [39] to visualize and quantify the nature view index. Firstly, by mounting the virtual camera at the sample view sites of the 3D photo-realistic CIM, the view photos are captured in batch. Thereafter, one of the best pre-trained deep learning models on Cityscapes, *Deeplab v3*, is transferred to segment the view photos into 19 classes of features automatically. Furthermore, a connected layer is constructed to map the view features into the two target groups through a multimodal regression. In the end, the predicted nature indices of view photos are collected for space planning.

4.3 Architectural space planning considering the view assessment

Finally, the quantitative result from the last stage is used together with traditional site observation and qualitative view assessment. The result is then weighed and balanced with other criteria in the built environment, e.g., users' requirements, site conditions, climate, laws and regulations, and construction method, to draft a preliminary design, justify building mass and orientation, develop details, and generate construction documents.

5 A Case Study

To validate the feasibility of the integrated approach, the Pokfield campus, the University of Hong Kong, Hong Kong SAR, was selected to be a case study. This area would be redeveloped into new office and education buildings. The experimental process workflow began with the physical site observation (see Figure 6). Researchers faced several challenges in this stage. Firstly, due to the complicated site terrain and surroundings, the team could not capture the view from every direction and level without assistive tools, e.g., a drone. Furthermore, some photos could be taken only by entering surrounded buildings. It was indeed tedious and time-consuming for practitioners to observe and collect all necessary data. All data, including photos, maps, and drawings, were then used for the traditional analysis (see Figure 7). It reveals that the visibility to natural elements such as mountains, sea, and vegetation, is blocked by high-rise high-density constructions in many directions and levels. However, what remains unclear is the exact level or angle to improve the detailed design of planning, interior space arrangement, openings, and façade design.

Apart from the traditional method, the simulation-based view assessment was implemented. The curation of the datasets included 2D site design data and 3D photo-realistic CIMs in this study. The 2D design of the case site, collected from HKU Estate Office [40], measured the site geometry accurately, from which the key view site can be determined by designers. The sketch map is shown in Figure 8a. The 3D photo-realistic CIMs were collected from the Planning Department [41], Hong Kong SAR, for surrounding environment expression, and one of the buildings was highlighted for method validation (see Figure 8b).

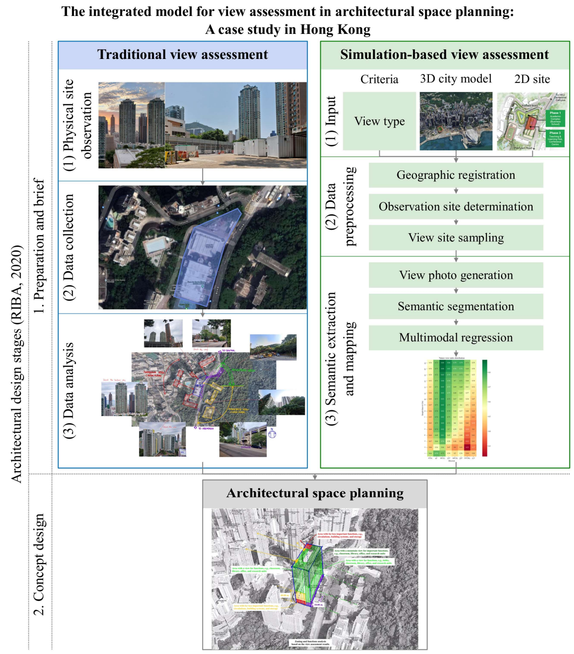

Figure 6. The implementation of proposed model in the case study

Figure 7. Traditional view analysis

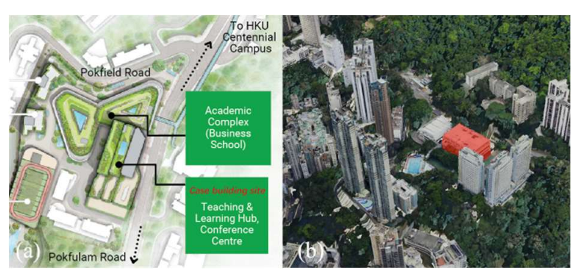

Figure 8. Data preparation of the case planned building site. (a) 2D site design, and (b) target building site and its environment.

Cesium (version 1.73) as an open-source 3D visualization platform was used in this study to load 3D photo-realistic CIMs and generate the view photos through computer programs. The *Deeplab v3* model within the *Tensorflow (version 2.4.1)* framework was to segment the view photos. Then the multimodal regression was finally implemented in the data mining platform *Orange3 (version 3.26.0)*. The whole process experimented in a workstation with an Intel i7-10700 CPU (2.90GHz, 16 cores), 128 GB memory, an 8G Nvidia GeForce RTX 2070 SUPER GPU, and Ubuntu 20.04 64-bit operating system. By implementing the view assessment workflow (see Figure 5), each direction of the building site has a portfolio of nature view indices. The heat map representing view index distribution around the case planned site was visualized from 0 m to 80 m (see Figure 9). The nature view index ranges from 0 to 1, from which 0 indicates ‘poor’ and 1 stands for ‘excellent’.

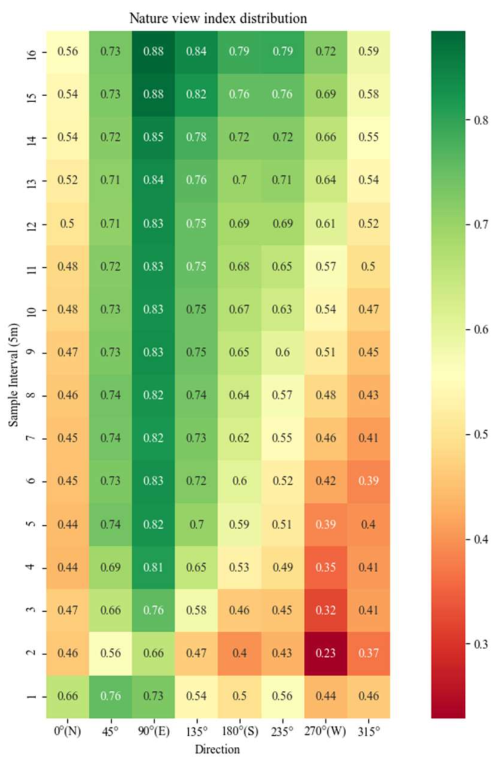

Figure 9. The simulation-based view assessment result

The simulation result reveals a huge different possession of natural resources in different directions and levels, further reflecting the design. For instance, the lower part tends to have lower proportional nature views, such as the area ranging from 180°and 315° horizontally, and from ground level (0 m) to 15 m vertically. On the other hand, the upper-level part has a more favourable view, especially in the area ranging from 45°and 235°. In some specific directions, the nature views are obviously scarce, such as the direction ranging from 315°(Northwest) to 0°(North). In some directions, the nature views are of significant variation from the vertical dimension, i.e. the direction from 135° to 315°.

The design team can use this detailed result for architectural space planning and design in three main stages. In the initial concept design, the building’s mass, form, and zoning are decided. The important space should be placed on the higher level with the best view in a site, while the podium area can be used for the back of the house or service zone, which are not required a good view, such as circulations, storage, and mechanical, electrical, and plumbing systems (see Figure 10). The vertical circulations or building systems may be placed in the northwest part. Then, this conceptual model is developed and detailed. The architectural plan, functions, rooms, circulations, and building envelope are designed with the consideration of view assessment results, site surroundings, and other factors. The important functions such as a lobby, living, and dining, are allocated on the tower part to enjoy the preferred view of green space and harbourfront area. Lastly, in interior design, the view evaluation result can also be used for space and furniture arrangement. The position and location of all features, e.g., working table and bed, should be well located to make occupants enjoy the excellent view outside the openings. It can be seen that the design team can refer to the view evaluation results throughout the entire design process.

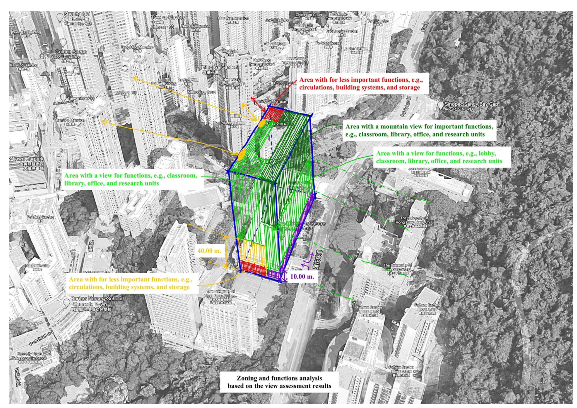

Figure 10. The application of simulation-based view assessment for architectural space planning

6 Discussion

This empirical research firstly reveals difficulties in the conventional site observation, which support the promising approach of using computational technologies to aid this process. Then, the implementation in the real-world context affirms that CIM, with its capability to manage and analyze a large amount of information, can be a less expensive virtual platform supporting view assessment in architectural design and space planning. CIM can be used through three main stages: input, data preprocessing, and semantic extraction and mapping. Its outcome can confirm the qualitative result from physical site observation and add more details to facilitate precise and rapid decision-making throughout the entire architectural design process. Furthermore, its integration with the conventional assessment approach transforms the process from qualitative to mixed methods: combining qualitative and quantitative data. These findings also support the current thought of generative design, where computational intelligence can automatically generate floor plans from project conditions. It has a high potential to integrate with other tools to achieve various criteria simultaneously and revitalize a labour-intensive task in design.

Despite its advantages, the practice of CIM-enabled view assessment also faces several challenges. For instance, it requires a huge effort to collect related information and build a digital model before simulation and automatic evaluation. The proposed model is thus efficient to be utilized for a site with high density and complicated surroundings like Hong Kong. Moreover, in reality, a view is merely one of the numerous design criteria. The view analysis results have to be weighed and balanced with other factors, e.g., users' requirements, site conditions, laws and regulations, feasibility, and aesthetics, before involvement in a project.

This research also has several limitations. As this study is grounded on the archival study and one case study in Hong Kong, additional cases from different contexts are necessary for generalization and model improvement. In addition, there is no "one size fits all" solution for every project. The view assessment criteria and CIM model development may be varied depending on particular conditions.

7 Conclusion

Architectural design is presently stipulated to prevent many difficulties by considering various criteria in the AEC industry. This trend makes the process more sophisticated and time-consuming, so generative design tools are urgently required. This research fulfils this demand by developing CIM to be an assistive tool for quantitative view evaluation in architectural design and space planning. The case study affirms CIM's capabilities to revitalize a conventional labour-intensive process and facilitate precise and rapid design decision-making. Besides, this study highlights both prospects and core challenges of CIM-enabled view assessment. For practitioners, it also offers the integrated model for view assessment in architectural space planning with practice examples.

However, this is merely the beginning of simulation-based quantitative view assessment for architectural design. It still requires additional case studies in other sociocultural conditions to validate and develop this potential further. Future research is also recommended to integrate the proposed model with other criteria and computational tools to advance the computer-aided generative design.

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