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A NOVEL METHOD FOR CALCULATING CAMERA COVERAGE IN BUILDINGS USING BIM

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SUMMARY: *Many organizations claimed that adopting surveillance cameras is costly for both installation and maintenance. This issue is mainly related to the camera placement, which is affected by the camera coverage calculation method. The main objective of this paper is to develop a novel method that can achieve accurate calculation of the camera coverage inside buildings. Building constraints including HVAC components can affect the camera coverage calculation due to physical effects such as vibration. The proposed method has the following steps: (1) defining the camera placement; (2) validating the camera scenes; (3) generating cells and assigning importance values; (4) visibility analysis; and (5) calculating the camera coverage. The paper also includes a sensitivity analysis for evaluating the suitable cell size in order to cover the monitored area. The feasibility of the method is tested using a case study. The case study demonstrates the benefits of using BIM in calculating the camera coverage in buildings. The study conducts four scenarios to evaluate the effect of the field-of-view and tilt angles on the camera coverage.*

KEYWORDS: *BIM, camera coverage, field-of-view, camera placement, coverage calculation.*

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1. INTRODUCTION

Surveillance cameras are vital elements to many public and private institutions due to their ability to insure comprehensive security solution that can protect their facilities (Video Surveillance, 2015). Many organizations claimed that adopting these surveillance cameras is costly for both installation and maintenance (Kelly, 2013). This issue is mainly related to the camera placement problem, which is affected by the camera coverage calculation method. Although previous studies have implemented different methods to address this problem, additional efforts are needed to achieve accurate calculation of the camera coverage. Previous studies implemented 2 Dimensional (2D) or 3 Dimensional (3D) techniques, which have the following problems. First, the usage of the 2D technique may increase the possibility of not covering some important areas which are located under the Field of View (FOV) of the camera, as shown in Figure 1, or in places where there are different ceiling or floor elevations. Second, traditional 3D techniques do not consider some building elements that can affect the camera coverage. For example, in Figure 2, the installer changed the height of the cameras in order to avoid the shield elements and this can affect the camera coverage. The problem is that the installer did not expect to find such an element due to the lack of an efficient method that considers the camera environment before installing the camera.

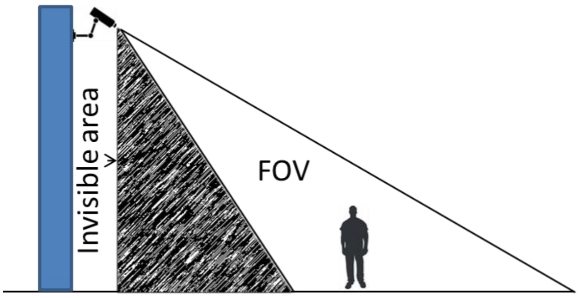


Figure 1: Invisible area under the FOV of the camera (Albahri and Hammad, 2015)

The main objective of this paper is to develop a novel method that can achieve accurate calculation of the camera coverage inside buildings using Building Information Modelling (BIM). This work is an extension of our previous study (Albahri and Hammad, 2015). BIM can address most limitations caused by using 2D and 3D techniques for camera placement. The method can automate the coverage calculation process in order to achieve accurate results. The proposed method will mainly benefit individuals who are responsible for designing and installing surveillance systems inside buildings. This method will be also used to serve future work of optimizing the placement of surveillance cameras inside buildings. The structure of the paper is as the following. Section 2 provides a literature review of related research. Section 3 describes the role of BIM in the coverage calculation process. Section 4 details the proposed method. Section 5 includes the implementation and case study. Section 6 provides the summary, conclusions and future work of this paper.

Figure 2: Problem of traditional 3D methods (Chen et al., 2013)

2. LITERATURE REVIEW

Challinger (2008) outlined that an effective security technique should have the ability to specify areas of risks and delineate standards for decreasing undesired incidents. For this purpose, most current practices focus on increasing the efficiency of surveillance systems to ensure the detection of people movement inside buildings. According to Wilkis (2015), there is no system that can ensure complete coverage, and every system has its own strong and weak points. Focusing on security systems of multiple surveillance cameras, the cameras may leave small uncovered areas which might be a target for suspicious activities. Therefore, many approaches have been developed for strengthening surveillance systems. Bigdelil et al. (2007) evaluated the capability of surveillance systems in railway platforms. The study aimed to achieve robust detection and identification of individuals in crowded situations. It proposed a configuration of a real-life trial system that includes various video analytic systems which are used to detect an event of interest. The study found that it was time consuming to implement the process of setting up commercial systems for diverse numbers and types of cameras.

Yabuta and Kitazawa (2008) proposed an algorithm for optimizing the camera placement by using a 2D method for calculating the camera coverage. The study solved the camera placement problem by taking into account a number of factors, namely the visual distance, the FOV and the resolution of the camera. However, the study has a number of limitations as follows: (1) the study was implemented in 2D, which is inadequate to cover some areas hidden behind building objects or located below the FOV of the camera; (2) the adopted segmentation process is not accurate since it represents different sizes of areas. This will lead to inaccurate coverage results especially in small hidden spaces behind obstacles.

OPTICOM (2013) outlined that vibration can be considered as the most significant factor which can affect the life span of surveillance cameras. Consequently, suitable placement of surveillance cameras is needed to avoid the negative consequences of vibration. Examples of vibration sources are Heating, Ventilating and Air Conditioning (HVAC) components which sometimes are placed on the ceiling. Chen et al. (2013) mentioned that having smoke curtains in the monitoring area can deteriorate the performance of the cameras. Additionally, MoogVideolarm (2012) outlined that heat sources (e.g. heaters) are other examples of sources that can affect surveillance cameras. Accordingly, installers may have to change the cameras' height in order to avoid these elements. This changing of the height can affect their coverage. Therefore, considering the position of these sources is necessary before placing surveillance cameras.

Chen et al. (2013) implemented a study that aimed to evaluate the role of BIM technology in determining if the design of the surveillance systems is suitable to meet the future security system requirements when the construction process is completed. They highlighted the importance of BIM in defining the design requirements of the surveillance system, such as the ability to ensure the appropriate coverage near main entrances. Furthermore, they indicated the benefit of BIM in finding physical obstacles that may affect the camera coverage at a specific location. They also utilized an efficient 2D measurement tool called "the Fill Region Tool", which helped in automating the calculation process of the coverage areas. However, this work did not take into consideration the process of optimizing camera selection, which should include camera number, type and placement. Instead, they focused on optimizing the real angle of depression of a number of placed cameras. Also, the study calculated the camera coverage by using the Fill Region Tool, which has many limitations due to the usage of the 2D calculation method.

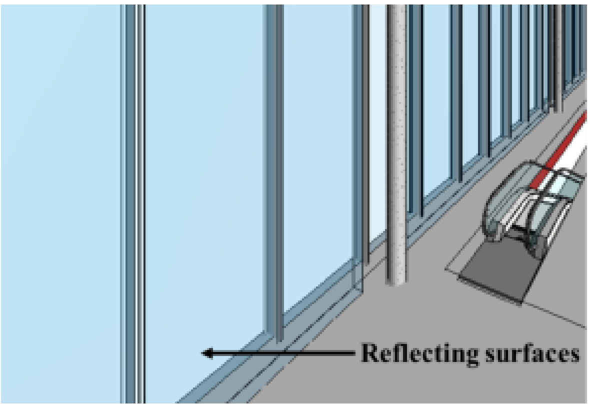
Murray et al. (2007), Kim et al. (2008) and Janos et al. (2007) implemented a coverage optimization process in a specific location of an urban area. Their optimization aimed to maximize the surveillance coverage in an urban area by achieving efficient camera deployment and taking into account cost constraints. The limitations of their practices can be outlined as follows: (1) their method was developed for external urban locations where the search space of the camera placement is limited in comparison with the search space of indoor building spaces; (2) they divided the study area in their visibility analysis into cells using a 2D grid of Geographical Information System (GIS), which may affect the visibility since it does not represent the real volumes of the static and mobile objects; and (3) the method did not consider the existence of different levels of important areas.

Amriki and Atrey (2012) used a 3D optimization method inside a bus to find a suitable camera placement by specifying the number of required cameras and their placement. The study used a 3D bus model in order to help in the process of detecting the covered and uncovered areas inside the bus. This study showed rational placement of cameras as well as a relative increase in coverage based on the number of cameras. In order to apply this method in the complex indoor building spaces, the geometrical constraints, interrelated systems (e.g. heating and air conditioning systems) and interior classification of spaces inside buildings should be considered.

The present paper mainly benefited from the method of Amriki and Atrey (2012) which calculated the camera coverage using cell segmentation process inside a 3D bus model. However, this work is different from their method in the following aspects: (1) Calculating the camera coverage inside a building, which usually includes different obstacles; (2) Using BIM to specify the constraints that can affect the camera coverage inside the building area; (3) Assigning different importance values of important areas, which contain the generated cells. This work also benefited from the study of Murray et al. (2007), which adopted similar visibility analysis. However, their method of segmenting the monitoring area adopted a 2D grid system, which can cause inaccurate coverage results as discussed in Section 1. Unlike their method, this work considers the height of the monitored area and applies sensitivity analysis to select the suitable cell size to optimize the calculation of the coverage.

3. ROLE OF BIM IN THE COVERAGE CALCULATION PROCESS

The task of camera coverage calculation can benefit from BIM through the following: (1) BIM can consider the location of the light sources that surround the coverage since most parameters of the light sources can be defined in BIM (Chen et al., 2013); (2) some systems, such as the HVAC components, can generate heat and vibration that might physically affect the cameras. BIM is able to determine the location of these systems and consider them in the camera placement layout; (3) since it uses a 3D model, BIM can detect invisible areas which are located inside the camera FOV; and (4) BIM can specify the location of other elements that may affect the coverage (e.g. shiny and reflecting surfaces), as shown in Figure 3(a), or elements attached to surfaces such as ceiling signboards (Chen et al., 2013), as shown in Figure 3(b). Unlike other tools such as GIS, which is limited to defining the spatial information of outside buildings and Computer Aided Design (CAD), which is focusing on the usage of design techniques, BIM has the ability to provide geometrical and non-geometrical attributes that can help in specifying different elements on the ceiling in order to be considered before placing the camera.



(a) Reflecting surfaces

(b) Ceiling signboards (Chen et al., 2013)

Figure 3: Factors affecting the camera coverage

The most common constraints that should be considered in placing cameras on the ceiling of buildings are: (1) HVAC components; (2) columns; (3) reflecting surfaces; (4) light sources; and (5) ceiling signboards. BIM is useful in specifying the location of these constraints, which might affect the camera coverage. The geometrical and non-geometrical attributes (i.e. constraint's location and type) can be used to automatically define the boarders of these constraints on the surface where the camera will be placed. Also, BIM can be used to create buffers that include the constraints. These buffers represent the area of influence (e.g. vibration or heat effect) for these constraints. The size of these buffers is determined by the specialists. These buffers will allow limiting the camera placement to valid positions on the placement surface. Figure 4 shows an example of limiting the camera placement to positions outside the influence of the constraints, which are represented with a grey color.

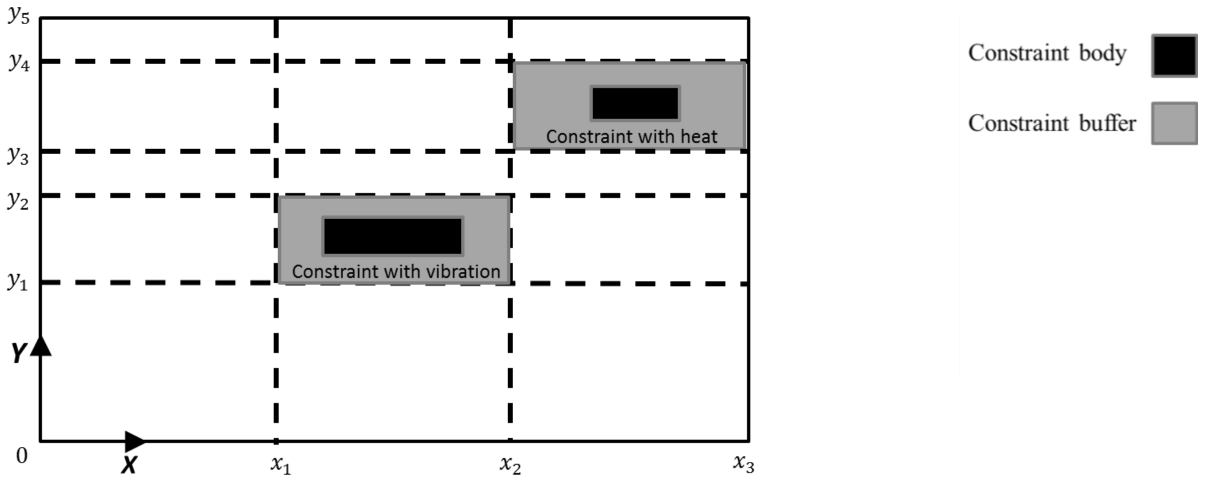


Figure 4: Example of specifying the constraints using BIM

4. PROPOSED METHOD

This paper proposes a BIM-based method for calculating the camera coverage inside buildings as shown in Figure 5. The method includes seven steps as the following: (1) defining the camera placement; (2) validating the camera scenes; (3) generating cells and assigning importance values; (4) visibility analysis; and (5) calculating the camera coverage. Each step is detailed in the following sections.

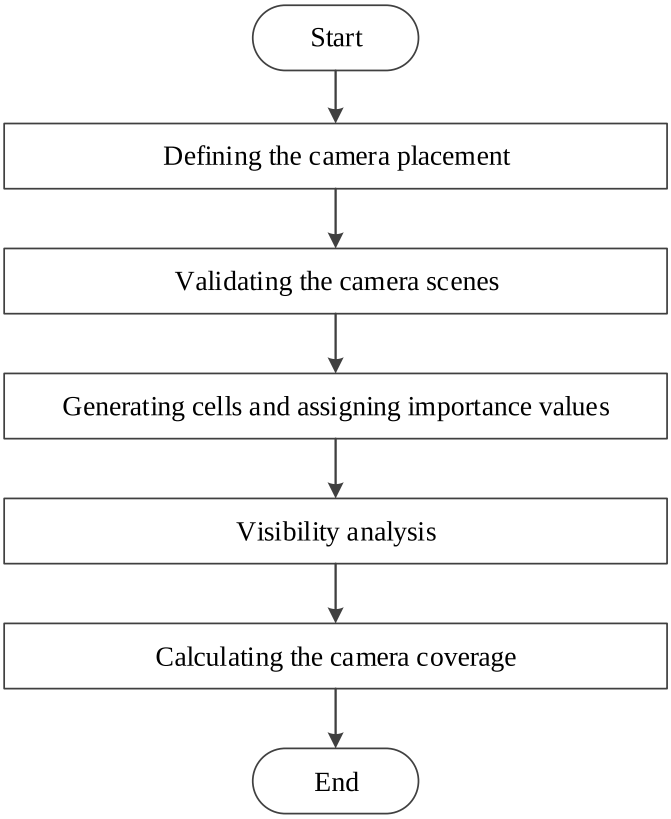


Figure 5: Proposed method for calculating the camera coverage

4.1 Defining the camera placement

A 2D grid is used to facilitate the process of placing the camera within the boundary of the surface area. Although it is beyond the scope of the current paper, it is important to note that changing the size of the 2D grid affects the search space of the optimization process. The smaller grid size will result in a larger search space and longer computational time, but in more accurate results of calculating the coverage, and vice versa. Figure 6 shows the method of placing a camera by using the 2D grid. It starts by selecting the surface where the camera will be placed and identifying the boundaries and the size of the grid. The user should select the camera type and assign it with a specific pose (i.e. location and orientation). The camera will be then placed based at this pose. This process will be repeated for each camera placement.

Every pose (*O*) comprises the camera coordinates (*X, Y, Z*), which represent the camera location, and the camera *Pan* and *Tilt* angles, which represent the camera orientation. As shown in Figure 7, the *Pan* angle (α) represents the camera rotation around a vertical axis with a range between 0° to 360°. While the *Tilt* angle (β) represents the angle with the vertical axis and ranges between 0° and 90°. As a way to decrease the search space, it is necessary to take into account the following rules before placing the camera: (1) all cameras are directed to face the important areas that are inside the BIM model; and (2) the cameras should avoid light sources, shiny and reflective elements.

4.2 Validating the camera scenes

The third step is to examine the validity of the camera pose by evaluating the virtual scene of this camera (i.e. by viewing what the camera can see). This can be achieved by generating 3D virtual scene using the camera FOV and clipping planes.

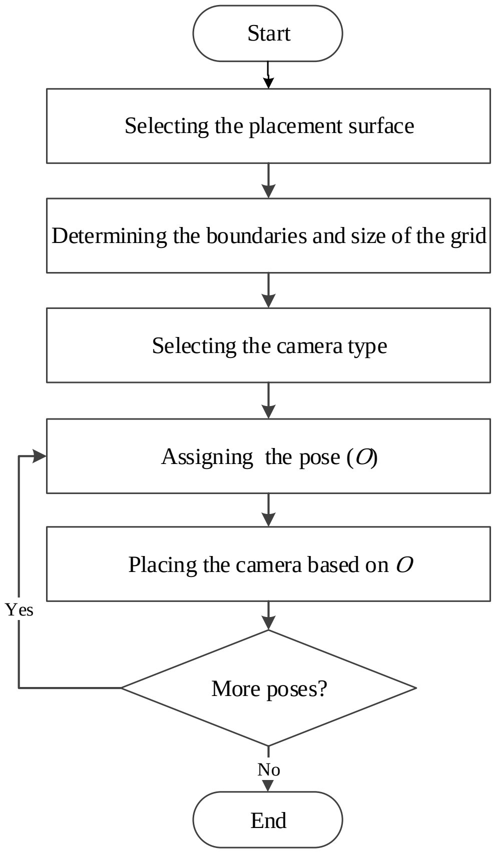


Figure 6: Placing camera using 2D grid

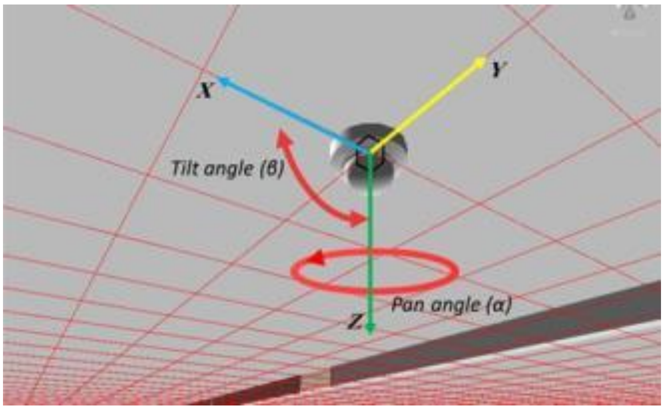


Figure 7: Camera orientation and the 2D grid in BIM

4.3 Generating cells and assigning importance values

This step is focusing on preparing the area that will be used in the calculation of the camera coverage. For this purpose, the floor of the building model is divided into a number of important areas (a_i) that differ in the importance level as shown in Figure 8.

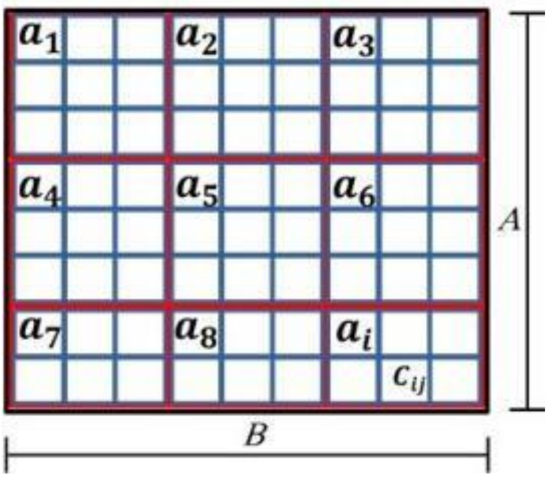


Figure 8: Dividing a floor with a number of important areas and cells

As most areas inside buildings have rectangular shapes, cubic cells (C_{ij}) are generated to cover all important areas. It is necessary to find the cell size that can represent the smallest part of the important area. The size of the cell is an important factor that can affect the coverage calculation accuracy. The smaller cell size will increase the number of cells and will increase the computational time but will provide more accurate results, and vice versa. Several layers of cells should be used in the vertical axis of the BIM model to cover the upper limit of the average human height. By covering the monitored areas with cells, it will be possible to determine the volume of important areas that is not covered by the placed cameras.

The numbers of cells along the *X*, *Y* and *Z* axis of the floor (*f*) are calculated by dividing the dimensions of *f* (i.e. *A* and *B*) by the edge length of the cell. In addition, it is important to mention that every generated cell has an importance value assigned by the user based on a set of rules such as the following rules used in the case study (Section 5): (1) value of 1 is assigned to cells which cover general areas such as corridors; (2) value of 2 is assigned to cells which cover stairs and elevators' halls; and (3) value of 3 is assigned to cells which cover entrances and escalators coming from the underground metro station.

4.4 Visibility analysis

The visibility analysis uses ray tracing in order to determine if a ray line is reaching a specific cell or not. Ray tracing can also assist in the process of detecting physical obstacles that might affect the camera coverage. In this study, there are three types of cells: (1) cells forming the structural components of the BIM model such as columns; (2) visible cells; and (3) invisible cells. A cell is considered visible if it is directly hit by the ray line and not hidden behind any element of the BIM model. Ray tracing is used in the visibility analysis as shown in Figure 9.

The process starts by generating a ray tracing line R_{x_j} from camera *x* inside its FOV and directed to cell *j*. If R_{x_j} is intersecting with an obstacle, the hidden cells behind this obstacle are highlighted and considered as invisible cells. Otherwise, if R_{x_j} is intersecting with cell *j*, then this cell will be considered with its importance value (*IV*) as a visible cell. It is also important to note that in case the cell is covered by more than one ray line from multiple cameras, the cell will be counted one time in the coverage calculation regardless of the overlapping between the coverages of cameras.

4.5 Calculating the camera coverage

Figure 10 shows a simplified 2D example of camera coverage calculation where a number of important areas (a_i) are divided into cells (C_{ij}) and assigned with importance value (IV_i). Also, a number of cameras (K_x) are placed to cover the important areas. The weighted number of cells in area a_i can be calculated using Equation 1. Then, the weighted covered cells (CCa_i) in area a_i is calculated by the summation of all covered cells (C_{iv}) in an important area (a_i) as shown in Equation 2. The total coverage of camera (K_x) is calculated using Equation 3 (Amriki and Atrey, 2012). This is done by the summation of the weighted covered cells in all areas divided by the summation of all weighted cells in the monitoring area. Finally, the total coverage of all placed cameras can be calculated using Equation 4.

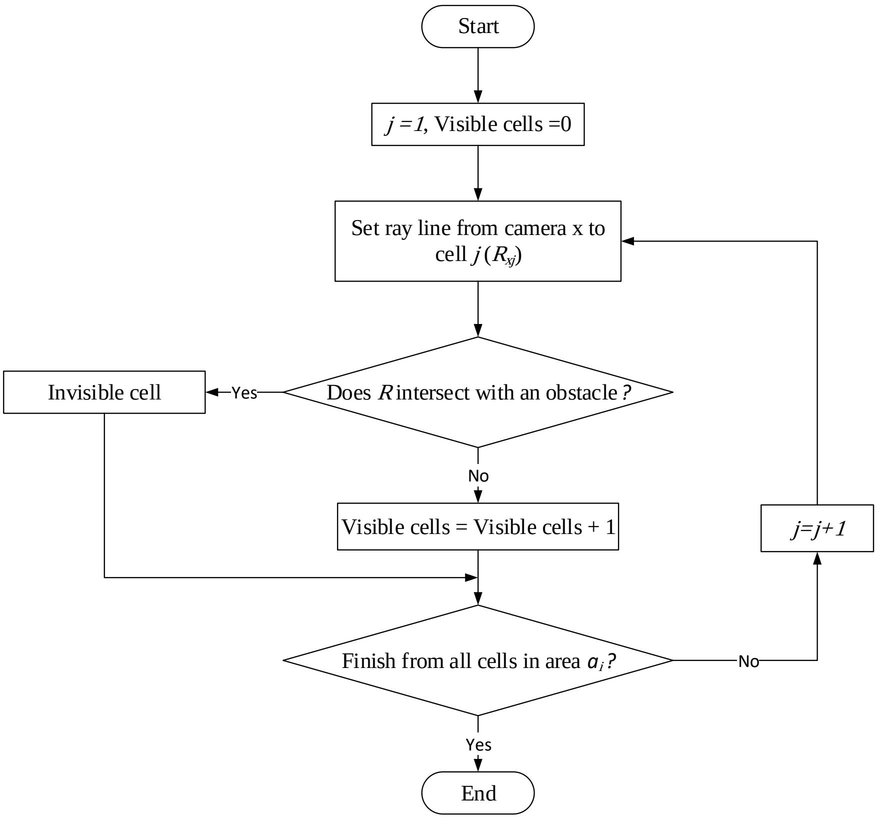


Figure 9: Camera visibility analysis in area a_i

$$W_{a_i} = IV_i \sum_{j=1}^{n} C_{ij}$$ Equation 1

$$CC_{a_i} = IV_i \sum_{v=1}^{n`} C_{iv}$$ Equation 2

$$Total\ coverage\ of\ camera\ K_x = \frac{\sum_{i=1}^{m} CC_{a_i}}{\sum_{i=1}^{m} W_{a_i}}$$ Equation 3

$$Total\ coverage\ of\ all\ cameras = \sum_{x=1}^{Q} Coverage\ of\ camera\ K_x$$ Equation 4

Where $W_{a_i}$is the weight of important area a_i, C_{ij}represents the cell j in important area i, and j = 1:*n*, IV_i is the importance value assigned to cell j in area i, and *i* = 1:*m*, C_{iv} is the covered cell *v* in area a_i and *v* = 1:*n*`, K_x is camera *x* and *x = 1:* Q and CC_{a_i} is the weighted covered cells in area a_i.

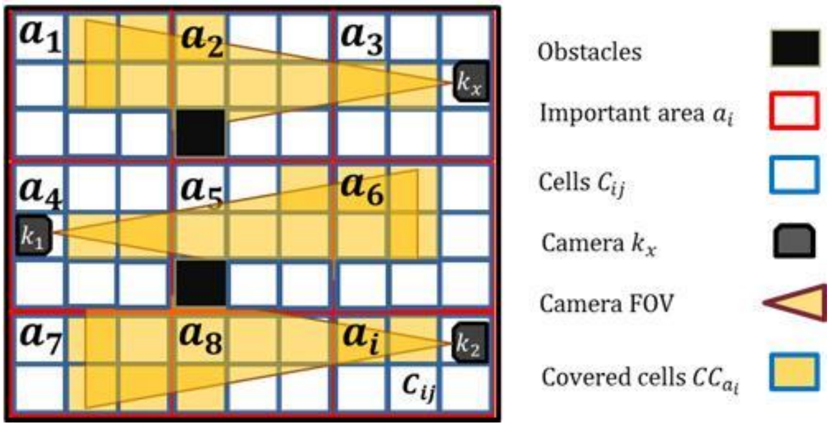


Figure 10: Example of coverage calculation (adapted from Albahri and Hammad, 2015)

5. IMPLEMENTATION AND CASE STUDY

A prototype system has been developed to demonstrate the feasibility of the proposed method. The case study is implemented on the ground floor of the Engineering and Visual Art (EV) building in Concordia University. This case study is demonstrating the applicability of the proposed method using BIM technology for evaluating the coverage of a number of cameras placed in this floor. This research uses a game engine in the coverage calculation process for the following benefits. The game engine is a platform that can deal with BIM models and apply many physical features (e.g. ray tracing and collision detection), which are already built inside it, to facilitate the implementation of the simulation. Another benefit of using the game engine is the ease of controlling the camera parameters (e.g. FOV and clipping planes) through the adjustment of the camera settings. Seven fixed cameras of various types (single and multiple camera types) cover specific locations that include important and unimportant areas. In addition, the floor has some physical constraints such as columns and stairs that can affect the camera coverage. The BIM model was developed using Revit and integrated with seven 3D camera models (Autodesk Revit, 2014) for the purpose of simulating the camera placement layout. These camera models are provided by several manufacturers, as shown in Figure 11.

Next is to import the integrated BIM into the game engine. This step includes two processes. The first process is integrating the BIM model with 3D models of surveillance cameras available from the camera manufacturers. Each camera has different parameters that affect the FOV and the distance between the clipping planes. Clipping planes define the space in which an object can be seen and rendered based on the distance between these planes. Parameters that affect the coverage are the focal length, the height of the camera, the height of the target and the distance between the camera and the target (Chen et al., 2013). The integrated BIM is imported to the game engine to facilitate the computational process. The second process is to align the FOV of a virtual camera available in the game engine with each FOV of the imported BIM cameras. The purpose of this alignment is to simulate the parameters of the BIM FOVs in the game engine. The virtual FOVs of the game engine are used to validate the virtual scenes (Section 4.2) and to serve the visibility analysis (Section 4.4).

The focus in this case study is on Camera 3. Multiple camera placements will be considered in our future work. Then, the integrated BIM model is imported into the game engine of Unity3D (Unity, 2015) using FBX format in order to facilitate the computational processes which were developed using C# language. Inside Unity3D, the process of generating cells over the monitoring area was developed in order to evaluate the camera visibility. These cells can help to obtain accurate results of the camera coverage by changing their size as will be explained later. Also, the process of generating a 2D grid system is developed to facilitate the placement of additional surveillance cameras on the ceiling if needed. Seven virtual FOVs were generated in Unity3D and aligned with the BIM cameras to simulate the current status of camera placement in this floor; using the information of the BIM camera models taking into account their parameters. The parameters of the virtual FOVs are adjusted to precisely match the cameras of the BIM model as shown in Figure 11. These parameters are FOV angle, camera height, and nearest and farthest point. The virtual FOVs will help to generate the virtual scenes and to apply the visibility analysis using the ray tracing concept as shown in Figures 15 and 17, respectively.

Figure 11: BIM model aligned with FOVs in the game engine

As explained in Section 3.1, the first step is to obtain the valid positions of the placement surface based on the following: (1) Constraints (i.e. HVAC and columns) are defined with their buffers; (2) Based on a grid system attached to the ceiling surface, the coordinates of the points on the grid are written in a file except those which are within the buffers of the constraints. Figure 12 shows a part of the monitored area in Autodesk Revit including a number of constraints which are assigned with buffers. In this case study, points which are not within the buffers are considered as the valid positions of surveillance cameras.

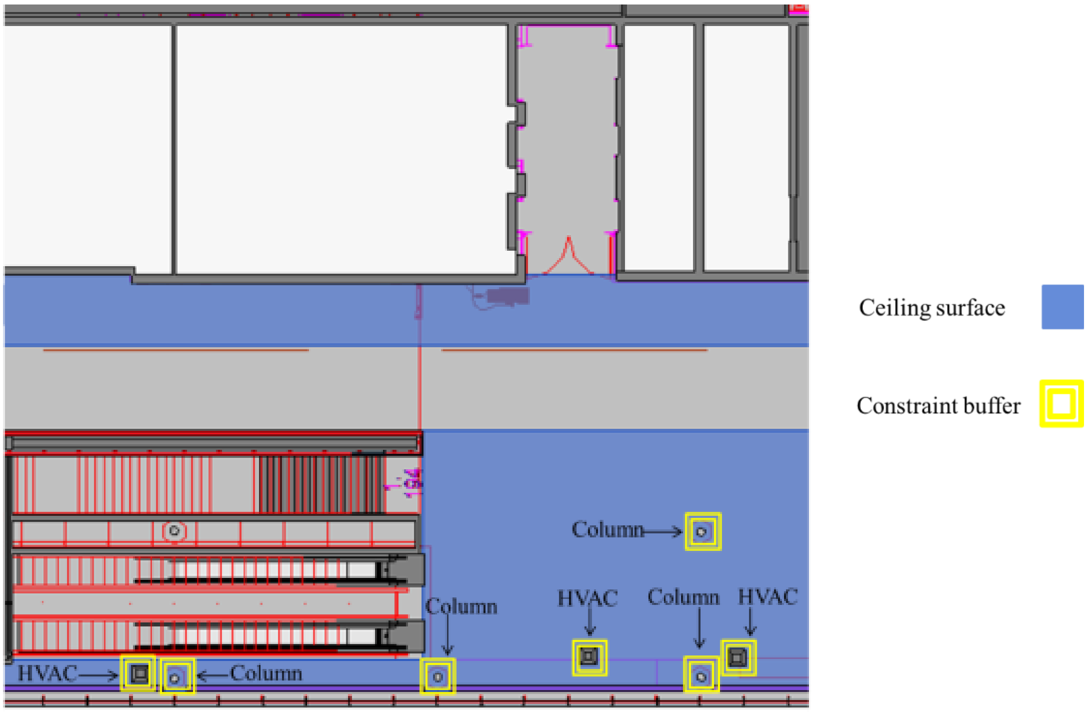


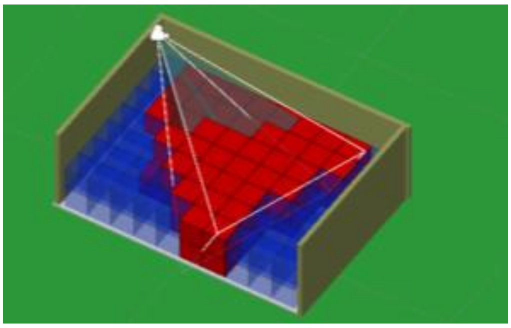
Figure 12: Defining the valid positions for the camera placement using BIM

The next step is to generate a 2D grid inside BIM. This grid is generated in order to facilitate the placement of the cameras. The shorter distance between the grid lines will offer more accurate results and vice versa. In this case study, a number of lines is generated in each direction (i.e. X and Y directions) on the ceiling surface. In the case study, the user determines 100 lines in the X and Y directions of the grid. The process of generating the 2D grid system starts by selecting the ceiling that will be covered with the grid system. Next, a box collider available in Unity3D is added to the ceiling where the camera will be placed. The collider surrounds the ceiling shape for the purpose of determining the borders of the grid. Finally, the user can select and place additional 3D cameras on the grid. Another step is to identify the areas that will be targeted by the selected camera. In this case study, 17 important areas were specified.

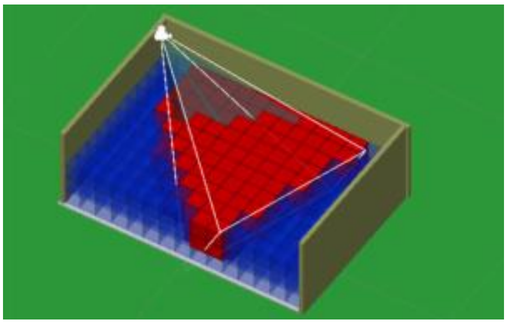
Then, a number of cells were generated over these important areas as shown in Figure 13. The process of generating cells was implemented using the following steps: (1) selecting the floor shape that will be covered with cells; (2) creating a mesh collider that determines the shape of the floor; (3) determining the suitable size of the cells; (4) determining the number of cells on the X, Y, Z axis of the floor shape; (5) specifying the importance value of each cell based on its important area a_i; and (6) running the cell generating process.

Figure 13: Plan view of the BIM model showing the important areas with their Importance Values (IV)

As previously discussed, cells are generated in a way to cover the upper limit of the average human height. A sensitivity analysis is conducted to evaluate the suitable edge size of the generated cells to cover two meters height, as shown in Table 1. The evaluation starts by generating cells with a side dimension of 0.1 m to cover an area of 10 m by 7 m, as shown in Figures 14 (a) and (b). The evaluation showed that the required number of cells to cover this area was 163,500 with 20 layers of cells. After conducting the camera coverage calculation process, it showed that the camera required 4.14 seconds to cover 81.39 m^3 of cells volume. The value of covered cells was calculated using Equation 5. Also, the change of the accuracy (C_{ac}) was calculated to evaluate different sizes of cells from 0.1m to 1m by using Equation 6.



(a) Generating 2 levels of cells



(b) Generating 3 levels of cells

Figure 14: Sensitivity analysis of the suitable cell size

$$CCV = Number\ of\ covered\ cells \times Cell\ volume \quad \text{Equation 5}$$

$$C_{ac} = \frac{Current\ CCV - First\ CCV}{First\ CCV} \quad \text{Equation 6}$$

Where CCV is the covered cell volume and C_{ac} is the change in accuracy

Cells with an edge of 0.7 m were selected as the suitable cell size because the result of covered cells volume was 79.91 m^3 with the least change of accuracy of 1.82% compared with the 0.1 m cell size. This cell size also showed that the time of the cell generation process and the time of camera coverage calculation were 0.09 second and 0.1 second, respectively. After generating the cells, it is necessary to classify the important areas based on the importance values of their cells. Table 2 shows the number of generated cells over each important area assigned with their importance values.

Table 1: Selecting the suitable cell size

Cell size (m)	*# of layers*	*# of cells*	*Covered cells volume (m^3)*	*Change in accuracy (%)*	*Time to generate cells (sec.)*	*Coverage calculation time (sec.)*
0.1	20	163,500	81.39	0	2.25	4.14
0.2	10	19,980	79.67	-2.12	0.16	0.38
0.3	7	6,300	83.80	2.96	0.05	0.22
0.4	5	2,430	79.55	-2.26	0.02	0.10
0.5	4	1,260	79.80	-1.96	0.01	0.05
0.6	4	864	93.96	15.43	0.01	0.02
0.7	3	450	79.91	-1.82	0.09	0.01
0.8	3	351	92.16	13.22	0.08	0.01
0.9	3	288	102.06	25.38	0.08	0.01
1.0	2	140	73.00	-10.31	0.07	0.01

Camera 3 was selected to evaluate the coverage and to generate 3D virtual scenes as shown in Figure 15. It is important to note that Camera 3 is a multiple camera type which includes 4 lenses and that generate 4 FOVs. These virtual scenes can help to validate if Camera 3 is properly placed by viewing what the camera can see in an animation mode. These virtual scenes can be automatically generated by selecting the FOVs of Camera 3 and specifying the screen dimensions of each FOV. This evaluation will show if there are any objects that may affect the visibility of this camera.

An experiment was conducted in order to examine the impact of FOV angle and the tilt angle (β) on the visibility of Camera 3. The first step is to determine the areas that will be covered by the camera. In this experiment, Camera 3 is targeting area 5 to area 8. The four areas are covered by 1,377 cells, as shown in Figure 16. These cells are assigned with Importance Values (IV) as the following: (1) cells covering areas a_5 and a_8 that represent general areas are assigned with IV=1; (2) cells of area a_6 that represents elevator hall are assigned with IV=2; and (3) cells covering area a_7 that represents the escalator location connecting to the metro station are assigned with IV=3.

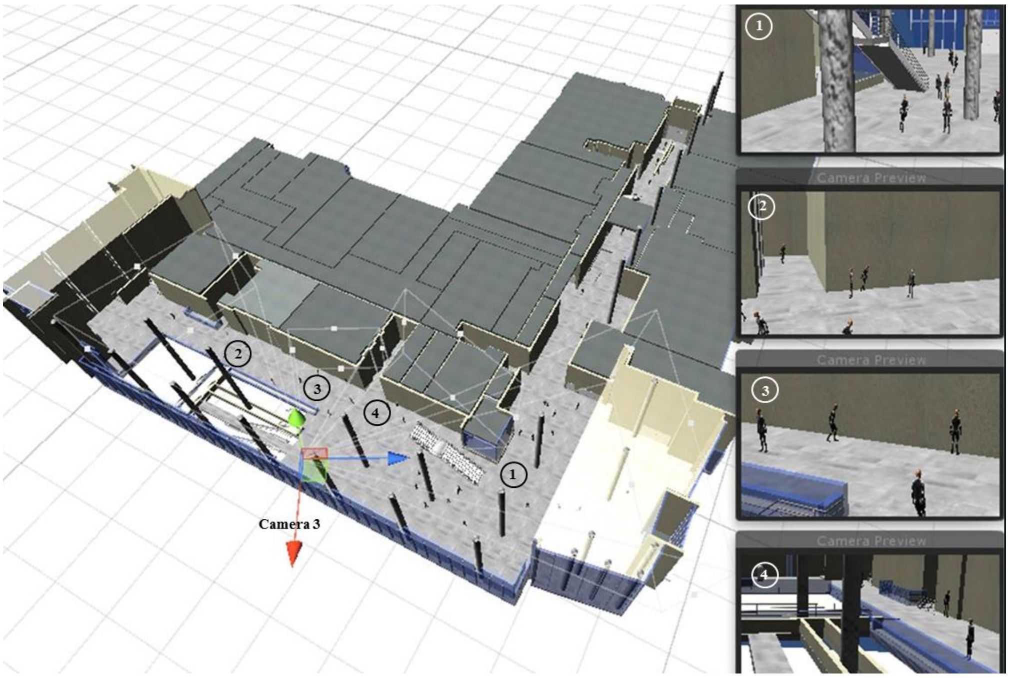


Figure 15: Generating virtual screen views

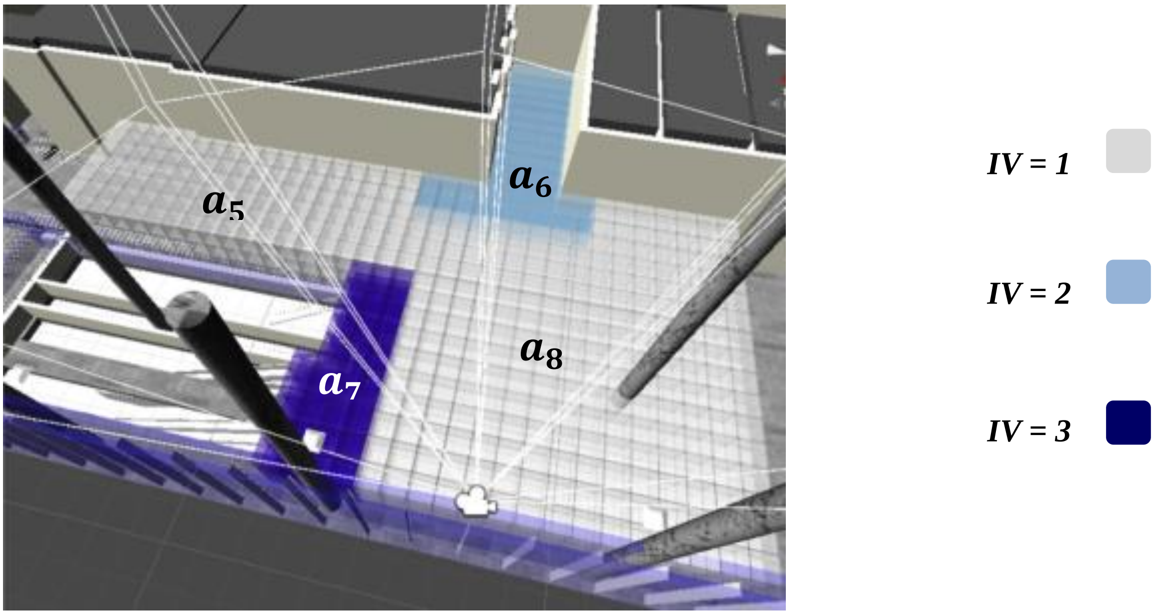


Figure 16: Cells assigned with importance values in areas a_5 to a_8

Camera coverage is calculated using Algorithm 1 based on the following aspects: (1) The visibility process is conducted through all important areas within the camera FOV; (2) The weight of the total monitoring area is calculated by multiplying the total number of generated cells by the importance values assigned to every important area; (3) Visible cells are considered with their importance values in order to be used in calculating the coverage for every important area; and (4) The total camera coverage is calculated by the summation of the coverage for every important area inside the camera FOV.

Algorithm 1: Calculating the camera coverage

```
total_camera_coverage = 0 ;
for i = 1:m do
CCa[i]= 0 ;
Wa[i]= 0 ;
  if area[i] intersectWith FoV
    for j = 1:n do
      if cell[j] intersectWith FoV
         for v = 1:n' do
           if cell[v] isVisible
             CCa[i]= CCa[i]+ C[i][v] x IV[i] ;
             cell_material_colour = red ;
           else
             cell_material_colour = green ;
           end if
         end for
      else
        cell_material_colour = no_color
      end if
      Wa[i]= Wa[i]+ C[i][j] x IV[i] ;
    end for
    camera_coverage[i] = CCa[i] / Wa[i] ;
  else
    camera_coverage[i] = 0;
  end if
  total_camera_coverage = total_camera_coverage + camera_coverage[i] ;
end for
```

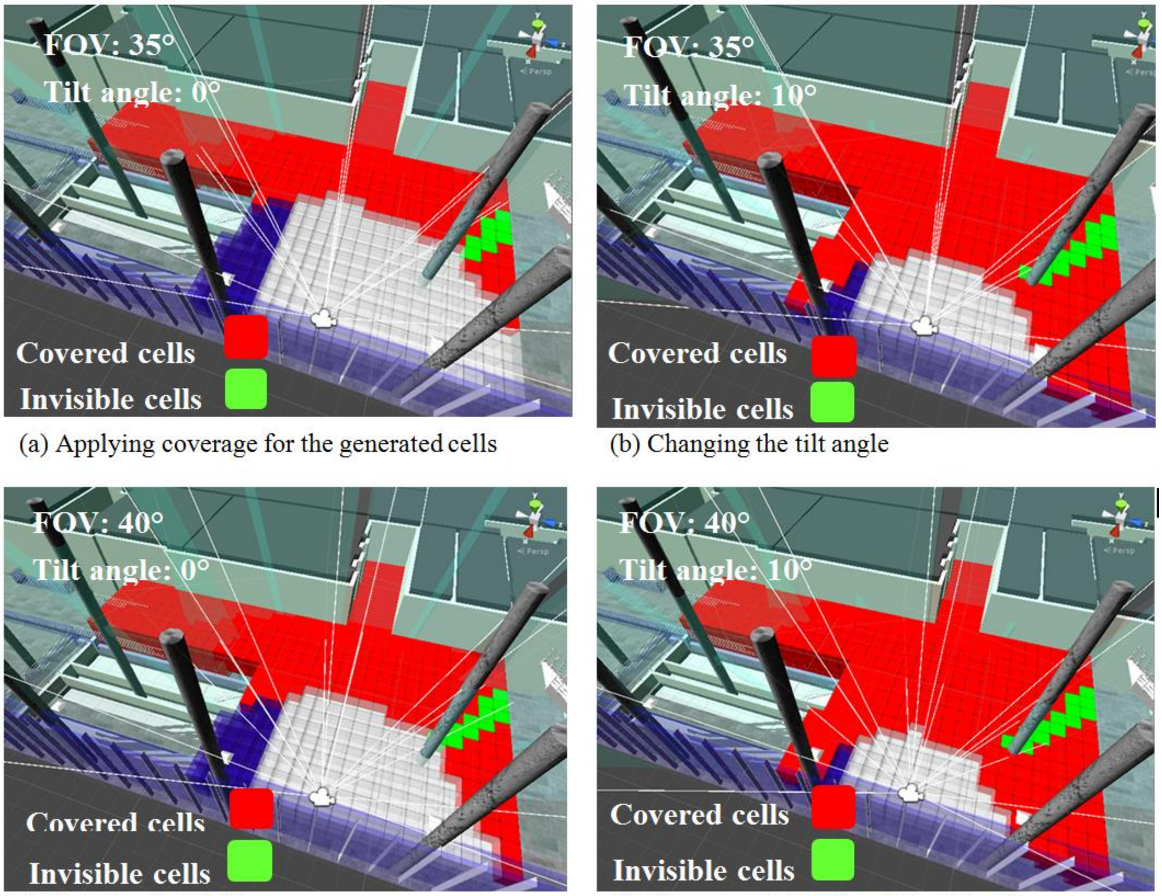
Figures 17 (a) to (d) show the four scenarios for evaluating the coverage of Camera 3 as the following: (a) FOV = 35° and β = 0°; (b) FOV = 35° and β = 10°; (c) FOV = 40° and β = 0°; and (d) FOV = 40° and β = 10°. The red color represents the visible cells while the green color represents the invisible cells behind a column. Table 3 shows the coverage results of the four scenarios. Implementing scenario *a* gave the coverage of 63.6%. By adjusting β to 10° in scenario *b*, the coverage became 87.12%. The coverage decreased when increasing the FOV to 40° while fixing β in scenario *c*. However, in scenario *d* when adjusting β to 10° and the FOV to 40°, the coverage of 89.4% was achieved. This analysis demonstrated that changing the FOV and β can impact the camera coverage results. The results showed the importance of using the 3D method and considering the camera height during the process of calculating the coverage in order to detect invisible spots which was simulated by the green cells.

Table 2: Number of generated cells in each area

Area	*Importance value*	*Description*	*Number of cells*
a_1	3	Area surrounding entrance 1	405
a_2	1	General area facing entrance 1	311
a_3	2	Area connects this building with another building	307
a_4	1	Area of corridor close to entrance 1	466
a_5	1	Area of corridor leads to elevators	378
a_6	2	Area surrounding elevators	231
a_7	3	Area facing escalators	105
a_8	1	General area facing elevators and escalators	663
a_9	2	Area surrounding stairs	428
a_{10}	1	General area facing entrance 2	1,782
a_{11}	1	Area surrounding entrance 2	119
a_{12}	3	General area leads to entrance 3	688
a_{13}	1	Area surrounding stairs and leads to entrance 3	312
a_{14}	2	Area surrounding stairs and leads to entrance 3	331
a_{15}	2	Area surrounding elevators	217
a_{16}	2	Area close to entrance 3	365
a_{17}	3	Area close to entrance 3 (different floor elevation)	204
		Total number of cells	7,312

Table 3: Scenarios of the camera coverage for areas a_5-a_8

# Scenario	β *(°)*	*FOV (°)*	CV_5	CV_6	CV_7	CV_8	COV_5 *(%)*	COV_6 *(%)*	COV_7 *(%)*	COV_8 *(%)*	*Total coverage of Camera 3 (%)*
a	0	35	378	231	12	282	100	100	11.4	42.5	63.60
b	10	35	378	231	87	483	100	100	82.8	72.8	87.12
c	0	40	378	231	24	303	100	100	22.8	45.7	66.80
d	10	40	378	231	93	507	100	100	88.5	76.4	89.40



(a) Applying coverage for the generated cells
(b) Changing the tilt angle
(c) Changing the FOV
(d) Changing the FOV and the tilt angle

Figure 17: Implementing scenarios on Camera 3

6. SUMMARY, CONCLUSIONS AND FUTURE WORK

This paper presented a new method for calculating the camera coverage inside buildings using BIM in order to automate the calculation process and to achieve accurate results. The proposed method included: (1) defining the camera placement, (2) validating the camera scenes, (3) generating cells and assigning importance values, (4) visibility analysis, and (5) calculating the camera coverage. The paper also included a sensitivity analysis of evaluating the suitable cell size which used to cover the monitoring area. The conclusions of the paper can be listed as the following: (1) BIM was used to specify the location of constraints that can affect the camera coverage; (2) different importance values were assigned to cells generated inside the building in order to achieve accurate calculation of the camera coverage; and (3) camera coverage was evaluated by changing the values of the FOV and tilt angles of the camera.The case study demonstrated the benefits of using BIM in calculating the camera coverage in buildings. Four scenarios conducted to evaluate the effect of the FOV and β angles on the camera coverage. The results showed the effect of the FOV and tilt angles on increasing the coverage to 89.40% in scenario (d). The experiment proves the necessity of considering the height of the camera during the process of calculating the coverage in order to detect invisible spots behind obstacles. Also, dividing the monitoring area into a number of important areas with different (IV) values facilitated the decision of selecting the proper FOV and tilt angles for the camera.The proposed method is beneficial for individuals who are responsible for installing cameras inside buildings. Future work will include optimizing the placement of different numbers and types of surveillance cameras inside buildings.

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