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LADM-IndoorGML for exploring user movements in evacuation exercise

Abdullah Alattas[a,b,*], Peter van Oosterom[b], Sisi Zlatanova[c], Dick Hoeneveld[d], Edward Verbree[b]

[a] King Abdulaziz University, Faculty of Environmental Design, Geomatics department, Al Ehtifalat St, Jeddah, 21589, Saudi Arabia
[b] Delft University of Technology, Faculty of Architecture and the Built Environment, Section GIS Technology, Julianalaan 134, P.O. Box 5030, 2600 GA, Delft, the Netherlands
[c] University of New South Wales, Faculty of Built Environment, Kensington Campus, NSW, 2052, Sydney, Australia
[d] TU Delft Safety & Security Institute, Delft University of Technology, Faculty Technology, Policy and Management, Jaffalaan 5, 2628 BX, Delft, the Netherlands

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ABSTRACT

The users' movements in the indoor environments differ based on the condition of the environments. During an indoor emergency, an efficient evacuation is required to help the users to move to the safe areas. Many types of incidents could impact the movements of users and this requires studying the behavior of the people during the evacuation. The reaction of the users to the incidents could affect the evacuation procedures and that could lead to several types of injuries or death. Each user understands and perceives the indoor environment differently and this plays a critical role in the evacuation. Furthermore, the users of the indoor environments have different rights to access the indoor spaces, which affects the movements of the users during an incident. This paper aims to support the evacuation of a building (educational building) in a crisis by using the integrated model of LADM-IndoorGML and the representation of the 3D model of the building. This research is presenting the initial assessment based on real world application. To reflect evacuation cases, we extended the conceptual model of LADM-IndoorGML to define the access rights for users of indoor environments during crisis. An evacuation exercise has been held at the Faculty of Applied Science at TU Delft to study the access rights during an incident. During the evacuation, Wi-Fi data has been collected for the users of the building for further analysis. A 3D model has been built for the Faculty of Applied Science to analyze the movement of the users. The collected data of the Wi-Fi access points have been structured and imported into the freeware database PostgreSQL/PostGIS. Furthermore, the geometry of 3D model was used to visualize the users' movements as individuals and groups of users according to their connection to Wi-Fi access. Appropriate visualization has been created using QGIS. This paper demonstrates the entire process of analysis and visualization of users' movements based on the Wi-Fi logs by using the extended LADM-IndoorGML. The outcome of the research has showed that the results for individual users and group users attached to the same access point differs. The study has also exhibited the importance of the time resolution on Monitoring the movements of a single user or group of users. The completed study clearly demonstrates that with the proposed extension, the integrated LADM-IndoorGML model is able to support the decision-making process during an incident in educational building.

1. Introduction

The indoor environments such as offices, homes, shopping centers, educational buildings, etc. are hosting most of the daily activities of the people. Those indoor environments have very complex structures that could be exposed to several types of dangers, such as fires, pollution incidents, explosions, etc. and that influence people life (Tashakkori et al., 2015). Additionally, the complexity of the indoor environments leads to more difficulty in managing the disaster, and that requires better preparation for evacuation analysis and procedures. The primary goal of the evacuation is to provide the safest routes for the users to reach the emergency exits. The time that follows the beginning of the disaster is very critical for the users of the indoor environment and the ERT because It plays an essential role in fighting and managing the impact of the disaster (Zlatanova and Fabbri, 2009).

Moreover, indoor navigation during a crisis is much slower than outdoor because of the uncertainty of the routes (Jeon et al., 2011). Several kinds of events could decrease the speed of movements of the

* Corresponding author at: Delft University of Technology, Faculty of Architecture and the Built Environment, Section GIS Technology, Julianalaan 134, P.O. Box 5030, 2600 GA, Delft, the Netherlands.

E-mail addresses: A.f.m.alattas@tudelft.nl (A. Alattas), P.J.M.vanOosterom@tudelft.nl (P. van Oosterom), s.zlatanova@unsw.edu.au (S. Zlatanova), d.hoeneveld@tudelft.nl (D. Hoeneveld), E.Verbree@tudelft.nl (E. Verbree).

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users of the indoor environment and increase the travel distance, such as smoke distribution. These kinds of distractions, including the blocked areas and inaccessible spaces, will increase the difficulty of routing inside the building, and that will affect the evacuation speed. Therefore, many researchers have investigated the network modeling and indoor wayfinding (Xiong et al., 2017). An automated method to explore the users' movements from Wi-Fi log data on the Delft University of Technology campus has been proposed by (Griffioen et al., 2017). Several emergency evacuation models have been developed based on different computational rules to allow the researchers to assess the evacuation safety such as Firescap, Exoudus, Simulex, Esm, and Mascm (Tang and Ren, 2012). Thus, it is crucial to have a clear conception about both indoor and outdoor environment to decrease the uncertainty of the routing during the incident. By having such information about the building, the ERT and the users will be able to deal with the incident in a better way (Holmberg et al., 2013). The 3D indoor-outdoor spatial model of (Tashakkori et al., 2015) provides the required information to find routes during emergency response because it includes information about the indoor environment and the network between the floors.

Although being very elaborated, those models have not addressed the users' Rights, Restrictions, and Responsibilities during emergency evacuation and the impact of these rights on the evacuation routes. Therefore, the conceptual models of IndoorGML and Land Administration Domain Model (LADM) have been linked in one LADM-IndoorGML model and adapted to define the accessibility of the indoor spaces based on the access rights for induvial or group of users (Alattas et al., 2017). The conceptual model of LADM-IndoorGML has studied several type of navigation applications (during non-crisis situation) based on RRR such as based on Student rights, Academic member rights, and cleaning team member rights (Alattas et al., 2017). LADM generates the connection between the indoor spaces and the users by determining rights, restrictions, responsibilities (RRR) for each space and then the RRR for each space is used to define the available spaces for each type of user. IndoorGML provides a space-based network for navigation and path computation. The integrated model defines the access rights of indoor spaces overtime to provide efficient indoor navigation for the user. This paper aims to support the evacuation of the building (educational building) in a crisis by using the integration model of LADM-IndoorGML and the representation of the 3D model of the building. This research is presenting the initial assessment based on real world application. In this work, the contribution can be stated as follows:

- Testing the conceptual model of LADM-IndoorGML for emergency exercise evacuation in an educational building.
- Structuring and analysis a Wi-Fi log data.
- Generating and populating database with real data from BIM model.
- Analyzing and visualizing of the users' movements based on the Wi-Fi logs by using the extended LADM-IndoorGML.

This paper is organized as follows. Section 2 describes the methodology to transform the conceptual model into the technical model. The preparation, representation, and analysis of the evacuation scenarios introduce in Section 3. Section 4 presents the implementation of the research, and it includes the creation of the 3D, preparation of the Wi-Fi log data and populates the database. The result is demonstrated in Section 5. The paper ends with a discussion and conclusion in Section 6.

2. Methodology

This section presents the method that has been used to study the users' behavior of the indoor environment to support the evacuation procedures in an educational building during a crisis. There were several stages to be able to analysis the users' movements. The first stage was to transform the conceptual model of LADM-IndoorGML to technical model, and there were three steps for this stage:

- Step 1: Generating the LADM-IndoorGML class diagram in Enterprise Architect software (sub-Section 2.1).
- Step 2: Extending the Class diagram of LADM-IndoorGML for crisis incident (sub-section 2.2)
- Step 3: Converting the table diagram to table diagram and then to SQL DDL (Data Definition Language) (Sub-Section 2.3).

The second stage represented the preparation of an emergency evacuation exercise with 2D and 3D floor plans to represents the possible routes that can be used by the users during the crisis (in Section 3). Then in the next stage, a 3D model was created by using Revit software to determine the movements of the users based on the location of the Wi-Fi access points (in Section 4.1). During the evacuation exercise, the records of the Wi-Fi access points were collected to be used for elaborating the movements of the users (in Section 4.2). Moreover, the location of the Wi-Fi access points was included in the 3D model by digitizing them from a paper map. Next stage was creating the database in PostgreSQL with the extension of PostGIS to store the data of the 3D model and the Wi-Fi connection records (in Section 4.3). The last stage was to utilize QGIS to represent the movements of users based on the location of the Wi-Fi access point (in Section 5).

2.1. Conceptual model

As mentioned previously, the transformation of the conceptual model to the technical model has to pass through several steps. The first step was to Generate the LADM-IndoorGML class diagram in Enterprise Architect software. The main issues of the transformation of the conceptual model to a technical model that have been reported in detail by (Alattas et al., 2018a). The first step aimed to create all classes for the conceptual model of LADM-IndoorGML in Enterprise Architect software and enrich the two models with attributes and their values.

LADM includes several packages such as Party package, Administrative package and Spatial Unit package. Each package contains feature classes and code lists for each attribute. The first step adjusted all packages by combining the new feature classes of the LADM-IndoorGML conceptual model. For example, the LA_Employee, LA_GroupEmployee, and LA_GroupStudent had to be included in Party package as shown in Fig. 1.

The UML diagram of IndoorGML did not include all the classes and their attributes, data types, and multiplicities. Therefore, the Java classes and the XML/GML schema of IndoorGML have been used to generate a complete class diagram. This step has been done by utilizing the code engineering tool in Enterprise Architect. However, the result of the class diagram was a representation of the Java implementation. For example, the class diagram represented the edge and node as classes, while they are determined as aggregations of SpaceLayer in the IndoorGML standard. The UML model had been corrected manually at this stage. The CellSpace class has three attributes (cellSpaceGeometry, duality, and externalReference).

The cellSpaceGeometry contains 2D, and 3D geometry data type and only one data type could be determined for each object. The second attribute is the duality, and it has the StatePropertyType as a data type which refers to zero or more states. The externalReference attribute has externalReferenceType as data type, and it consists of two components (informationSystem and externalObject). The CellSpaceBoundary include three attributes (cellSpaceBoundaryGeometry, duality, and externalReference). The duality attribute has TransitionPropertyType as a data type. The cellSpaceBoundaryGeometry attribute includes 2D or 3D geometry data type.

By having the two UML diagrams for LADM and IndoorGML, the relationship between LADM and IndoorGML has been defined in (Alattas et al., 2017) by linking the LA_SpatialSource class and LA_SpatialUnit in LADM to the CellSpace class in IndoorGML. The LA_SpatialSource is responsible for collecting the Primal spaces from CellSpace class in IndoorGML. The LA_SpatialSource will share the primal space

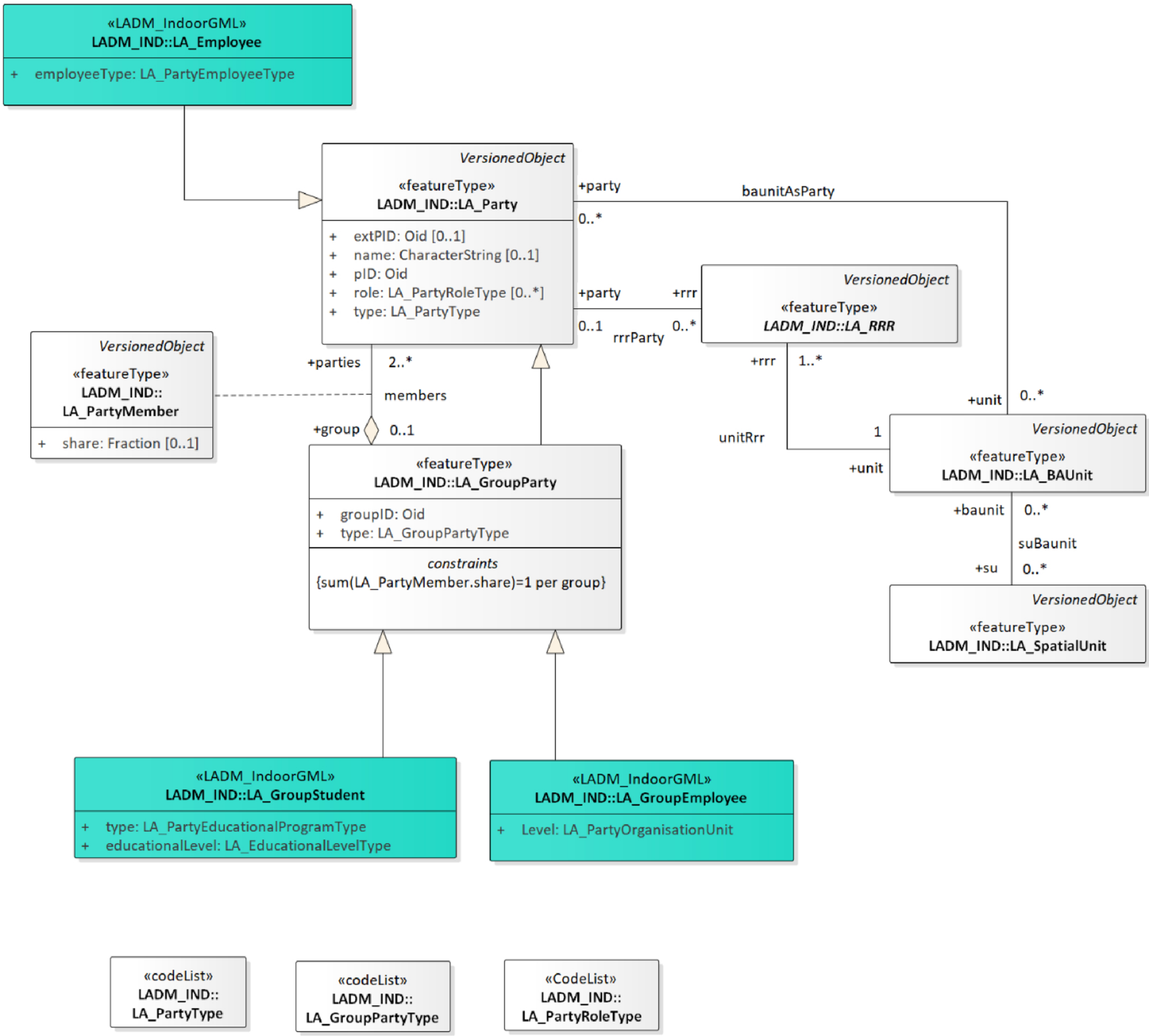


Fig. 1. Party class diagram contain the LADM-IndoorGML new classes (in blue the new classes) (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.).

information with LA_Party, LA_RRR, LA_BAUnit, and LA_SpatialUnit. The LA_Party class will obtain the party information from the LA_AdministativeSource. Based on the relation between the party and space, the LA_RRR will register the rights, restrictions, and responsibilities in the LA_BAUnit. Finally, the LA_SpatialUnit will transfer the access rights to the CellSpace class in IndoorGML.

2.2. LADM-IndoorGML for crisis incidents

As mentioned previously, the conceptual model of LADM-IndoorGML has been extended in (Alattas et al., 2018b) to determine the access rights for the users of the indoor environment during an incident. There are two types of indoor spaces that are defined by the conceptual model according to user rights 1) common right spaces and 2) private right spaces. These rights can be reflected by the party package. It is one of the main packages of LADM (Alattas et al., 2017). The party package has the LA_Party class, LA_GroupParty which is a specialization of LA_Party and LA_PartyMember which is an optional association class. The LA_GroupParty was extended by adding LA_GroupEmergencyResponseTeam as subclass to represents the Emergency Response Team (ERT) during an incident (Alattas et al., 2018b) as shown in Fig. 2.

Additionally, the LA_RRR is a subclass of the administrative package of LADM and it has a timeSpace attribute that responsible for the representation of the temporal description of every rights, restrictions and responsibilities based on the type of user as shown in Fig. 3. During an incident, the ERT has the rights to access all indoor spaces. However, the condition of the indoor space will change the RRR for each user. For example, during an incident, the users could face a situation where the only route that can be used to escape from the building is blocked, and the users have to find an alternative route where they need to pass through restricted spaces based on their RRR. However, the timeSpace attribute provides conditional access rights for the users based on the condition of the indoor space to escape from the incident zone.

2.3. Technical model

The third step was converting the class diagram to the table diagram

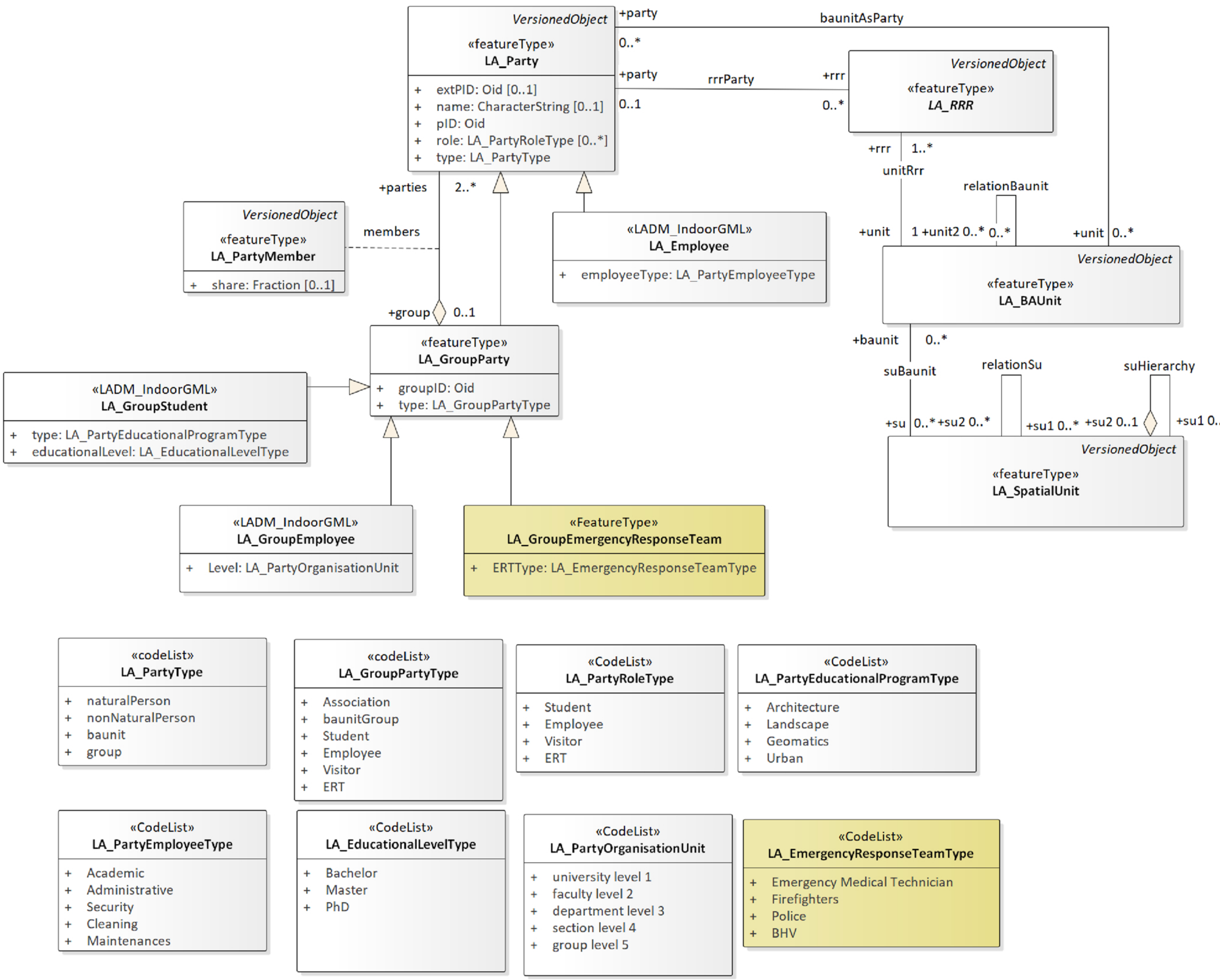


Fig. 2. New subclass for the LA_GroupParty class and code list (yellow) (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.).

as describes in (Alattas et al., 2018c). In this step a limited number of classes had been selected to be converted to table diagram as shown in Fig. 4. The transformation tool of Enterprise Architect (EA) has been used to convert the class diagram to the table diagram.

The result of the transformation had some issues related to the primary key and a foreign key, constraints, data type, spatial data type, code list classes and indexing. For example, the transformation tool has generated a new primary key even if the class diagram had one. Some classes had constraints, However, they were not considered during the transformation even when changing the appearing feature of the table diagram. Moreover, some of the data types were not recognized such as Oid and Fraction, and they have very important meaning.

The spatial data types such as GM_Point, GM_MultiSurface, and GM_MultiCurve were replaced with “varchar” during the transformation. EA offers some types of spatial data such as geometry, geometry collection, linestring, multilinestring, point, multipoint, polygon, and multipolygon, which had to be selected manually. The transformation also did not provide spatial index (R-tree) for spatial data. The spatial data type has been modified manually in this stage. EA does not support geometry type “multipolygon z,”. Therefore, this required manual corrections in the SQL code. During the transformation from class diagram to table diagram, the transformation tool generates B-tree index for the FK. All issues were resolved manually and the correct table diagram.

The next step is to transfer from table diagram to SQL DLL. The selected classes of the conceptual model of LADM-IndoorGML has been used to generate the SQL DLL by using the code engineering. The SQL DDL has been generated in automated way. The transformation tool in EA was used to convert the class diagram into a table diagram. All issues that have been discussed by (Alattas et al., 2018a) were considered. A SQL DDL was generated by using the code engineering tool in EA. The code engineering was converted the entire table diagram into SQL DDL.

3. Evacuation scenarios

The second stage of the methodology that has been used to study the users’ behaviour during an incident to support the evacuation procedures was preparing the evacuation scenarios. The two evacuation scenarios were prepared in (Alattas et al., 2018b) for the real exercise. The Faculty of Applied Science has several departments that are sharing six wings and those wings consist of around 1200 spaces. The building consists of a front block (main building) and five wings (A, B, C, D, and E) attached to it. Each wing has multiple emergency exits, and all wings are connected by the main building and the bridges located on the first floor. The spaces of the building are used for different purposes such as chemical and physics laboratories, offices, meeting rooms, lecture rooms, and mechanical rooms. Wing C is the central wing and

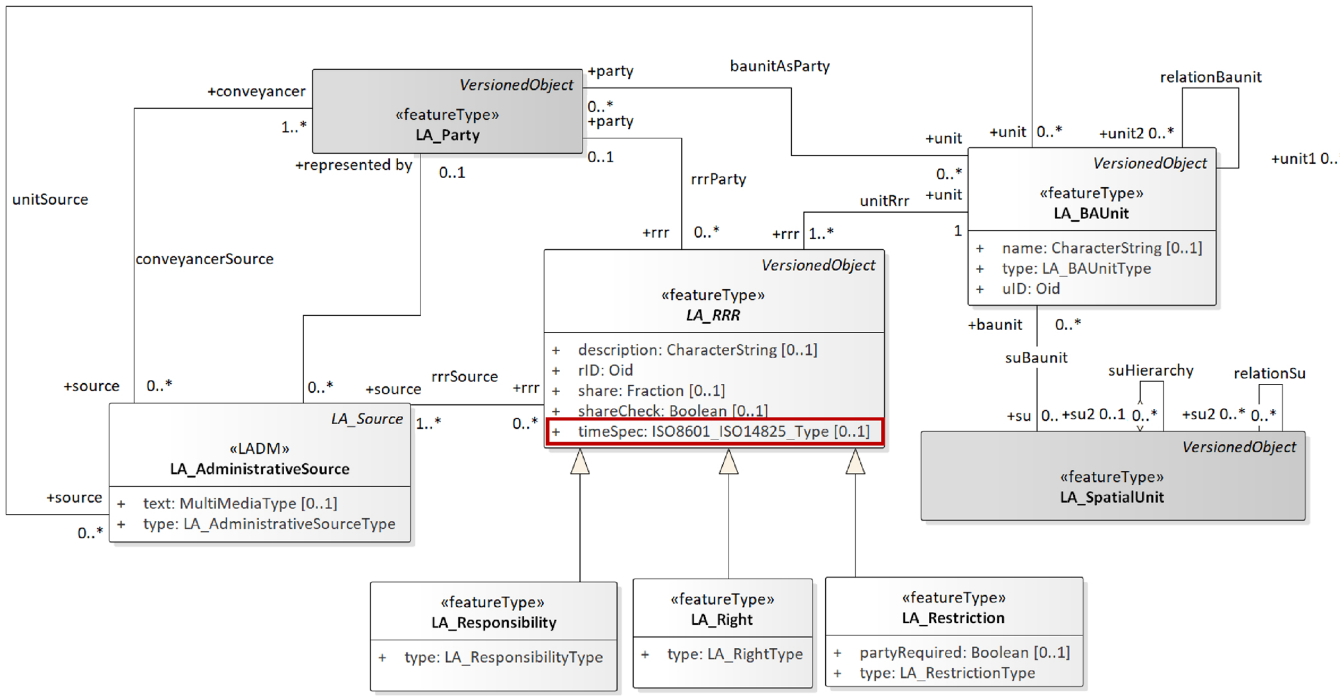


Fig. 3. The administrative package of LADM.

considered as the main logistic route for all the goods delivery, and there are some laboratories and workshops located in wing C. Each scenario has been represented by 2D and 3D floor plans to support the ERT during the evacuation exercise.

3.1. Emergency evacuation scenarios

The first prepared scenario deals with an alleged bomb treat. The main reception of the Faculty of Applied Science receives a phone call about a bomb being placed at the main entrance of the building. No information about the exact location of the bomb is provided. Immediately, the management of the building orders evacuation of the entire building. The stairs that are located at the intersection between the main building and wing C, B, and D are blocked by the ERT to keep a distance from the most dangerous zones because they connect those wings with the main building. When the slow-whoop starts, the Emergency Response Team (ERT) guides the users of the faculty to move away from the blocked areas and to find the nearest emergency exits.

There is a technician in the ground floor of wing C moving a large Dewar vessel with liquid nitrogen when the slow-whoop starts. The technician hits an object, and Dewar topples over, and the vapor of Liquid nitrogen starts to spread all over the corridor. A quick decision is made to block the corridor to stop vapor of Liquid nitrogen from reaching another part of the building. However, some workers are trapped between the main entrance and the blocked corridor. To evacuate the trapped users, an alternative path is provided to allow the workers to pass through locked workshop to reach the emergency exit that located in the middle of wing C. The ERT could control the dangerous spaces based on the available information about the incident and assist the users to an alternative route even if the users do not have access to pass some spaces based on their rights.

The second scenario covers a leakage of flammable gas. The incident starts when leakage of flammable gas is detected from a pipe feeding a laboratory that is in the basement close to wing C. It is unclear how big area has been affected by the leakage. The Fire Brigade is alarmed, and the management of the Faculty of Applied Science decides to evacuate the building because of an explosion risk. The center of all floors of the main building and the centre of the first and second floor of wing B, C, and D are considered dangerous areas.

Based on the available information about the situation, the ERT closes all doors that lead to the dangerous areas and guides the users to find other routes to the emergency exit. When the slow-whoop is activated, the users located in the dangerous areas are evacuated through the main entrance of the building. The rest of the users that located out of the danger zones are directed to other exits in wing A, B, C, D, and E. The arrived firefighters ventilate the building and the technical staff seal the gas leak. After half an hour, the users may return to the building as it is considered safe again. For both Scenarios, there were 2D, and 3D evacuation plans to reflect the crisis and to help the users to find their way out of the building.

3.2. 2D/3D representation of the scenario

Based on the previous scenarios, there was a preparation for 2D and 3D representation of the floor plans of the building to illustrate the possible navigation routes for the users during the incident. The main goal of 2D and 3D evacuation plans was to provide two different illustrations for the same indoor environment (representing the same incident) and to understand which one of them clearer and more understandable for the ERT and the users. For example, the 2D and 3D representation of the floor plans for the first scenario have reflected the same incident but with different amount of details as shown in Fig. 5. The feedback of ERT has shown that the 3D representation of the floor plans provides more information to the first responder and the fire fighters to understand the indoor environment. The 3D evacuation plan provides a clear vision about the construction elements of the building and how they can affect the movements of the users.

3.3. Analysis of the evacuation exercise

The emergency exercise took place on the 17-7-2018. There was a meeting with ERT before the emergency exercise to discuss and prepare for the two proposed scenarios. The ERT decided to concentrate on the second scenario and started preparing for the exercise. Eight observers participated in covering the emergency exits and in reporting the user's

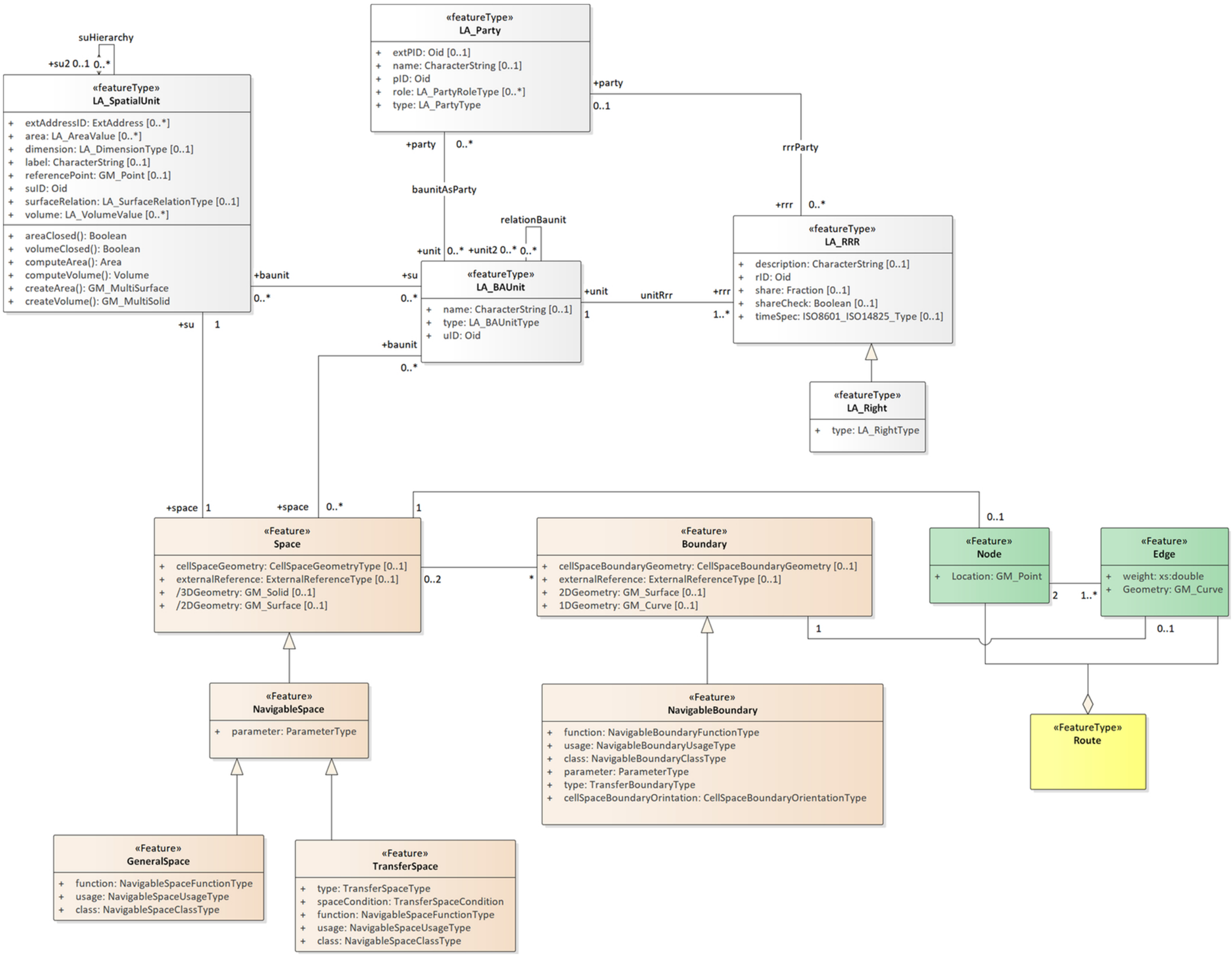


Fig. 4. The selected classes from the conceptual model of LADM-IndoorGML.

behaviour during the exercise. The users started to move from their offices and labs when the emergency alarm launched and navigate to the emergency exits. The most significant number of users (around 120) decided to use the main entrance of the building. Four users have used the emergency exit that is located in the middle of wing C as shown in Fig. 6. 75 users used the middle exit of wing B, however the other exit of the same wing was closed. None of the users used the bridge between the Aula building and the Faculty of Applied Sciences. 64 users selected the emergency exit located in the middle of wing A. The reports of the observers have clearly shown that the users followed the same route of their daily activity.

4. Implementation

4.1. Creating 3D model

A 3D model for the Faculty of Applied Sciences was created by using Revit software. The modeling process started by collecting the architectural drawings (digital version) of the building and it includes three types of data:

1 Floor plans drawings.
2 Sections drawings.
3 Facades drawings.

Then, the floor plans drawings will be imported to Revit to create the 3D model. The section drawing will be used to define the height of each level of the building. After creating all the spaces of the building based on the floor plans drawings, the building facades will be created according to the information of the facades' drawings. By having a complete 3D model of the building, different information was attached to each space such as space number, usage, type, specification, organization unit, cleaning frequency (Cleaning), floor finishing (carpet or marble), chair information, department information and section information as shown in Fig. 7.

4.2. Preparing of the Wi-Fi data

The evacuation exercise allowed to explore the user's movements during the exercise (reports from observers) and by collecting Wi-Fi log data from the main Wi-Fi network of TU Delft. The Wi-Fi log data were important source of information to understand the movements and to complement the conclusions of the observers.

4.2.1. Description of the Wi-Fi data

The Wi-Fi log data has been collected from the Wi-Fi network of TU Delft (Eduroam network). The accessibility of this Wi-Fi network is limited to the employees, students and ERT. The Wi-Fi log data table consists of eight columns and 13,858 rows that represent the users logging data for the entire day as shown in Fig. 8. Each column has

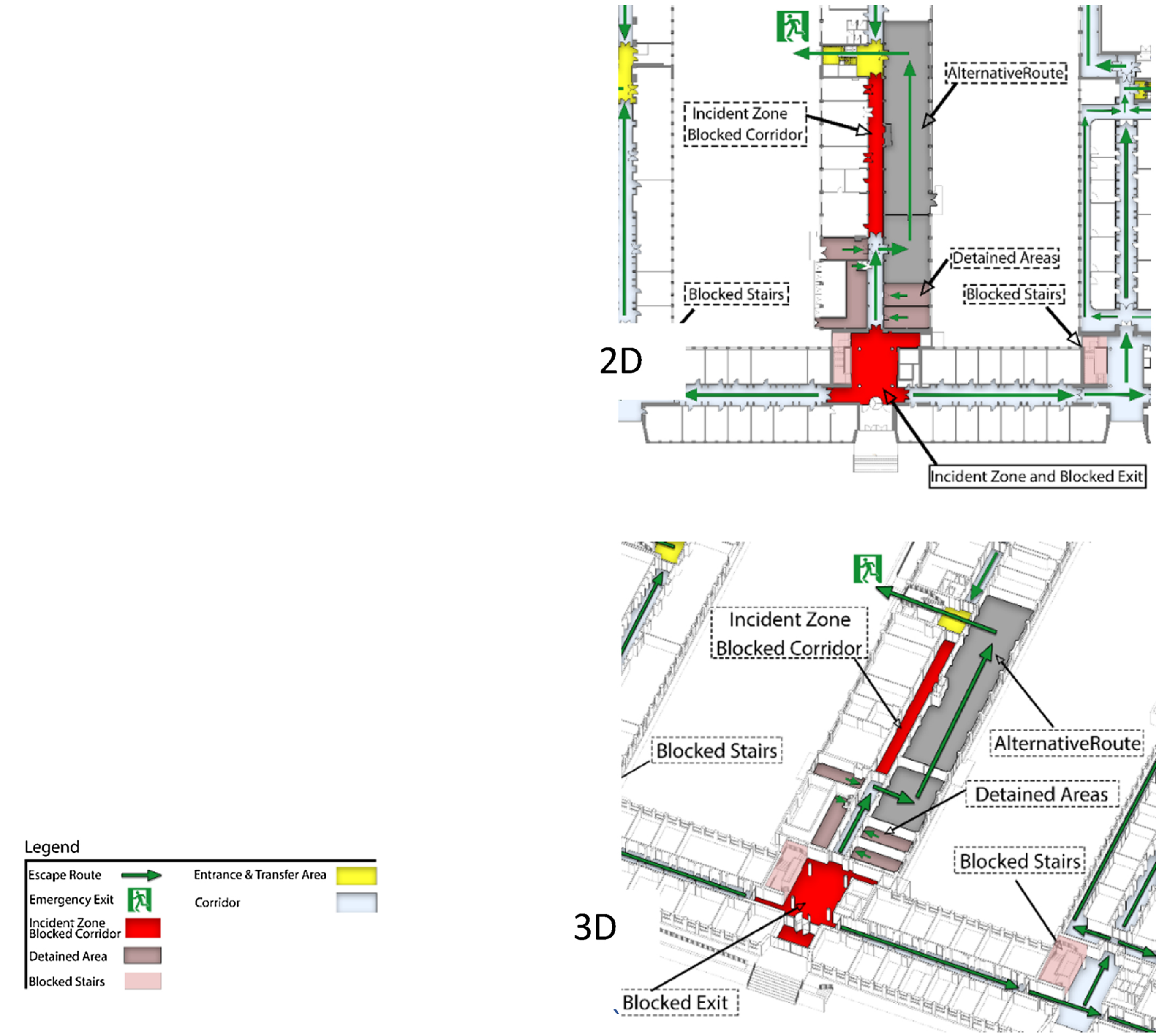


Fig. 5. 2D and 3D evacuation plans.

different value as describe in Table 1.

The Client Username is the Username of the user of the Wi-Fi network, and it is a unique ID that could be repeated more than once in the same data. The second type of information is the Client MAC Address, and it is the media access control address. The Client MAC Address is a unique identifier for a particular part of hardware such as mobile phone, laptop etc. Besides, each user could have more than one Client MAC Address in the same data. The Association Time column provides the date and time for each device record. The AP Name is the name of the Wi-Fi access point, and it is a unique name. The location information (Building Number, Level etc.) for each Wi-Fi access points is described in the Map Location column. Session Duration column describes the connection time for each device to a specific access point. The signal to noise ratio (SNR) is a record for each device by comparing the signal strength to the level of background noise. The received signal strength indicator (RSSI) represents the collected signal strength (Bon et al., 2016).

The column format of the Wi-Fi log data was modified to be used later in PostgreSQL. For example, all the spaces between the words were replaced with an underscore and the Association Time column was replaced with two separate columns as Date and Time as shown in Fig. 9.

4.2.2. *Positioning of the Wi-Fi access points*

Based on the Wi-Fi log data, the Wi-Fi access points were identified. However, the log data does not provide the XYZ coordinate for each Wi-Fi access point. Therefore, we used the only available data, which was a paper map for each floor that represents the location of Wi-Fi Access point, as shown in Fig. 10.

The position of each Wi-Fi access point was digitized manually in Revit and included in the 3D model of the Faculty of Applied Science. In total 387 Wi-Fi access points around the entire building were digitized. The XYZ coordinates were extracted to a schedule in Revit and then exported to an Excel sheet, as shown in Fig. 11.

4.3. *Database import*

A database was created in PostgreSQL, and there were three steps to

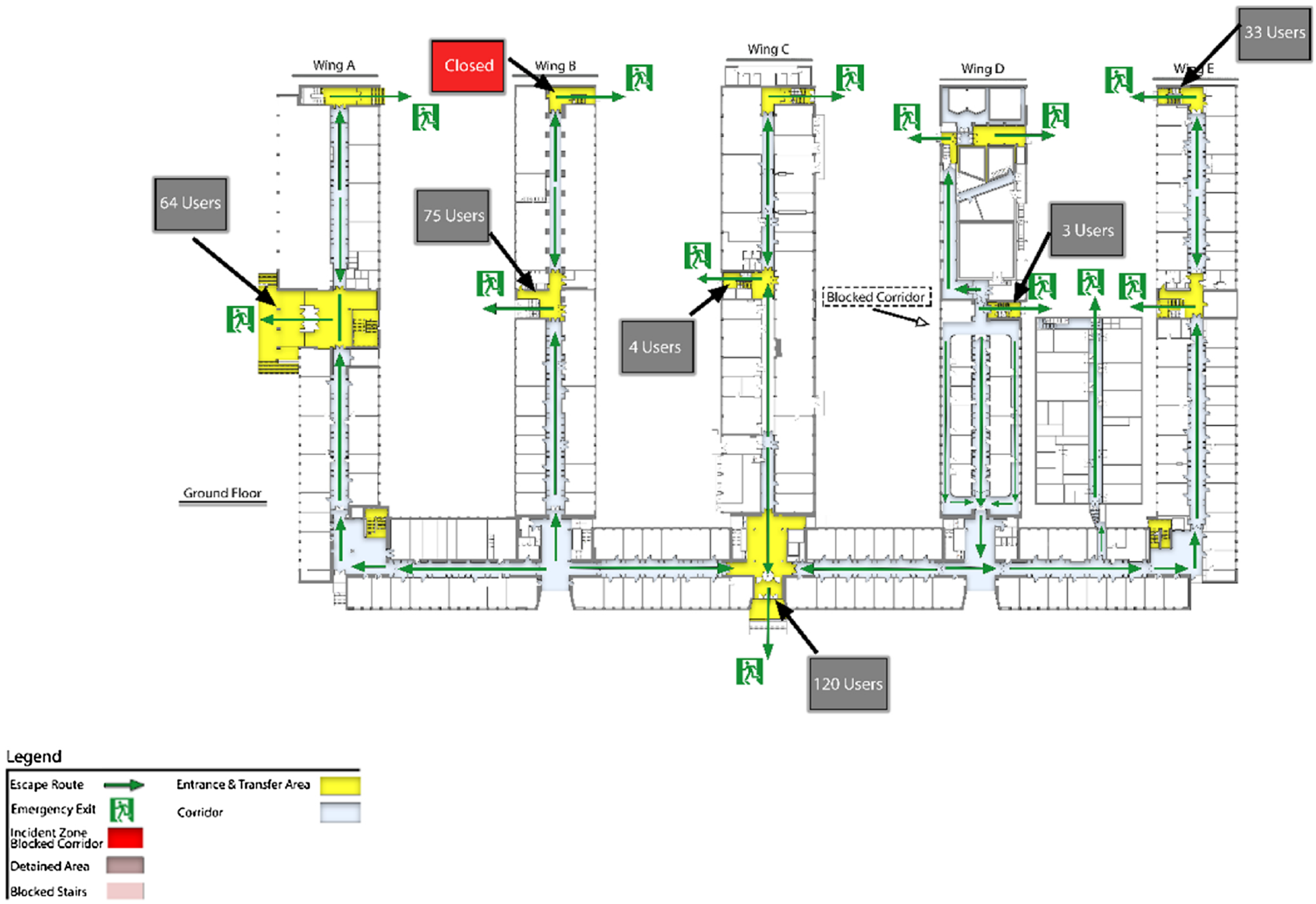


Fig. 6. 2D floor plans represents the number of users that escape from the building.

populate the database from the technical model of LADM-IndoorGML and the 3D model. The first step was to import the technical model (SQL DDL) directly to the Postgres. All the tables that are related to the conceptual model have been created and populated manually. The second step was to import the textual information of the 3D model to the database, and that has been done by using Open Database Connectivity (ODBC) to link between Postgres and Revit software. The schedule that has all the information about the spaces was imported to the database in an automated way. The 3D geometry of the 3D model was imported into the database in the third step by converting the 3D

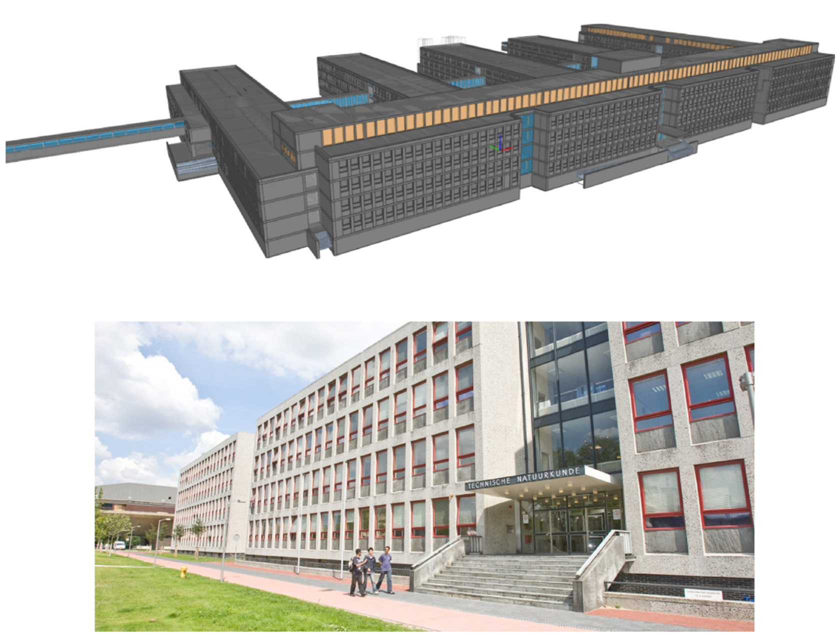


Fig. 7. A 3D model of Faculty of Applied Sciences (upper) and real picture of the entrance (bottom) (Applied Sciences, 2016).

	A	B	C	D	E	F	G	H
1	Client Username	Client MAC Address	Association Time	AP Name	Map Location	Session Duration	SNR	RSSI
2	2OwujnM8CCuhOYC/C+V9lkzlYXUWTtjN7XQXqBkDDag=	/KAwXVQDBTfm62e7ownm1/X1PTHxySqMcXfEq/469L0=	Wed Jul 11 10:42:49 CEST 2018	A-22-0-002	System Campus > 22-TNW-TN > Kelder	1hrs21min 44sec	32	-63
3	2OwujnM8CCuhOYC/C+V9lkzlYXUWTtjN7XQXqBkDDag=	/KAwXVQDBTfm62e7ownm1/X1PTHxySqMcXfEq/469L0=	Wed Jul 11 14:32:14 CEST 2018	A-22-0-002	System Campus > 22-TNW-TN > Kelder	1hrs36min 47sec	14	-82
4	QwQBHLfkHTNeHMItzCp9MMn6vaBtTCbVWcHTBgwFxoA=	sUhVoxVsz5MUCGO9FuNSF5gcPRtkamiiOgzAVhO5iaA=	Wed Jul 11 14:37:19 CEST 2018	A-22-0-002	System Campus > 22-TNW-TN > Kelder	1hrs31min 40sec	29	-70
5	QwQBHLfkHTNeHMItzCp9MMn6vaBtTCbVWcHTBgwFxoA=	sUhVoxVsz5MUCGO9FuNSF5gcPRtkamiiOgzAVhO5iaA=	Wed Jul 11 16:24:20 CEST 2018	A-22-0-002	System Campus > 22-TNW-TN > Kelder	5min 3sec	44	-52
6	QwQBHLfkHTNeHMItzCp9MMn6vaBtTCbVWcHTBgwFxoA=	sUhVoxVsz5MUCGO9FuNSF5gcPRtkamiiOgzAVhO5iaA=	Wed Jul 11 17:40:12 CEST 2018	A-22-0-002	System Campus > 22-TNW-TN > Kelder	40min 34sec	26	-72
7	4jTkOldiJUtbFG61b9nZBkd87laG09RPUFI2o1tiZT4=	x8y50/NQDdPkx3H5e9/gKJG+rd15usQDETpnEosdBTE=	Wed Jul 11 14:11:55 CEST 2018	A-22-0-002	System Campus > 22-TNW-TN > Kelder	5min 3sec	33	-65
8	4jTkOldiJUtbFG61b9nZBkd87laG09RPUFI2o1tiZT4=	x8y50/NQDdPkx3H5e9/gKJG+rd15usQDETpnEosdBTE=	Wed Jul 11 14:16:59 CEST 2018	A-22-0-002	System Campus > 22-TNW-TN > Kelder	15min 14sec	31	-67
9	4jTkOldiJUtbFG61b9nZBkd87laG09RPUFI2o1tiZT4=	x8y50/NQDdPkx3H5e9/gKJG+rd15usQDETpnEosdBTE=	Wed Jul 11 14:32:15 CEST 2018	A-22-0-002	System Campus > 22-TNW-TN > Kelder	5min 3sec	33	-61
10	4jTkOldiJUtbFG61b9nZBkd87laG09RPUFI2o1tiZT4=	x8y50/NQDdPkx3H5e9/gKJG+rd15usQDETpnEosdBTE=	Wed Jul 11 14:57:40 CEST 2018	A-22-0-002	System Campus > 22-TNW-TN > Kelder	25min 21sec	42	-54
11	4jTkOldiJUtbFG61b9nZBkd87laG09RPUFI2o1tiZT4=	x8y50/NQDdPkx3H5e9/gKJG+rd15usQDETpnEosdBTE=	Wed Jul 11 15:23:01 CEST 2018	A-22-0-002	System Campus > 22-TNW-TN > Kelder	20min 17sec	35	-63
12	4jTkOldiJUtbFG61b9nZBkd87laG09RPUFI2o1tiZT4=	x8y50/NQDdPkx3H5e9/gKJG+rd15usQDETpnEosdBTE=	Wed Jul 11 15:43:20 CEST 2018	A-22-0-002	System Campus > 22-TNW-TN > Kelder	10min 7sec	36	-58
13	4jTkOldiJUtbFG61b9nZBkd87laG09RPUFI2o1tiZT4=	x8y50/NQDdPkx3H5e9/gKJG+rd15usQDETpnEosdBTE=	Wed Jul 11 16:19:16 CEST 2018	A-22-0-002	System Campus > 22-TNW-TN > Kelder	15min 10sec	44	-53
14	4jTkOldiJUtbFG61b9nZBkd87laG09RPUFI2o1tiZT4=	x8y50/NQDdPkx3H5e9/gKJG+rd15usQDETpnEosdBTE=	Wed Jul 11 16:34:28 CEST 2018	A-22-0-002	System Campus > 22-TNW-TN > Kelder	5min 3sec	24	-74

Fig. 8. the users logging data for During evacuation exercise.

Table 1
Description of the log data.

Column title	Description
Client Username	A unique ID for each user and could be repeated more than once in the same data
Client MAC Address	A unique ID for each device and could not be repeated in the same data
Association Time	The time and date for each data log
AP Name	The name of Wi-Fi access point
Map Location	The location of Wi-Fi access point for example Building 22
Session Duration	The Session Duration describe the connection time for each device to specific access point
SNR	The signal to noise ratio
RSSI	The received signal strength indicator

spaces into IFC model. Consequently, the IFC model was imported to the database by using in-house software. The 3D geometry was linked to the semantic information, schedules, and all other properties in the database by the unique geometry ID. Afterward, the data has been reorganized according to the spatial schema of LADM-IndoorGML using SQL queries. Fig. 12 shows the table in Postgres that contain information about the function of the spaces and the 3D geometries.

A number of queries was performed to illustrate how the DBMS can be used. For example, Fig. 13 shows the spaces that are accessible for student and staff.

By having the Excel sheets for the Wi-Fi Log data and the XYZ coordinates for all Wi-Fi access points, the tables were created in the LADM-IndoorGML database in PostgreSQL. The XYZ coordinates table were used to convert the position of each Wi-Fi access point into geometry as shown in Fig. 14 by using the following query:

create table pointgeom

as select ST_MakePoint(x, y, z), ap_name, level

from Wi-Fiaccesspoint;

The Wi-Fi Log data table included records for two days (10-07-2018 and 11-07-2018) while the evacuation exercise was on 11-07-2018 from 15:55:00 to 16:35:00 h. Thus, a new table was created that includes only the records for evacuation exercise period as shown in Fig. 15 by using the following query:

create table userandpointgeomfinal

as select Wi-Fi.client_username, Wi-Fi.ap_name, Wi-Fi.time, Wi-Fipointgeom.level, Wi-Fipointgeom.st_makepoint

from Wi-Fi

inner join Wi-Fipointgeom on Wi-Fi.ap_name = Wi-Fipointgeom.ap_name

where date ='2018-07-11′ and Time between '15:55:00′ and '16:35:00′

order by Wi-Fi.time;

Furthermore, the FME software was used to check if the Wi-Fi access points (geometry) overlap with ifcSpaces of the 3D model of Faculty of Applied Science as shown in Fig. 16.

5. Results

5.1. Identification of individual trajectories

The Wi-Fi log data shows that each user has several records during the evacuation exercise. The way we used this data to analyses the movement is illustrated with two examples.

Example 1. The records have shown that the user X was connected to six different Wi-Fi access points and the time difference between each connection was around five minutes as shown in Fig. 17. The position of the first Wi-Fi Access point was in the Basement level and the time of the record was 16:03:59. The user was on the basement until 16:14:07 and then a new connection record shows that the user moved from the basement to the ground floor, and then the user connection returned to the basement for next 15 min. The last Wi-Fi access point that appeared in the log data for this user was in the basement and very close to the emergency exit. The records show that the user has moved from wing E to Wing B during the evacuation exercise.

The Log data for the user was used to create trajectory line as shown in Fig. 18 by using the following query. The trajectory has been visualized as 3D line in QGIS as shown in Fig. 19.

SELECT ST_MakeLine (ARRAY(SELECT st_makepoint FROM pointgeomuser1 ORDER BY time));

Another single user Y was connected to three different Wi-Fi access points. The first record was at 16:03:58 in the ground floor (in front of the main entrance) and then the user had another record at 16:09:02 in ground floor around the corner of the building between wing A and the main wing of the building as shown in Fig. 20. The last record of the user was in the basement next to the emergency Exit. The log data has been used to create a trajectory line for the movement of the user as shown in Fig. 21.

	A	B	C	D	E	F	G	H	I
1	Client_Username	Client_MAC_Address	Date	Time	AP_Name	Map_Location	Session_Duration	SNR	RSSI
2	2OwujnM8CCuhOYC/C+V9lkzlYXUWTtjN7XQXqBkDDag=	/KAwXVQDBTfm62e7ownm1/X1PTHxySqMcXfEq/469L0=	Jul 11 2018	10:42:49	A-22-0-002	System Campus > 22-TNW-TN > Kelder	1hour21minute 44second	32	-63
3	2OwujnM8CCuhOYC/C+V9lkzlYXUWTtjN7XQXqBkDDag=	/KAwXVQDBTfm62e7ownm1/X1PTHxySqMcXfEq/469L0=	Jul 11 2018	14:32:14	A-22-0-002	System Campus > 22-TNW-TN > Kelder	1hour36minute 47second	14	-82
4	QwQBHLfkHTNeHMItzCp9MMn6vaBtTCbVWcHTBgwFxoA=	sUhVoxVsz5MUCGO9FuNSF5gcPRtkamiiOgzAVhO5iaA=	Jul 11 2018	14:37:19	A-22-0-002	System Campus > 22-TNW-TN > Kelder	1hour31minute 40second	29	-70
5	QwQBHLfkHTNeHMItzCp9MMn6vaBtTCbVWcHTBgwFxoA=	sUhVoxVsz5MUCGO9FuNSF5gcPRtkamiiOgzAVhO5iaA=	Jul 11 2018	16:24:20	A-22-0-002	System Campus > 22-TNW-TN > Kelder	5minute 3second	44	-52
6	QwQBHLfkHTNeHMItzCp9MMn6vaBtTCbVWcHTBgwFxoA=	sUhVoxVsz5MUCGO9FuNSF5gcPRtkamiiOgzAVhO5iaA=	Jul 11 2018	17:40:12	A-22-0-002	System Campus > 22-TNW-TN > Kelder	40minute 34second	26	-72
7	4jTkOldiJUtbFG61b9nZBkd87laG09RPUFI2o1tiZT4=	x8y50/NQDdPkx3H5e9/gKJG+rd15usQDETpnEosdBTE=	Jul 11 2018	14:11:55	A-22-0-002	System Campus > 22-TNW-TN > Kelder	5minute 3second	33	-65
8	4jTkOldiJUtbFG61b9nZBkd87laG09RPUFI2o1tiZT4=	x8y50/NQDdPkx3H5e9/gKJG+rd15usQDETpnEosdBTE=	Jul 11 2018	14:16:59	A-22-0-002	System Campus > 22-TNW-TN > Kelder	15minute 14second	31	-67
9	4jTkOldiJUtbFG61b9nZBkd87laG09RPUFI2o1tiZT4=	x8y50/NQDdPkx3H5e9/gKJG+rd15usQDETpnEosdBTE=	Jul 11 2018	14:32:15	A-22-0-002	System Campus > 22-TNW-TN > Kelder	5minute 3second	33	-61
10	4jTkOldiJUtbFG61b9nZBkd87laG09RPUFI2o1tiZT4=	x8y50/NQDdPkx3H5e9/gKJG+rd15usQDETpnEosdBTE=	Jul 11 2018	14:57:40	A-22-0-002	System Campus > 22-TNW-TN > Kelder	25minute 21second	42	-54
11	4jTkOldiJUtbFG61b9nZBkd87laG09RPUFI2o1tiZT4=	x8y50/NQDdPkx3H5e9/gKJG+rd15usQDETpnEosdBTE=	Jul 11 2018	15:23:01	A-22-0-002	System Campus > 22-TNW-TN > Kelder	20minute 17second	35	-63
12	4jTkOldiJUtbFG61b9nZBkd87laG09RPUFI2o1tiZT4=	x8y50/NQDdPkx3H5e9/gKJG+rd15usQDETpnEosdBTE=	Jul 11 2018	15:43:20	A-22-0-002	System Campus > 22-TNW-TN > Kelder	10minute 7second	36	-58
13	4jTkOldiJUtbFG61b9nZBkd87laG09RPUFI2o1tiZT4=	x8y50/NQDdPkx3H5e9/gKJG+rd15usQDETpnEosdBTE=	Jul 11 2018	16:19:16	A-22-0-002	System Campus > 22-TNW-TN > Kelder	15minute 10second	44	-53
14	4jTkOldiJUtbFG61b9nZBkd87laG09RPUFI2o1tiZT4=	x8y50/NQDdPkx3H5e9/gKJG+rd15usQDETpnEosdBTE=	Jul 11 2018	16:34:28	A-22-0-002	System Campus > 22-TNW-TN > Kelder	5minute 3second	24	-74
15	4jTkOldiJUtbFG61b9nZBkd87laG09RPUFI2o1tiZT4=	x8y50/NQDdPkx3H5e9/gKJG+rd15usQDETpnEosdBTE=	Jul 11 2018	16:39:32	A-22-0-002	System Campus > 22-TNW-TN > Kelder	20minute 14second	27	-70
16	4jTkOldiJUtbFG61b9nZBkd87laG09RPUFI2o1tiZT4=	x8y50/NQDdPkx3H5e9/gKJG+rd15usQDETpnEosdBTE=	Jul 11 2018	16:59:47	A-22-0-002	System Campus > 22-TNW-TN > Kelder	15minute 9second	33	-65

Fig. 9. The replacement of the Association Time column with two separate columns as Date and Time.

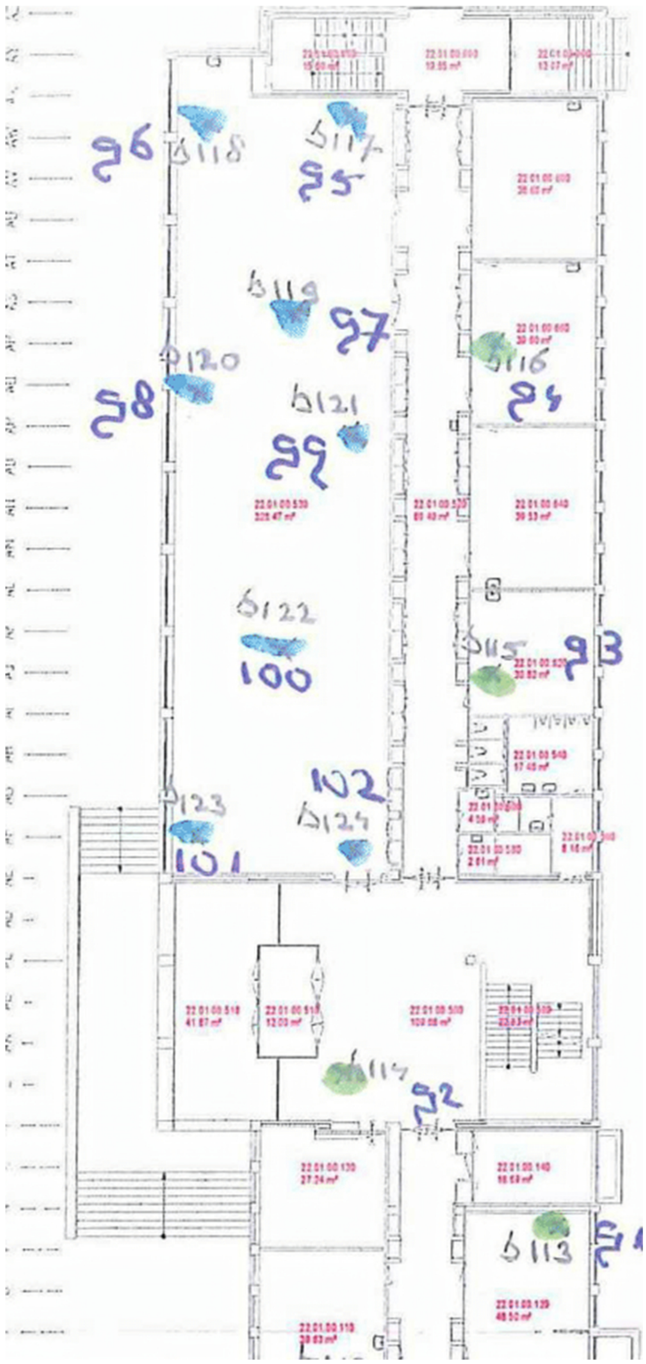


Fig. 10. Part of the paper map of Wi-Fi access point locations.

5.2. Visualization of movements

The visualization of trajectories is important, but it is confusing when too many people have to be monitored. Therefore, we have explored another approach, in which the Wi-Fi log data are analyzed per access point and not per induvial user. We count the number of devices that are connected to each Wi-Fi access point during the interval of five minutes. The time of the evacuation exercise has been divided into eight periods, and there will be a separate snapshot for each period that describes the movements as a group of users during the time of the evacuation exercise as shown in Fig. 22. All the records are subdivided into eight time-frames and explained below:

The first time-frame is between 15:55:00 and 16:00:00 hours and the total number of devices is 105. The second floor and ground floor had the highest number of connected devices, while the basement and fourth floor had the lowest as shown in Table 4. The Wi-Fi access points have been classified into four groups based on the number of devices that were connected to each Wi-Fi access point as shown in Table 2. The distribution of the four groups has shown that most of the activity was on the ground floor, second floor, and third floor. Several Wi-Fi access points that had between two and four connected devices as shown in Fig. 22a.

The Second time-frame is between 16:00:00 and 16:05:00 hours and the total number of devices is 102.

Table 4 shows the number of devices that were connected to the Wi-Fi network based on the floor level, and the largest number of connected devices were in second, ground and first floors. The Wi-Fi access points have been classified into three groups as shown in Table 2. The Wi-Fi access points that had three connected devices were on the third floor. While the rest of the Wi-Fi access points of the second time frame had between one and two connected devices and these Wi-Fi access points were all over the building as shown in Fig. 22b.

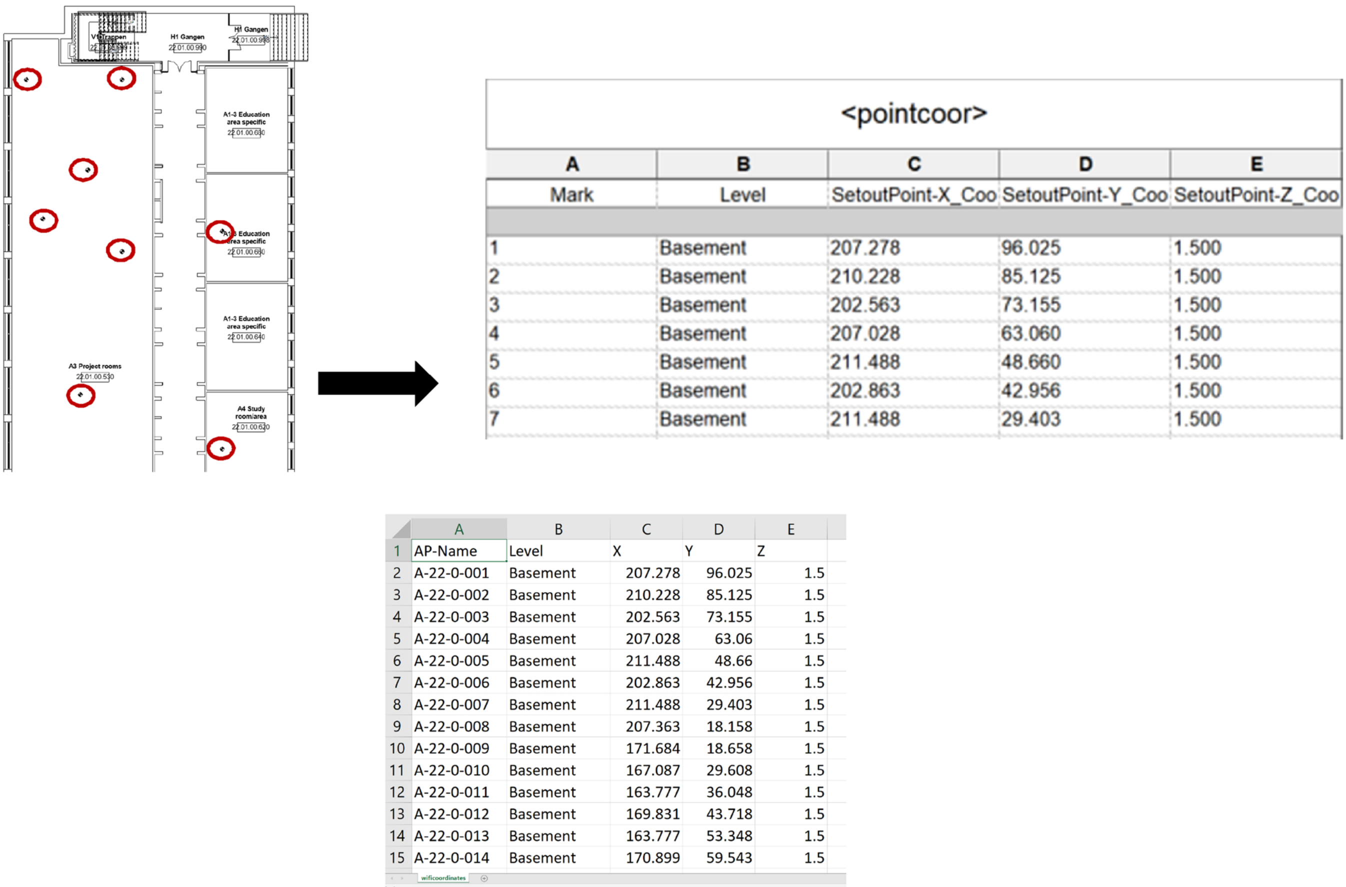
The third time-frame is between 16:05:00 and 16:10:00 hours and the total number of devices is 224.

The highest number of devices that were connected to the Wi-Fi network of the second floor. The ground, first, and second floors contained almost all the connected devices as shown in Table 4. The Wi-Fi access points have been classified into ten groups as shown in Table 2. The second floor of the main building had two Wi-Fi access points that had 11 and 25 connected devices in the third time frame. While the first and second floor of wing A had two Wi-Fi access point that had 12 and 13 connected devices. Furthermore, the ground floor of wing A had one Wi-Fi access points that had six connected devices. The rest of the Wi-Fi access points in this time frame had between one and five connected devices and they were distributed all over the building as shown in Fig. 22c.

The fourth time-frame is between 16:10:00 and 16:15:00 hours and the total number of devices is 133. The number of devices that were connected to the Wi-Fi network in ground floor was the second highest number after the second floor as shown in Table 4. The Wi-Fi access points have been classified into seven groups based on the number of devices that were connected to each access point as shown in Table 2. the Wi-Fi access points that were on the second floor had the most significant number of connected devices between 2 and 11 devices. At the same time, the Wi-Fi access points of the ground floor had up to eight connected devices. The Wi-Fi access points on the first floor had no more than four connected devices. The rest of the Wi-Fi access points had between one and three connected devices as shown in Fig. 22d.

The Fifth time-frame is between 16:15:00 and 16:20:00 hours and the total number of devices is 238. The Ground floor had the largest number of connected devices as shown in Table 4. The Wi-Fi access points have been classified into six groups based on the number of devices that were connected to each access point as shown in Table 3. The Wi-Fi access points of the ground floor had between one and seven connected devices while the Wi-Fi access point of the first floor had up to five connected devices. The rest of Wi-Fi access points of this time frame had between one and three connected devices as shown in Fig. 22e.

The Sixth time-frame is between 16:20:00 and 16:25:00 hours and the total number of devices was 154. Table 4 shows the number of devices that were connected to the Wi-Fi network in the first floor was the highest in this time frame. Then, the second and the ground floors contained two large groups of devices. The Wi-Fi access points have been classified into five groups based on the number of devices that were connected to each access point as shown in Table 3. The first floor of wing B had Wi-Fi access points that had between two and five connected devices. On the other hand, the ground floor of the main building and wing E had Wi-Fi access points that had between two and four connected devices. The rest of the levels had Wi-Fi access points that had between one and three connected devices as shown in Fig. 22f.

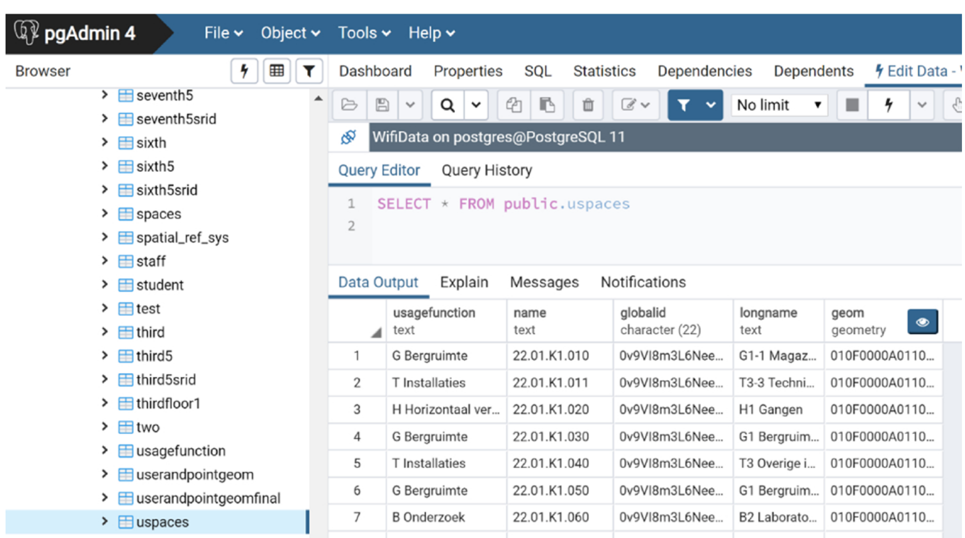


<pointcoor>

A	B	C	D	E
Mark	Level	SetoutPoint-X_Coo	SetoutPoint-Y_Coo	SetoutPoint-Z_Coo
1	Basement	207.278	96.025	1.500
2	Basement	210.228	85.125	1.500
3	Basement	202.563	73.155	1.500
4	Basement	207.028	63.060	1.500
5	Basement	211.488	48.660	1.500
6	Basement	202.863	42.956	1.500
7	Basement	211.488	29.403	1.500

	A	B	C	D	E
1	AP-Name	Level	X	Y	Z
2	A-22-0-001	Basement	207.278	96.025	1.5
3	A-22-0-002	Basement	210.228	85.125	1.5
4	A-22-0-003	Basement	202.563	73.155	1.5
5	A-22-0-004	Basement	207.028	63.06	1.5
6	A-22-0-005	Basement	211.488	48.66	1.5
7	A-22-0-006	Basement	202.863	42.956	1.5
8	A-22-0-007	Basement	211.488	29.403	1.5
9	A-22-0-008	Basement	207.363	18.158	1.5
10	A-22-0-009	Basement	171.684	18.658	1.5
11	A-22-0-010	Basement	167.087	29.608	1.5
12	A-22-0-011	Basement	163.777	36.048	1.5
13	A-22-0-012	Basement	169.831	43.718	1.5
14	A-22-0-013	Basement	163.777	53.348	1.5
15	A-22-0-014	Basement	170.899	59.543	1.5

Fig. 11. Shows the coordinates of the Wi-Fi access points from Revit to excel sheet.



	usagefunction text	name text	globalid character (22)	longname text	geom geometry
1	G Bergruimte	22.01.K1.010	0v9VI8m3L6Nee...	G1-1 Magaz...	010F0000A0110...
2	T Installaties	22.01.K1.011	0v9VI8m3L6Nee...	T3-3 Techni...	010F0000A0110...
3	H Horizontaal ver...	22.01.K1.020	0v9VI8m3L6Nee...	H1 Gangen	010F0000A0110...
4	G Bergruimte	22.01.K1.030	0v9VI8m3L6Nee...	G1 Bergruim...	010F0000A0110...
5	T Installaties	22.01.K1.040	0v9VI8m3L6Nee...	T3 Overige i...	010F0000A0110...
6	G Bergruimte	22.01.K1.050	0v9VI8m3L6Nee...	G1 Bergruim...	010F0000A0110...
7	B Onderzoek	22.01.K1.060	0v9VI8m3L6Nee...	B2 Laborato...	010F0000A0110...

Fig. 12. Part of the LADM-IndoorGML schema.

The seventh time-frame is between 16:25:00 and 16:30:00 hours and the total number of devices was 98. Table 4 shows the number of devices that were connected to the Wi-Fi network in the ground floor. The Wi-Fi access points have been classified into four groups based on the number of devices that were connected to each access point as shown in Table 3. The Second and third floors had one Wi-Fi access points that had for connected devices while the rest of the levels of the building had Wi-Fi access points that had between one and three connected devices as shown in Fig. 22g.

The eighth time-frame is between 16:30:00 and 16:35:00 hours and the total number of devices was 83. Table 4 shows the number of devices that were connected to the Wi-Fi network based on the floor level. The Wi-Fi access points have been classified into three groups based on the number of devices that were connected to each access point as shown in Table 3. The second and third floor had one Wi-Fi access points that had between one and three connected devices. On the other hand, the rest of the floors had Wi-Fi access points that had between one and two connected devices as shown in Fig. 22h.

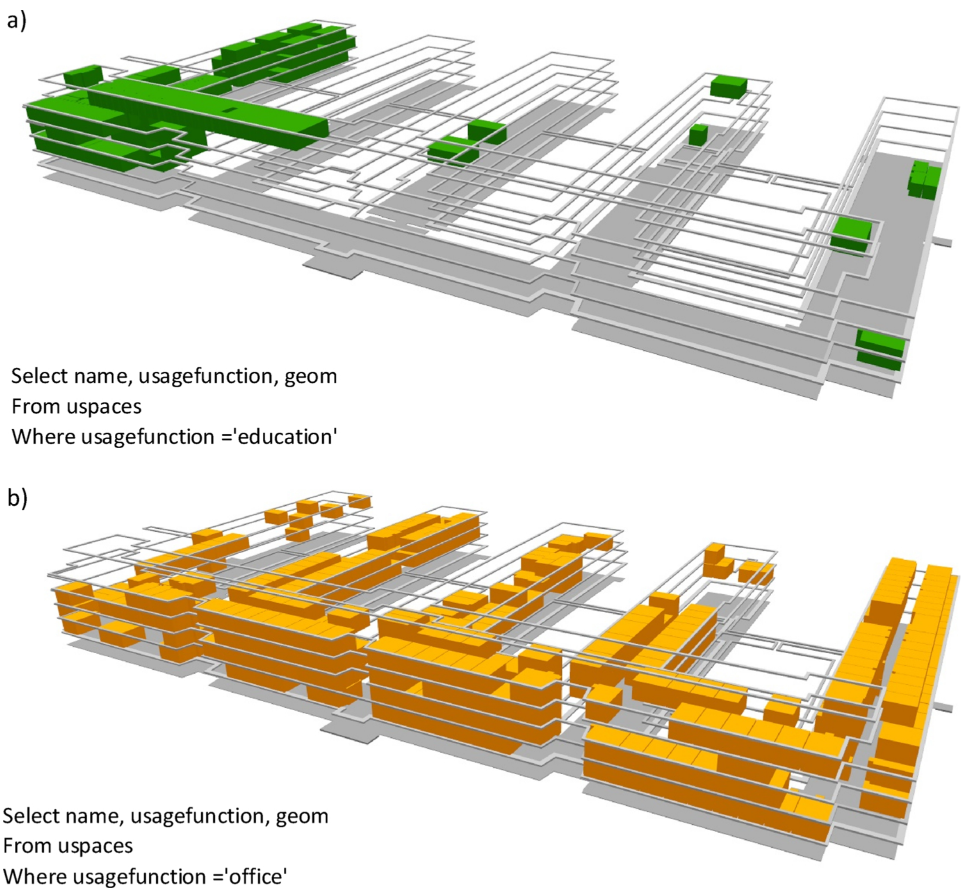


Fig. 13. Accessible spaces for a) student and b) staff.

	ap_name character varying	level character varying	st_makepoint geometry
1	A-22-0-001	Basement	0101000080378941 60E5E869409A99999990158400...
2	A-22-0-002	Basement	01010000809EEFA7C64B476A4000000000004855400...
3	A-22-0-003	Basement	0101000080BC7493180452694052B81E85EB495240...
4	A-22-0-004	Basement	01010000803789416 0E5E0694048E17A14AE874F400...
5	A-22-0-005	Basement	0101000080560E2DB29D6F6A4014AE47E17A544840...
6	A-22-0-006	Basement	0101000080560E2DB29D5B6940EE7C3F355E7A4540...

Fig. 14. Geometry table of Wi-Fi access points.

	client_username character varying	ap_name character varying	time time without time zone	level character varying	st_makepoint geometry
1	6GBUJheGrGrmS+FI...	A-22-0-132	15:58:32	FirstFloor	0101000080E17A14A...
2	5+QZVR5ucbNjOU04...	A-22-0-131	15:58:32	FirstFloor	0101000080E17A14A...
3	hviqQoOIK5d3H3q/F...	A-22-0-039	15:58:32	GroundFloor	0101000080A01A2F...
4	CDQ9WMKdyjXTwQ...	A-22-0-072	15:58:32	GroundFloor	01010000806891ED7...
5	e5EK0dDBYBKtfBC0...	A-22-0-135	15:58:32	FirstFloor	0101000080A69BC4...
6	oUsges23gml3X/Nw...	A-22-0-238	15:58:32	SecondFloor	0101000080B29DEFA...
7	FJMCKBeXkuoIT2Gu...	A-22-0-230	15:58:32	SecondFloor	01010000807D3F355...

Fig. 15. Log data table for evacuation exercise in PostgreSQL.

5.3. Comparison

During the evacuation exercise, the observers counted the number of users that evacuated from the building. Table 5 shows a comparison between the number of users that had been evacuated based on the observers and based on the Wi-Fi log data. The Wi-Fi access point has been chosen according to the nearest distance to the emergency exit and they are located on the ground floor.

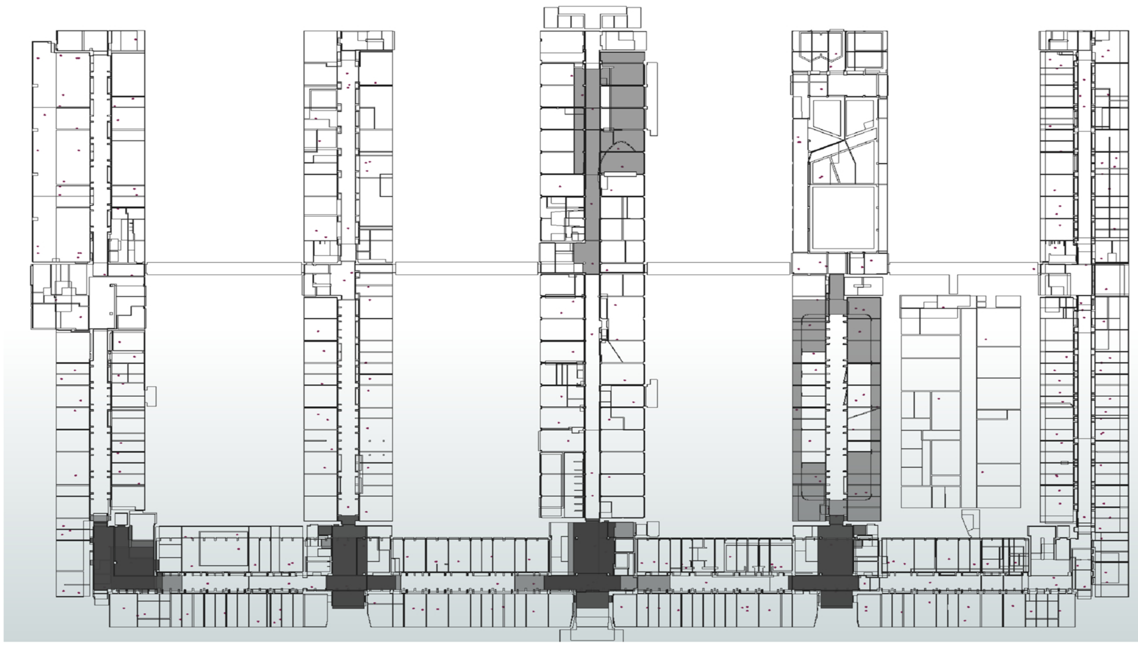


Fig. 16. The overlap between the Wi-Fi access points and the ifcSpaces of the 3D model of Faculty of Applied Science.

	client_username character varying	ap_name character varying	time time without time zone	ap_name character varying	level character varying	st_makepoint geometry
1	LFFQvTIBbkxxwiw1v...	A-22-0-004	16:03:59	A-22-0-004	Basement	01010000803789416...
2	LFFQvTIBbkxxwiw1v...	A-22-0-008	16:09:03	A-22-0-008	Basement	0101000080560E2DB...
3	LFFQvTIBbkxxwiw1v...	A-22-0-046	16:14:08	A-22-0-046	GroundFloor	0101000080F2D24D6...
4	LFFQvTIBbkxxwiw1v...	A-22-0-017	16:19:16	A-22-0-017	Basement	0101000080A69BC4...
5	LFFQvTIBbkxxwiw1v...	A-22-0-021	16:24:20	A-22-0-021	Basement	01010000806891ED7...
6	LFFQvTIBbkxxwiw1v...	A-22-0-023	16:29:24	A-22-0-023	Basement	01010000800C022B8...

Fig. 17. The log records for single user.

	st_makeline geometry
1	010200008006000000037894160E5E0694048E17A14AE874F40000000000000F83F560E2DB29DEB69409CC420B07228324000000000000000F83FF2D24D62106C69406891ED7C3F752C4000000000000012...

Fig. 18. Generating line geometry for movement of single user.

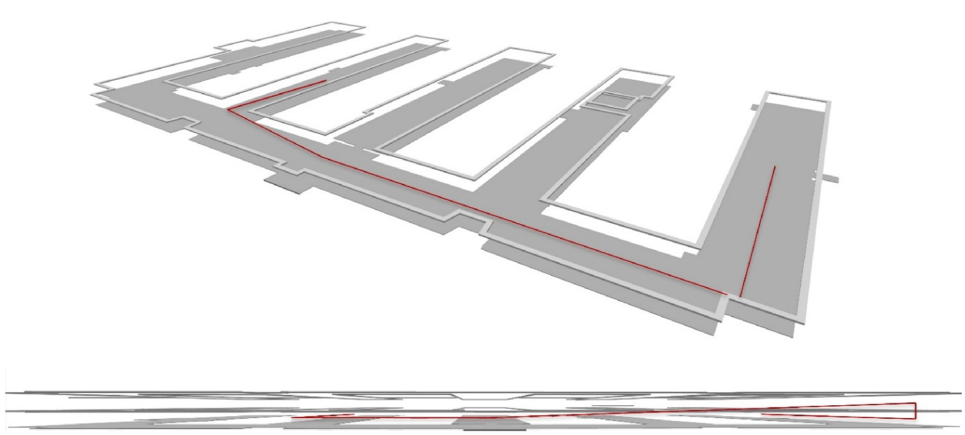


Fig. 19. the trajectory line for single user.

Another way to compare between the observers' records and the log data, and that by taking into consideration the Wi-Fi access points which located above or below (in the vertical direction) of the emergency exit, to reflect the user movements from all levels to the ground floor as shown in Table 6.

The third way of comparing between the number of users that had been evacuated based on the observers and based on the Wi-Fi log data was by including the Wi-Fi access point the located on the vertical and horizontal direction for all exits as shown in Table 7.

	client_username character varying	ap_name character varying	time time without time zone	level character varying	st_makepoint geometry
1	Tvt7wYNA4KLQjUFO...	A-22-0-066	16:03:58	GroundFloor	010100008021B0726...
2	Tvt7wYNA4KLQjUFO...	A-22-0-087	16:09:02	GroundFloor	01010000804C37894...
3	Tvt7wYNA4KLQjUFO...	A-22-0-017	16:19:15	Basement	0101000080A69BC4...

Fig. 20. The log records for single user.

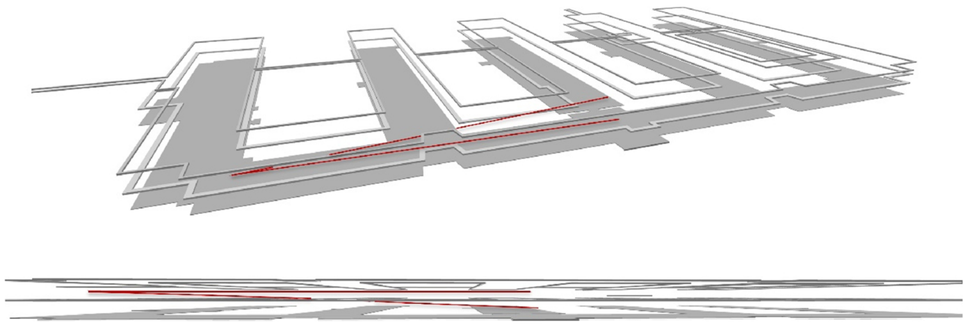


Fig. 21. The trajectory line for single user.

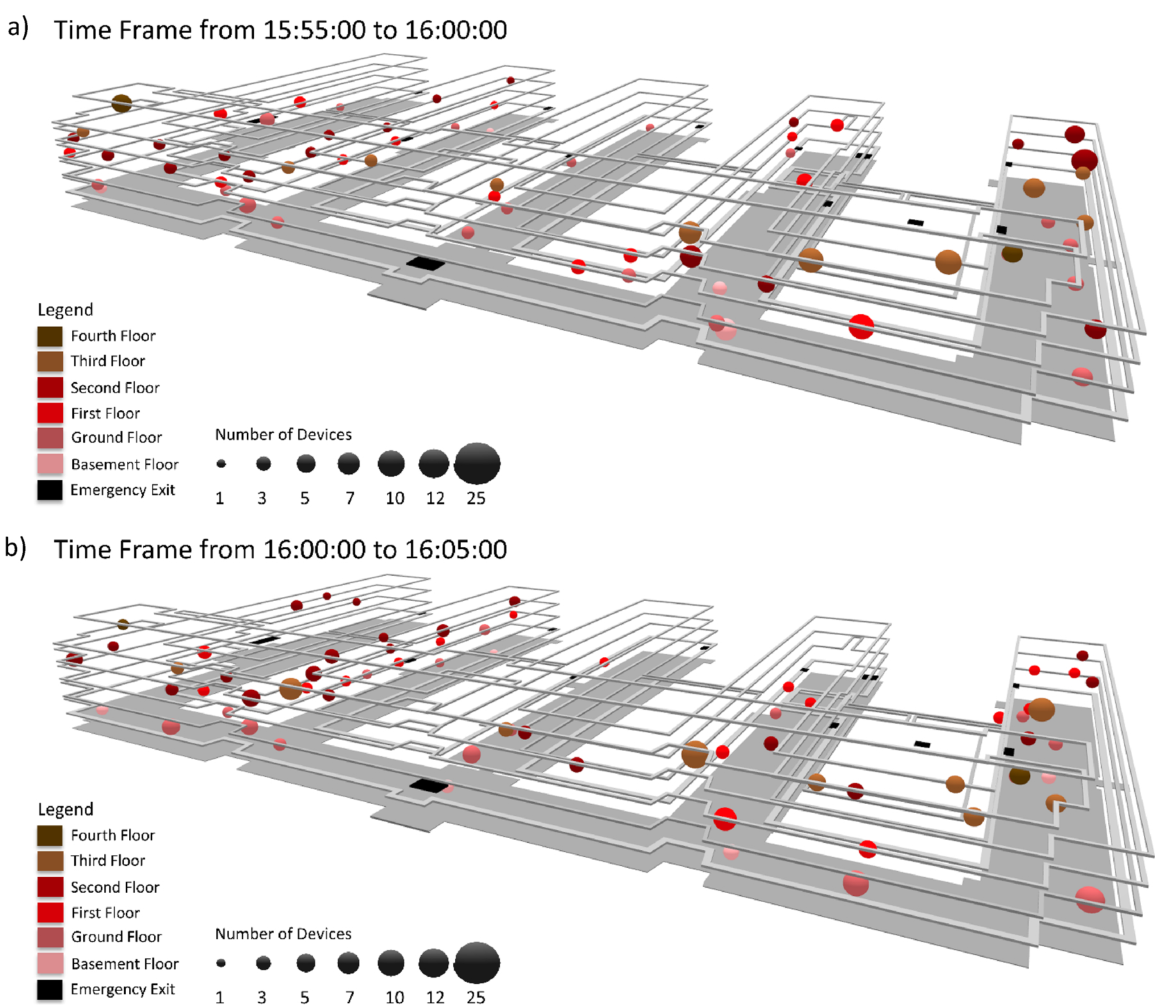


Fig. 22. The eight time-frames that represents the movements of the users as groups.

6. Discussion and conclusion

6.1. Discussion

This paper presents the analysis and visualization of the Wi-Fi log data using the extended LADM-IndoorGML model to support the ERT and the users during an incident. The Integrated LADM-IndoorGML model, defining Rights, Restrictions, and Responsibilities, is extended to cover different times: normal operational time / office hours, outside office hours and crisis situation, and include data of importance for ERT. This type of information is essential to ERT to be able to evacuate the users of the building and to study the movement of the users during

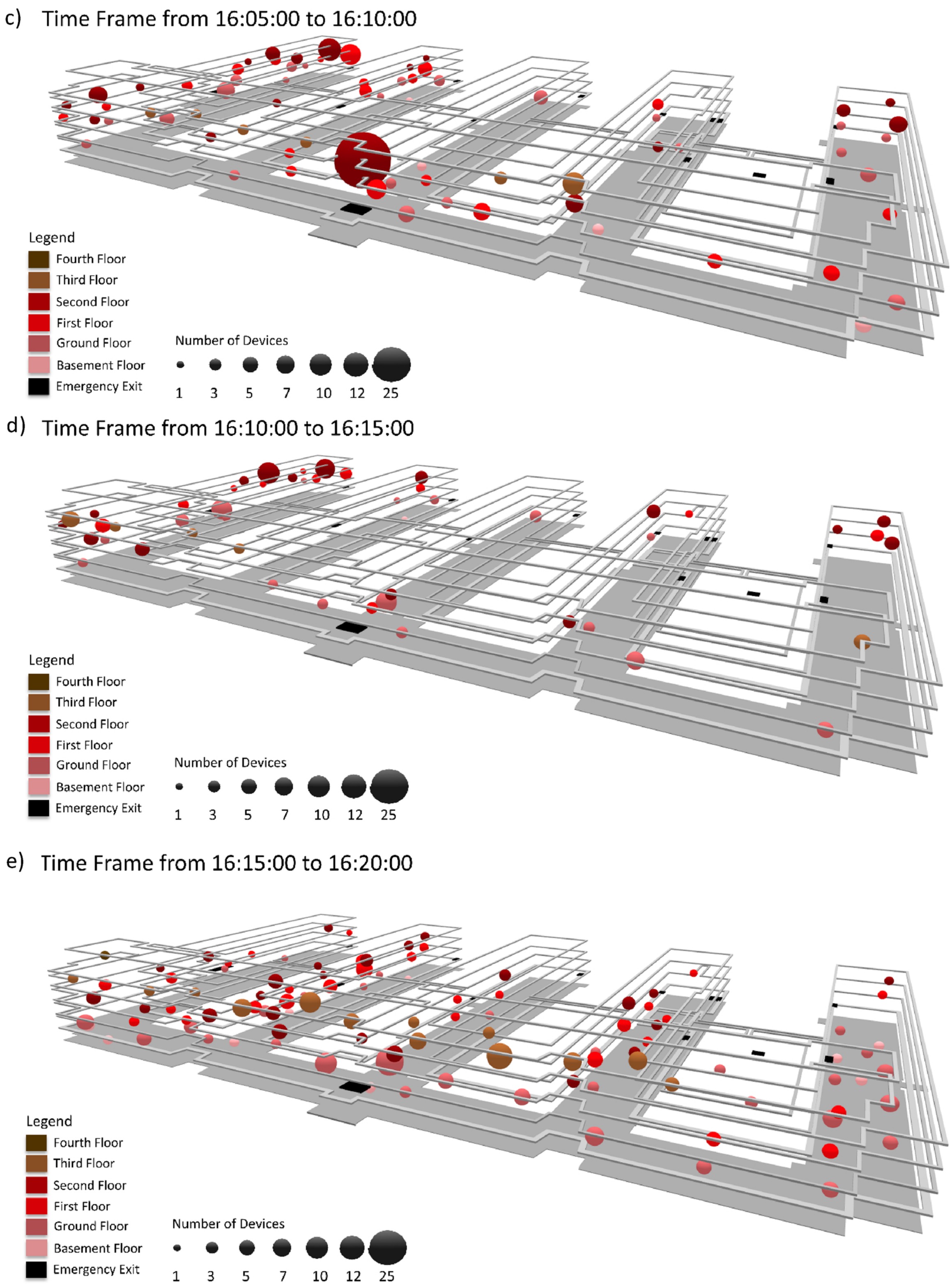


Fig. 22. (*continued*)

the incident. Furthermore, by indicating and visualizing which areas are considered as restricted or accessible, the ERT can deal with the incident in more efficient way. Out study clearly shows that the 2D representation of the indoor environments does not provide the entire picture of the indoor spaces and important details such as construction elements. The hypothesis that 3D representations (and route computations) result is better/ faster for evacuation is confirmed.

Each type of buildings has a complex indoor environment and several types of users. The user behavior is changing based on the type of building and the condition of the indoor space, such as during an incident. By understanding the movement of the users of these indoor environments during an emergency, we are able to provide better navigation routes for different types of users and during different kind of indoor conditions.

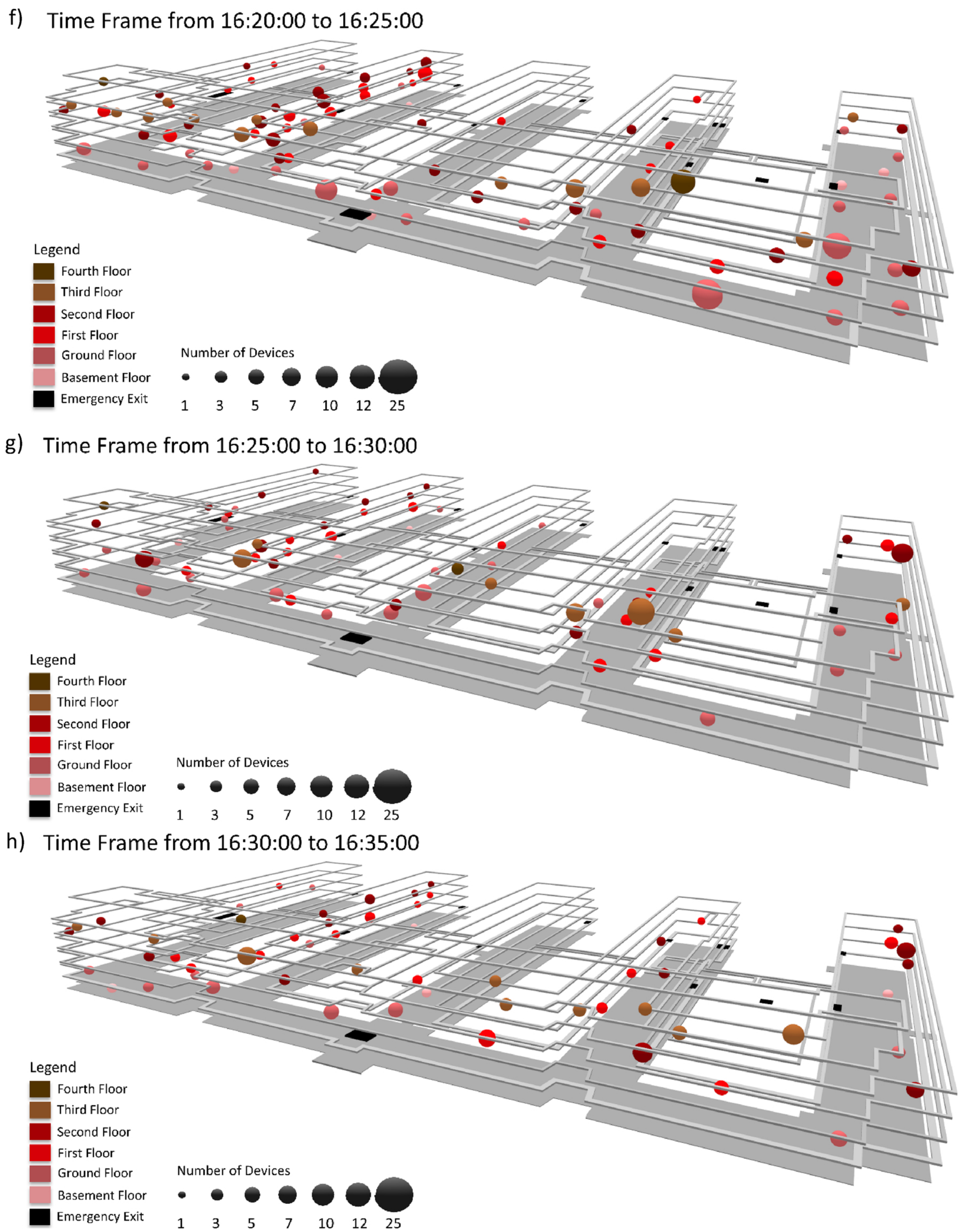


Fig. 22. (*continued*)

The study consisted of stages to define rights, restrictions, and responsibilities during an incident. The work started by converting the conceptual model of LADM-IndoorGML to a technical model. Then a database in PostgreSQL was created and populated by using real data that has been collected during an evacuation exercise. 2D and 3D floor plans were prepared to support the ERT and the users during the exercise. The WiFi data that was collected during the exercise, was used to analyze and visualize the movements of the users. For this purpose, the locations of the Wi-Fi access points were digitized manually in Revit and imported automatically to the database. The representation of access points in the 3D model allowed to record the relationship between the building elements and the movements of the users.

There were two different types of analysis and visualization that have been covered, 1) following individual users and 2) monitoring the number of users attached to one Wi-Fi access point. The representation of individual user movements has shown that a new record was available every five minutes and that is a long time for a walking person even in a normal day. This period of time is enough for users to move to the other side of the building and return to the same position. The first example showing induvial movement demonstrates that the user has all

Table 2
The number of Wi-Fi access points and their connected devices in the first, second, third, and fourth time frames.

Time-frame number	Group number	Number of Wi-Fi Access points	Number of connected Devices
First	1	68	1
	2	12	2
	3	3	3
	4	1	4
Second	1	59	1
	2	17	2
	3	3	3
Third	1	56	1
	2	15	2
	3	14	3
	4	2	4
	5	3	5
	6	2	6
	7	1	11
	8	1	12
	9	1	13
	10	1	25
Fourth	1	32	1
	2	14	2
	3	8	3
	4	5	4
	5	1	8
	6	1	10
	7	1	11

Table 3
The number of Wi-Fi access points and their connected devices in the fifth, sixth, seventh, and eighth time frames.

Time-frame number	Group number	Number of Wi-Fi Access points	Number of connected Devices
Fifth	1	110	1
	2	38	2
	3	8	3
	4	4	4
	5	1	5
	6	1	7
Sixth	1	84	1
	2	20	2
	3	3	3
	4	4	4
	5	1	5
Seventh	1	63	1
	2	9	2
	3	3	3
	4	2	4
Eighth	1	59	1
	2	9	2
	3	2	3

the Wi-Fi records in the basement except one record that is in the ground floor. This gives an impression that the user moved from the basement floor to the ground and then returned to the basement. However, the user might have been walking only in the basement and escape from the building by using the emergency exit that located on the same floor.

The representation of the users' movement as a group illustrated the flow of the users' movement. Therefore, the time of the emergency exercise was divided into eight time-frames, where each time frame represents the Wi-Fi access points based on the number of connected devices. The order of the time frames showed that at the beginning of the evacuation exercise, the users were distributed almost all over the building. Then, the third time frame showed that the number of users was increased in the ground, first, and second floors. The second floors had the highest number of devices. In the next time frame, Wi-Fi log data showed that there was significant increase in the movements of the users. Next, the movements of the users was mostly detected on the ground floor. This means the users of the building have moved from different spaces and levels to the ground floor. In the next time frame, the first floor contained the highest number of users; however; the difference between the number of connected devices was not that significant. The last time frame showed that the number of connected devices was almost the same in the ground, first, second, and third

Table 5
A comparison between the number of users that had been evacuated based on the reporting of the observers and based on the Wi-Fi log data.

Wing	Based on observers	Based on Wi-Fi log data	Wi-Fi access point
Main	120	29	A-22-0-066
A	64	24	A-22-0-092
B	75	3	A-22-0-080
C	4	1	A-22-0-070
D	3	1	A-22-0-058
E	33	2	A-22-0-035

Table 6
A comparison between the number of users that had been evacuated based on the observers and based on the Wi-Fi log data by considering the Wi-Fi access point in the vertical direction.

Wing	Based on observers	Based on Wi-Fi log data
Main	120	83
A	64	30
B	75	24
C	4	4
D	3	5
E	33	22

Table 7
A comparison between the number of users that had been evacuated based on the observers and based on the Wi-Fi log data by considering the Wi-Fi access point in the vertical and horizontal direction.

Wing	Based on observers	Based on Wi-Fi log data
Main	120	130
A	64	70
B	75	82
C	4	9
D	3	11
E	33	34

Table 4
Number of connected devices during the entire time of the evacuation.

Level	T-F one	T-F two	T-F three	T-F four	T-F fife	T-F six	T-F seven	T-F eight
Basement	5	5	5	1	14	7	3	4
Ground	27	25	53	40	72	37	32	19
First	23	20	67	26	66	41	22	20
Second	28	33	90	59	49	38	24	22
Third	17	116	9	7	36	25	14	17
Fourth	5	3	0	0	1	6	3	1

floors and a large number of devices has evacuated from the building.

The study has shown that by determining the location of the Wi-Fi access point, the representation of the user's movements is possible as an individual or group of users based on the location of the Wi-Fi access point. The visualization of each Wi-Fi access point as a sphere aims to reflect the number of connected devices by changing the size of the sphere. Although the study could not provide a very accurate trajectory of movement, it indicated quite well which spaces contained more connected devices than other spaces. Eventually, this was used to study the users' movements flow.

The comparison between the number of users that were evacuated based on the reporting of the observers and based on the Wi-Fi log data showed that the best match is achieved by considering WiFi access points near to the exit point in both vertical and horizontal direction.

The study revealed a few shortages within the provided WiFi data. The time resolution of the Wi-Fi log data, i.e. that a new record was available every five minutes, is a critical issue. Furthermore, the Wi-Fi data did not include any information about the type of user such as student, employee, etc. because of the privacy issues, and that did not allow to visualize the movements based on their RRR.

6.2. Conclusion

A large part of this research is dedicated to the development and testing of LADM-IndoorGML for emergency exercise evacuation in an educational building. Several important issues have been investigated, successfully implemented and tested, namely extension of LADM-IndoorGML for emergency management, model-driven approach to create a database schema, import of BIM data (semantics, attributes and geometry), Wi-Fi log data structuring and analysis. The research has shown that many of the steps can be automated. All BIM attribute and geometry data could be imported automatically: the attribute data via direct connection from Revit and the geometry via in-house software. Most of the tables of the LADM-IndoorGML schema have been also populated in an automated way, except the tables that are related to LADM and specifically the access rights during the crisis. This process can be readily applied for any building with available BIM model.

The LADM-IndoorGML has been tested in real evacuation emergency exercise. It has clearly shown that all the needed information available in the extended model can serve evacuation purposes and support the decision process in educational building. However, further tests with different types of buildings might be needed to verify the model. As it is visible from the UML, many of the attributes are defined as code list, which is good basis for extension of the model for different types of buildings.

6.3. Future work

Future research will concentrate on other type of sensors to detect the users' movement in the indoor environment based on their RRRs. Several types of buildings will be covered such as residential, shopping malls, and healthcare buildings, and during different indoor conditions such as normal operational time / office hours, outside office hours, and crisis situation. In addition, future work will focus on the development of a web user interface for interactive 3D visualizations within a web browser. Two web applications will be considered: maintenance and navigation (on a mobile device). The web user interface will be utilized to investigate the relationship between the indoor spaces and the users to determine the rights of use for the indoor spaces. Moreover, the subdivision of the indoor space will be studied to assess the accessibility of the indoor spaces based on the rights, restrictions, and responsibilities (RRRs). Furthermore, several type of building will be cover in our future work such as commercial, residential, and healthcare buildings to study and define the RRR for each type of building.

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