World Academy of Science, Engineering and Technology
International Journal of Civil and Architectural Engineering
Vol:15, No:1, 2021

Prioritizing the Most Important Information from Contractors' BIM Handover for Firefighters' Responsibilities

Akram Mahdaviparsa, Tamera McCuen, Vahideh Karimimansoob

Abstract**—**Fire service is responsible for protecting life, assets, and natural resources from fire and other hazardous incidents. Search and rescue in unfamiliar buildings is a vital part of firefighters' responsibilities. Providing firefighters with precise building information in an easy-to-understand format is a potential solution for mitigating the negative consequences of fire hazards. The negative effect of insufficient knowledge about a building's indoor environment impedes firefighters' capabilities and leads to lost property. A data rich building information modeling (BIM) is a potentially useful source in three-dimensional (3D) visualization and data/information storage for fire emergency response. Therefore, this research's purpose is prioritizing the required information for firefighters from the most important information to the least important. A survey was carried out with firefighters working in the Norman Fire Department to obtain the importance of each building information item. The results show that "the location of exit doors, windows, corridors, elevators, and stairs", "material of building elements", and "building data" are the three most important information specified by firefighters. The results also implied that the 2D model of architectural, structural and way finding is more understandable in comparison with the 3D model, while the 3D model of MEP system could convey more information than the 2D model. Furthermore, color in visualization can help firefighters to understand the building information easier and quicker. Sufficient internal consistency of all responses was proven through developing the Pearson Correlation Matrix and obtaining Cronbach's alpha of 0.916. Therefore, the results of this study are reliable and could be applied to the population.

Keywords**—**BIM, building fire response, ranking, visualization.

I. Introduction

THE basic mission of fire service is closely related to the control of fire risks in the entire community. The fire department plays a vital role in defending communities from fires and other life-threatening situations. According to the National Fire Experience Survey [9], the public fire departments in the U.S. in 2018, responded to 1,318,500 fires, a decrease of 0.075 from 2017. It was announced that an estimated 499,000 were structure fires which were 5% more than the year before (475,500). Fig. 1 shows the number of structure fires with more detail from 1977 to 2018. An estimated $25.6 billion in property damage occurred as a result of fire in 2018, an 11% increase over the $23 billion in 2017 (Fig. 2). These statistics prove that structure fires must be taken more into consideration due to the critical and desperate nature of consequences from this type of fire incident. Firefighters should extinguish the fire in unfamiliar buildings which may lead to a subsequent hazard like trapping in the building. Interior structure firefighting in OSHA (Occupational Safety and Health Administration), also known as the emergency fire response in the building, is the physical firefighting activities and rescue process within the buildings which have caught on fire beyond the initial stage. To make a wise decision, firefighters, especially incident commanders, have to assess the building situation using the available information [23], [33].

When firefighters are heading to the building with the fire incident inside, they may find themselves in need for a large amount of information including collection, analysis, and representation of building and building components [19]. The opportunities to provide firefighters with understandable format of building information is a key-element which can equip them better for the incident location and mitigate the fire hazard. Furthermore, in an emergency response building information accessibility is not efficient and automated [20]. Reference [30] emphasizes that it is vital for firefighters to be aware of the incident environmental situation in a building. They believe that if firefighters are prepared with information about interior spaces, number of building occupants in each space, and other critical information about the facility in advance, their capabilities would increase dramatically. Results from [2] revealed the importance of precise evaluation of an incident and how inappropriate decisions can extend the response time. The study concluded that it is essential that when arriving at an incident the firefighters have actual and reliable information about 1) the building's interior, 2) surrounding neighborhoods and facilities, and 3) quickest routes to the incident location inside the building.

Reference [14] reported the importance of an integrated plan to provide emergency responders with building information, so they have a comprehensive understanding of the indoor and outdoor environment. The study recommended that remote access to building information would improve the first responder's knowledge about the building and thereby enhance safety and minimize injuries and damages. Unfortunately, most of the required facility emergency information is not provided to firefighters until reaching the scene, which causes their decision making to be a complex process to save lives and property [30].

Akram Mahdaviparsa is Graduate Student, University of Oklahoma, Norman, OK, USA (e-mail: mmp@ou.edu).
Tamera McCuen is Professor, University of Oklahoma, Norman, OK, USA
Vahideh Karimimansoob is Graduate Student, University of Texas A &M, College Station, TX, USA.

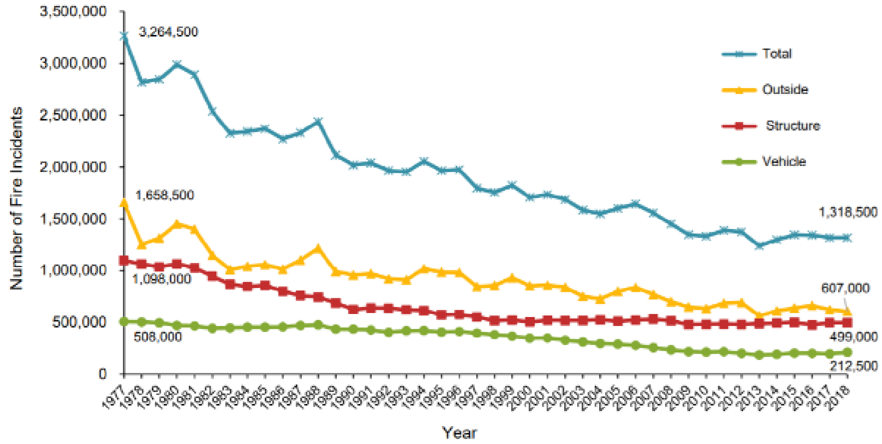

Fig. 1 Fire incidents by type in the US between 1977-2018 [9, p.11]

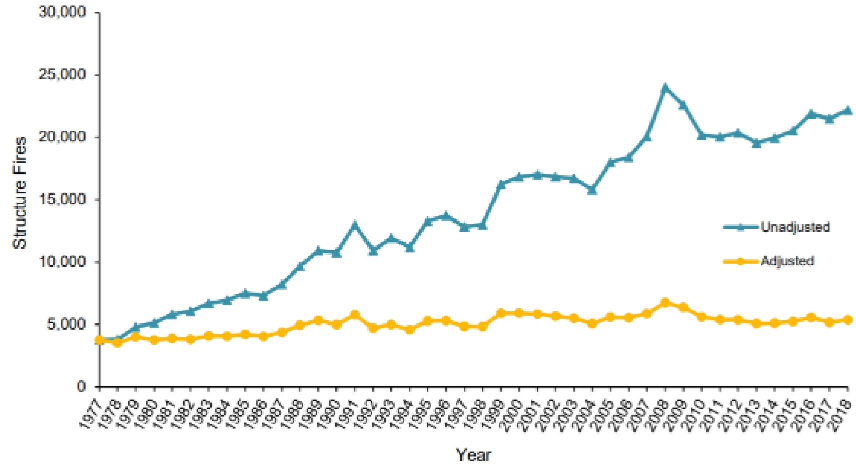

Fig. 2 Average loss per structure fire in the US between 1977-2018 [9, p.16]

Today, the process of fire response management in an outdoor environment is commonly managed through a Geographic Information System (GIS), while a high volume of geometrical and semantic information about buildings needs to be reached by firefighters to help them in managing the overall process [17]. Although the capabilities of GIS have advanced in recent years, it has many deficiencies for analyzing and showing building data. BIM using 3D visualization along with relevant data/information is a practical source for mitigating fire disasters [5], [11]. Reference [22] defined BIM as a repository of information for the building owner (and operator) to use and maintain information throughout the life cycle of a building between all the stakeholders. It will be documented and available from contractors' handover in the operation phase. The detailed information provided in BIM models are used to evaluate life safety and fire protection systems throughout the building life cycle. BIM can represent diverse and comprehensive information dynamically and graphically, making it a powerful tool for data contextualization. BIMs currently provide valuable physical information, which can include dimensions, physical properties, and functional properties. The apparent value of this information has been realized in design and construction, but not so much for use in emergencies [14]. Therefore, this research's purpose is to categorize and prioritize necessary building information for firefighters according to the importance from the most important information to the least important one. The research question is: How do firefighters prioritize information from contractors' BIM handover considering the importance of time in their responsibilities? As a result, the purpose of this study is to better categorize the required building information for firefighters need to save a property (building) when a fire occurs.

A. Building Fire Response

The fire departments of the United States are the first line of defense for citizens in need when a structure fire causes a wildfire to spread or a building to collapse [4]. The "First-In officer" usually has five minutes between dispatching from the fire station and arrival at the fire incident location. The First-In officer must make sure that the route to the fire incident is specified and correct. Furthermore, the officer should start the process of collecting more information about the building which is on fire. Since it is not easy to read the screen of the digital device (laptop, tablet) or hard copy when the fire truck is moving, the information must be simple, readable, and quickly understandable [18]. In addition, [12] mentioned that when firefighters are in the fire truck dispatching to the incident location, they can pull up the building model from city's database for finding out the location of shutoff valves, extinguishers and exit doors. The first action of the firefighters immediately upon arrival at the fire is probably the greatest single factor in determining the success or failure of the operation. The First-In officer will assign firefighters to several tasks which include: a. Fire attack b. Ventilation, c. Salvage, d. Search and rescue operation, e. First aid, f. The overhaul, g. Investigation and return to service [13], while [16] believes that fire response management requires detailed geometric and semantic information about the building. This required building information for an emergency has been investigated in a limited existing literature.

Reference [18] worked on the final report from the next NIST workshop which was "To Define Information Needed by Emergency Responders during Building Emergencies". The workshop brought together a wide range of participants from public safety organizations such as fire, police, medical, building technology, government, and security. The goal was to have a different perspective on the information requirement to create the building information framework for the firefighters. They provided a list of information which included 110 items as a starting point for the development of a minimum set of requirements to support emergency response operations in case of fire. The next workshop held by NIST in October 2008 was focused on building information exchange for first responders and brought together key stakeholders in a dialogue on the delivery of building information to the first responder communities in order to identify opportunities for collaboration and standardization [1]. Moreover, [36] presented a model of information which consists of four elements (response tasks, response departments, datasets, and emergency-aided models) for emergency response. In one other study done by [19] a card game with first responders was designed to evaluate their needs for various information items used in developing situational awareness at a building fire emergency scene.

B. BIM in Building Fire Response

BIM remains a dynamic topic in the design and construction fields of research with an increased focus on the integration of information. As result expectations are that BIM will continue to enhance the integration process and interoperability of technologies across disciplines. Industry Foundation Classes (IFC) is a file format developed by the International Alliance of Interoperability (IAI, also known as buildingSMART) for the purpose of interoperability between many different software platforms potentially accessed for building information during the facility lifecycle [17]. The IFC format provides for the exchange of data rich 3D facility representation that can be accessed by firefighters before arrival and entry to an emergency incident. Expectations are that this integrated information would enhance their capability and improve their safety in the building at the time of the incident [3], [30]. There is a range of research which proves the BIM capabilities for building fire response. Reference [15] mentioned that BIM can be used for the analysis of energy use, defect detection, firefighting, renovation and demolition, and safety in facility management. Although BIM can provide a basic model in emergencies there is a need for firefighters to have an indoor model to be easily accessible and readable [2], [6].

In a recent study by [19] interactive interviews with the Los Angeles Fire Department (LAFD) first responders and found that the first responders have a low access to BIM. However, they anticipate that access would increase in the very near future. The opportunities BIM provides first responders offer a possible solution to a gap reported by [27] where the development of a BIM based environment with an evacuation route for endangered people and real representation of the building posed challenges for emergency management. They developed a method for first responders to find the quickest route in a complex building. Their study concluded that generating a BIM for the indoor network is a time-consuming task with an intricate data structure not necessary for the purpose of emergency response. Reference [21] analyzed the similarities and differences of indoor network methods and algorithm, created an indoor network through ESRI's Campus Viewer Tool by using BIM/ CAD model of a building and conducted interviews with a fire marshal and his team. Participants claimed that the indoor location information is one of the most important items in all stages of building emergency response operations, and having a ready to use, simple and quick access platform can help first responders safely meet their goals more efficiently.

A similar conclusion was reported by [35] who found that while all semantic and geometric information supports interoperability, data redundancy should be reduced in the BIM model with data transformation specific to the goals for firefighters. Another study on this topic [30] emphasized the simplicity of methods used to present building information due to the limited time first responders have after dispatching until arrival to the scene to get information from the model. Therefore, the information included in the building model must be chosen with enough knowledge and care.

With a new methodology [34] proposed an outline based on semantic information and computer technology to develop navigation and route finding under fire emergency hazards. Their method was novel because of the semantic relationship between BIM and the objects captured by visual and thermal imaging cameras. Moreover, [10] believes that fire protection and the response is an essential public service in urban areas – it is the most costly, non-trivial public service which is known to be a time-sensitive service. Reference [28] pointed out that when BIM technology improves, the fire protection industry can use all the graphic and attribute information available in a BIM model to plan the overall safety of the building and its occupants. Reference [24] created a graphic database and an information database, poured into a cloud platform where different users can view, through a web and mobile interface. The information coming from the BIM models overlapped by specific information for assistance.

Reference [32] focused on investigating whether the process of fire response management can be facilitated through the implementation of an IFC model in the geospatial environment. Reference [17] applied BIMs in a geospatial environment in order to facilitate data management in fire response. Their research demonstrated that BIMs could provide the required geometric and semantic information about buildings in support of fire response management processes (i.e., BIMs can provide attribute information queries about building elements). Reference [5] addressed BIM as a potential source of 3D building data with the ability to have semantic information as one of the most important characteristics of a 3D model. Their study could provide useful decision support of fire-fighting operations such as route navigation for firefighters in a virtual 3D environment, demonstration of movement of smoke at different stages during a building fire, deployment of a virtual ladder truck in a fire scene, and attribute queries of building elements using BIMs. One the other hand, their BIM contained information about walls, windows, doors, stairs, etc. of a target building used for 3D visualization and attribute query. Using this method, fire-fighters could find the best window to break in and the best position to deploy the ladder trucks before arrival at the fire scene.

Reference [16] conducted interviews with the participants from Istanbul Technical University (ITU) Centre for Disaster Rescue for finding a successful fire response management operation. The result of their study shows the following information is required for the building fire response: The building's usage, the location of fire sensors and fire, electronic control, the location of emergency exits, the electrical installations and pipelines, the location of fire hydrants, materials of building elements (i.e. of walls, doors, windows, etc.), the opening directions of doors and windows, the 3D geometrical model of the building. In addition, during a fire in a building, it is possible that the first respondent does not have enough time for collecting and analyzing the information. Therefore, the different stages of establishing a response to fire require the prioritization of information items. To establish and use building information, detailed implementation requirements should be examined, including the type of assistance, the level of detail and the format for presenting the information.

The motivation for this study was to identify the building information needed for a fire emergency in the building. The main objective is to classify better building information that firefighters need to preserve the property (buildings) in case of fire. The rest of the article is structured as follows: method, data analysis, and conclusions.

II. Materials and Methods

Researchers used other people's experiences, research, and material to understand the external reality and validate its truth [8]. This view helps find the truth through quantitative reasoning. The methodology in this research includes quantitative research by collecting data from the main participants who are firefighters working in the Norman Fire Department. Considering a 7% margin of error, 90% confidence level, and 109 population size (109 firefighters in the Norman Fire Department), 62 questionnaires [25] were distributed among firefighters and 42 questionnaires were completed.

To make sure that the survey is relevant and clear, the questionnaire was revised twice. Discussions and informal interviews about the questionnaire draft were conducted with one fire inspector, one firefighter, and one former fire marshal in Norman. Their feedback helped improve questionnaire design. The questionnaire prioritizes the most important information from contractors' BIM handover to help firefighters save building properties. Although the main firefighter's responsibilities are saving both lives and building properties, the focus of this research is only on information about building properties. The data analysis was done to rank information according to the rank given by participants.

The closed-ended survey design was selected to produce aggregated data quickly and provide the specific ranking for every building element. Also, the questionnaire can be replicated easily to check for reliability. The focus of this study did not explain the firefighters' opinions about building information or specify what information was made available to them. Instead, this study evaluates various beliefs and experiences of firefighters in ranking building information from BIM contractors' handover. However, the lack of detail in this subject matter remains an issue, which could benefit from future research.

Data Analysis

The final version of the questionnaire as an objective means of collecting data in this study consisted of three sections.

The first section of the survey focused on prioritizing the sources of information currently used by firefighters, as well as the sources of information required and desired. To obtain the most effective and successful response to fires, they were asked to rank the levels of importance of each item mentioned in a table, from the most important to the least important. By removing non-building-related information items and merging related items, a list of 25 information items was developed based on the NIST workshop (2005, 2007, 2013) and research done by [19]. The final version of this section included 10 aggregated items divided into four main categories: BIM-architecture, BIM-Structure, BIM-Mechanical-Plumbing-Electrical (MEP) and BIM- indoor network analysis.

The second part tested the spatial skills of the participants. This test included items about visualization and orientation for which they had to apply their knowledge about graphics, modeling, and building components. They were asked to circle the preferred format of the representation (2D floorplans or 3D model of the building) which was easier to understand for them.

The final section highlighted the demographic information of the participants, including job title, years of experience, age, educational level, comfort level, and interest to use technology in their job. The reason behind this section was to both validate and identify invalid responses, as well as the evaluation of the factors related to the information requirement which has a high impact on firefighters' decision-making process. In this survey, firefighters from all 9 fire stations of the Norman Fire Department were invited to participate. A total of 62 firefighters were invited and 42 responses were received with a response rate of 67.74%. By filtering invalid and incomplete questionnaires, a total of 35 valid responses were analyzed in this study.

III. Results and Findings

A. Participants' Profiles

The number and percentage of participants with different job title are summarized in Table I. This table shows that 57.14% of participants were firefighters as the largest group of participants and the second largest group was captains with the percentage of 28.14%.

TABLE I
JOB TITLE OF SURVEY PARTICIPANTS

Job title	Number of participants	% of the total response
Captain	10	28.57%
Firefighter	20	57.14%
Engineer	1	2.86%
Driver	3	8.57%
Assistant chief	1	2.86%
Inspector	0	0%
Investigator	0	0%
Total	35	100%

The percentage of each demographic information within the participants is shown in Table II. One important finding from this table is that 91.42% of the participants indicated that they tend to use technological instruments like a tablet, a laptop for pulling up the building information. It proves that the process of providing firefighters with the BIM model will be acceptable by them.

TABLE II
PERCENTAGE OF PARTICIPANTS' DEMOGRAPHIC INFORMATION

Coding	Age Range	%	Gender	%	Job Title	%	Education	%	Experience	%	Comfort /Tech	%	Interest /Tech	%
1	26-35	8.57	M	100	Captain	28.57	High School	0	-1	0	Very	62.85	Yes	91.43
2	36-45	31.42	F	0	Firefighter	57.14	Some College	31.42	1-5	28.57	Somehow	34.28	No	8.57
3	46-55	40			Engineer	2.85	Vocational	5.71	5-10	34.28	Not very	2.85		
4	56-65	14.28			Driver	8.57	Associate	22.85	+10	37.14	Completely uncomfortable			
5	+65	5.71			Assistant Chief	2.85	Bachelor's	31.42						
6					Inspector	0	Master's	8.57						
7					Investigator	0								

Through analyzing the demographic information, there is no meaningful significant correlation between each demographic information except correlation between job title and years of experience. As Table III shows the experience has correlated with job title with the correlation coefficient of 62%.

TABLE III
CORRELATION BETWEEN JOB TITLE AND EXPERIENCE

	Job Title	Experience
Job Title	1	0.62
Experience	0.62	1

TABLE IV
THE FREQUENCY OF RESPONSES

Items	Rank 1	Rank 2	Rank 3	Rank 4	Rank 5	Rank 6	Rank 7	Rank 8	Rank 9	Rank 10
Structural	1	3	7	2	8	4	1	2	2	5
Electrical	0	2	3	4	4	10	7	2	2	1
HVAC	1	2	3	4	6	5	5	5	3	1
Plumbing	3	0	0	0	3	1	3	8	9	8
Way-Finding	1	5	2	10	3	2	4	4	2	2
ICT	0	0	0	2	1	4	7	8	7	6
B-Data	5	2	6	4	4	4	5	3	0	2
Material	6	9	6	4	4	1	1	2	1	1
Contact	2	2	3	3	1	4	2	1	9	8
Location of DWES	16	10	5	2	1	0	0	0	0	1

B. Ranking Building Information

Participants were asked to rank building information items that help them understand and evaluate fire incident situations.

The frequency of responses is summarized in Table IV. Table V lists all the total rank value, rank, rank percentage, and mean of each item in the first section of the questionnaire. Furthermore, for more comprehension, Fig. 3 represents the bar chart of the total rank value of all 10 building information items mentioned in section 1 of the survey.

TABLE V
THE TOTAL RANK VALUE, RANK, PERCENT RANK, AND MEAN OF EACH ITEM

Items	Total Rank Value	Rank	Rank Percentage	Mean
Structural	195	5	55%	5.457143
Electrical	190	6	45%	5.771429
HVAC	188	7	36%	5.771429
Plumbing	118	10	9%	7.714286
Way-Finding	207	4	64%	5.2
ICT	119	9	18%	7.8
B-Data	224	3	73%	4.742857
Material	260	2	82%	3.6
Contact	148	8	27%	6.828571
Location of DWES	311	1	91%	2.114286

Reference [19] mentioned that "some sources, such as "fire system", are usually enforced by building codes in modern buildings and provided by building owners or managers as part of building fire management plans", but there are some other items that are not enforced by codes which need to be considered for structure fire response. As demonstrated in Table V, over 70% of the participants considered Location of Exit Door, Windows, Corridors, Elevators, Stairs; Material of Building Elements, and Building Data as the three most important information items identified in the questionnaire. Some of these information items are not well established and require almost new innovative technology for representation and analysis.

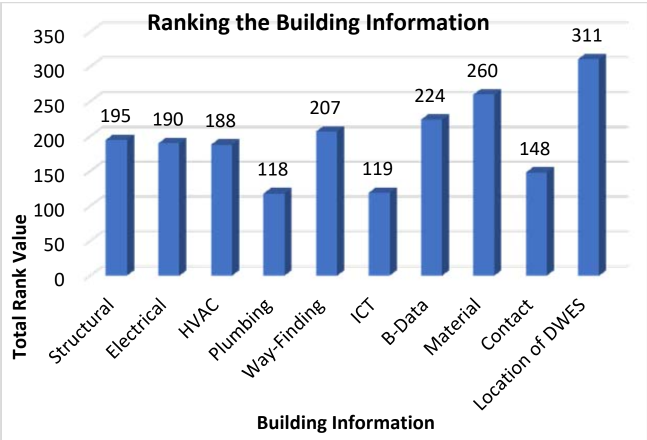

Fig. 3 Total rank value of 10 items

C. Analyzing the Visualization Task

One of the objectives of the survey was to discover if the 2D and 3D representations of the BIM model for each building is "understandable" or not. According to [26], visualization allows the viewer to understand information in a higher pace as connections and relationships are best conveyed through visual methods. He believed that information representation through visualization is the best mean to understandability. This understandability takes place using the right visualization techniques for providing the right dimensions and conveying the information to the viewer at the right time. So, the term "understandable" was used to measure the participant's response to the building models (architectural, structural, MEP) in 2D plans and 3D format. A representation is counted as successful where it can encode information in a way that the viewers' brains can understand, and eyes can encode. Achieving this goal can be possible by studying human perception and it is a science than an art. Translating abstract information into visualization which can be decoded in an efficiently, easily, and meaningfully manner is the goal of understandability [29]. The understandability concept was used in this section to measure the first responders' perception of the building models to find out how much they can encode the building information presented in 2D plans and 3D models.

In the second section of the survey, firefighters were provided with the architectural model, structural model, MEP models, and way finding model in 2D and 3D formats. Analyzing participants' responds, as shown in Table VII, responders believed that the 2D model of architectural, structural, and way finding is more understandable in comparison with the 3D models. Regarding the MEP model, the result is completely different and more than 75% of participants mentioned 3D model of MEP system could convey more information. Furthermore, all firefighters unanimously believed that the color in visualization can help them to understand the building information easier and quicker.

TABLE VI
THE PERCENTAGE OF UNDERSTANDABILITY OF 2D AND 3D MODELS

Visualization	Architectural Model	Structural Model	Way-Finding Model	MEP-Model 1	MEP-Model 2
2D	73.33%	60%	65.51%	25%	14.29%
3D	26.67%	40%	34.49%	75%	85.71%

D. Reliability

Survey reliability means that if the application is reaped by users, the same results will be obtained. Several methods have been proposed to evaluate the survey reliability which includes a split-halves method, alternative-form method, the retest method, and the internal consistency method. In this study, the internal consistency reliability analysis was used in this study to assess the reliability of the survey. The Cronbach's alpha (or coefficient alpha) is the most popular of the internal consistency coefficients [7].

Reference [31] discussed that "Alpha was developed by Lee Cronbach in 1951, to provide a measure of the internal consistency of a test or scale; it is expressed as a number between 0 and 1. Internal consistency describes the extent to which all the items in a test measure the same concept or construct and hence it is connected to the inter-relatedness of the items within the test. Internal consistency should be determined before a test can be employed for research or examination purposes to ensure validity" (p.54). To prove the reliability of the ranking items – the result of the first part of the survey- a Pearson Correlation Matrix was created. The Pearson Correlation Matrix is used when there is more than one independent variable, and all pairs of correlated sets are represented concisely in a matrix format [31]. After developing a Pearson Correlation Matrix (Figs. 5 and 6) in this study, the code below was written in RStudio to calculate Cronbach's alpha (refer to Fig. 4):

```
Output:
The Alpha is
$`sample.size`
[1] 35
$number.of.items
[1] 35
$alpha
[1] 0.9164574
```

The Cronbach's alpha coefficient for the 35 items (participants) is 0.916, suggesting that the items have relatively high internal consistency. All analysis processes were done through Microsoft Excel 2018 except Pearson Correlation Matrix and Cronbach's alpha. Another output of the mentioned scripts is the Pearson Correlation Matrix (Fig.

5). The red cells show the correlation coefficient more than 0.5 between pairwise correlation among participants. In addition, Fig. 6 demonstrates a spectrum of correlation coefficient from positive correlation with green color to the negative correlation with red color. It proves that there is a significant internal consistency of all responses. Therefore, the results of the survey are reliable and can be applied to the population.

```
library(psych)
#Create Data frame
data.frame <- read.csv("R.csv")
#transpose
test.data<-t(data.frame)

#data frame
test.data<-data.frame(test.data)
test.data
class(test.data)
#Provide names
names(test.data)<-c('Respon1', 'Respon2', 'Respon3', 'Respon4', 'Respon5', 'Respon6', 'Respon7', 'Respon8', 'Respon9', 'Respon10', 'Respon11', 'Respon12', 'Respon13', 'Respon14', 'Respon15', 'Respon16', 'Respon17','Respon18', 'Respon19', 'Respon20', 'Respon21', 'Respon22','Respon23', 'Respon24','Respon25', 'Respon26', 'Respon27', 'Respon28', 'Respon29', 'Respon30', 'Respon31', 'Respon32', 'Respon33', 'Respon34', 'Respon35')

test.data

#Correlation Matrix
cor.matrix<-cor(test.data[,1:35], method=c('spearman'))
write.table(cor.matrix, file="cor.export.csv", sep=",")

library(psy)
cronbach(cor.matrix)
```

Fig. 4 Scripts in RStudio for creating Correlation Matrix and Cronbach's alpha

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
1																																			
2	0.10																																		
3	0.39	0.10																																	
4	0.36	0.07	0.83																																
5	0.56	-0.39	-0.14	-0.10																															
6	0.76	-0.03	0.37	0.56	0.43																														
7	0.14	-0.03	0.64	0.19	-0.30	-0.02																													
8	0.38	-0.14	0.55	0.54	0.12	0.39	0.20																												
9	0.56	-0.21	0.24	0.31	0.44	0.83	0.08	0.16																											
10	0.50	0.13	0.82	0.50	0.02	0.33	0.68	0.76	0.20																										
11	0.53	0.16	0.83	0.71	-0.05	0.30	0.54	0.42	-0.03	0.67																									
12	0.85	0.13	0.33	0.26	0.38	0.71	0.26	0.20	0.76	0.41	0.31																								
13	0.12	-0.53	0.43	0.41	0.43	0.36	0.15	0.44	0.56	0.37	0.04	0.19																							
14	0.75	0.22	0.41	0.21	0.56	0.36	0.14	0.55	0.16	0.68	0.48	0.50	0.22																						
15	0.83	-0.08	0.47	0.30	0.67	0.59	0.22	0.56	0.58	0.67	0.38	0.75	0.53	0.87																					
16	0.77	0.08	0.18	-0.05	0.52	0.38	0.31	-0.18	0.44	0.24	0.35	0.78	-0.03	0.52	0.62																				
17	0.45	-0.02	0.61	0.71	0.28	0.62	0.18	0.44	0.60	0.47	0.43	0.55	0.68	0.39	0.59	0.20																			
18	0.76	0.09	0.27	-0.01	0.49	0.33	0.37	-0.08	0.44	0.35	0.37	0.81	0.08	0.59	0.71	0.98	0.28																		
19	0.81	0.26	0.56	0.41	0.45	0.44	0.24	0.59	0.20	0.75	0.66	0.59	0.21	0.96	0.85	0.54	0.53	0.61																	
20	0.42	-0.02	0.54	0.70	0.33	0.67	-0.13	0.71	0.45	0.52	0.30	0.21	0.61	0.49	0.55	-0.12	0.60	-0.07	0.50																
21	0.66	0.38	0.39	0.20	0.42	0.35	0.16	0.58	0.13	0.72	0.43	0.45	0.16	0.96	0.78	0.39	0.39	0.47	0.93	0.50															
22	0.33	-0.05	0.62	0.77	0.04	0.65	0.27	0.20	0.64	0.30	0.45	0.49	0.54	0.03	0.30	0.18	0.88	0.20	0.22	0.44	0.03														
23	-0.35	0.14	-0.07	-0.32	-0.45	-0.66	0.47	-0.39	-0.58	-0.08	0.18	-0.20	-0.44	-0.24	-0.39	0.08	-0.25	0.09	-0.16	-0.81	-0.21	-0.16													
24	0.13	-0.44	-0.28	-0.31	0.08	0.22	0.19	0.21	0.36	0.03	-0.30	0.31	0.03	-0.15	0.10	0.07	-0.07	0.03	-0.16	-0.20	-0.13	-0.04	0.01												
25	-0.02	-0.41	0.04	0.04	0.28	0.04	0.13	-0.26	0.41	-0.16	-0.08	0.30	0.54	-0.14	0.18	0.27	0.54	0.33	-0.08	-0.18	-0.24	0.54	0.22	0.09											
26	0.79	0.04	0.32	0.33	0.52	0.84	0.16	0.53	0.65	0.55	0.33	0.71	0.31	0.64	0.73	0.45	0.60	0.43	0.67	0.56	0.67	0.45	-0.42	0.36	-0.01										
27	0.58	0.48	0.65	0.37	-0.08	0.37	0.67	0.15	0.36	0.66	0.61	0.72	0.05	0.48	0.52	0.62	0.53	0.68	0.61	0.09	0.53	0.52	0.24	-0.04	0.18	0.50									
28	-0.05	-0.03	0.54	0.27	-0.08	-0.02	0.56	0.01	0.33	0.38	0.18	0.26	0.62	0.07	0.28	0.18	0.58	0.32	0.13	0.08	0.07	0.55	0.20	-0.18	0.67	-0.01	0.54								
29	0.12	-0.02	-0.25	-0.36	0.10	-0.10	0.24	-0.61	-0.12	-0.28	0.15	0.13	-0.45	-0.14	-0.19	0.54	-0.21	0.41	-0.09	-0.66	-0.19	-0.02	0.61	0.13	0.24	0.02	0.21	-0.12							
30	0.13	-0.41	-0.01	-0.05	0.14	0.09	0.12	0.76	0.01	0.41	-0.03	0.03	0.21	0.27	0.31	-0.24	0.02	-0.19	0.22	0.22	0.30	-0.21	-0.15	0.67	-0.22	0.36	-0.18	-0.25	-0.35						
31	0.76	0.12	0.39	0.16	0.56	0.48	0.33	0.53	0.38	0.72	0.42	0.66	0.33	0.90	0.89	0.59	0.54	0.65	0.89	0.41	0.90	0.22	-0.14	0.15	0.08	0.82	0.62	0.22	0.02	0.36					
32	0.95	0.25	0.47	0.37	0.43	0.60	0.25	0.39	0.33	0.59	0.68	0.77	-0.02	0.81	0.77	0.75	0.43	0.75	0.89	0.32	0.75	0.28	-0.12	0.02	-0.08	0.73	0.67	-0.04	0.20	0.12	0.79				
33	0.79	0.31	0.36	0.13	0.31	0.56	0.48	0.18	0.52	0.56	0.43	0.85	0.03	0.62	0.68	0.79	0.44	0.79	0.68	0.12	0.65	0.36	0.04	0.25	0.12	0.78	0.85	0.24	0.35	0.04	0.82	0.82			
34	0.71	0.38	0.35	0.12	0.21	0.39	0.49	-0.04	0.33	0.43	0.53	0.77	-0.13	0.53	0.53	0.84	0.38	0.83	0.62	-0.09	0.53	0.36	0.28	0.07	0.20	0.59	0.88	0.26	0.55	-0.19	0.68	0.79	0.94		
35	0.67	0.42	0.49	0.30	0.01	0.35	0.54	0.09	0.25	0.50	0.66	0.76	-0.15	0.48	0.48	0.72	0.44	0.75	0.64	-0.08	0.48	0.43	0.36	0.04	0.19	0.49	0.92	0.30	0.42	-0.13	0.60	0.79	0.85	0.94	

Fig. 5 The correlation coefficient of more than 0.5 between responders

IV. Conclusion

Having required building information for the firefighters in a precise, timely, coordinated and comprehensive form, as well as analyzing and representing this building information in a more understandable visual format will help firefighters make wise decisions and will decrease loss of the lives and properties. Regarding the importance of building information in the case of a structure fire, this study prioritized this necessary building information to help save life and properties. To do so, a survey was conducted with firefighters working in the Norman Fire Department and the result shows that the location of exit door, windows, corridors, elevators, stairs is the most important information considered by firefighters and the location of plumbing systems was ranked as the least important one. This paper also examined the preferable visualization format for firefighters. They believed that while the 2D model of architectural, structural, and way finding is more understandable in comparison with the 3D model, for the MEP system, the 3D model could convey more visual information. Furthermore, another finding of this study shows that all firefighters unanimously believed that color plays an important role in data representation visually and can help them understand the building information quicker and easier. To examine the reliability of the results, a Pearson

Correlation Matrix was developed, and the Cronbach's alpha coefficient was calculated. The Cronbach's alpha coefficient for the 35 participants was 0.916, suggesting that the items have relatively high internal consistency and the results are reliable. The author will carry out the future work to develop more detailed information needs and integrate it with the outdoor information obtained from GIS-based technology to have a comprehensive information source with benefit from the capabilities of GIS in a BIM-based platform to help firefighters make wise decisions in case of fire.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
1																																			
2	0.10																																		
3	0.39	0.10																																	
4	0.36	0.07	0.83																																
5	0.56	-0.39	-0.14	-0.10																															
6	0.76	-0.03	0.37	0.56	0.43																														
7	0.14	-0.03	0.64	0.19	-0.30	-0.02																													
8	0.38	-0.14	0.55	0.54	0.12	0.39	0.20																												
9	0.56	-0.21	0.24	0.31	0.44	0.83	0.08	0.16																											
10	0.50	0.13	0.82	0.50	0.02	0.33	0.68	0.76	0.20																										
11	0.53	0.16	0.83	0.71	-0.05	0.30	0.54	0.42	-0.03	0.67																									
12	0.85	0.13	0.33	0.26	0.38	0.71	0.26	0.20	0.76	0.41	0.31																								
13	0.12	-0.53	0.43	0.41	0.43	0.36	0.15	0.44	0.56	0.37	0.04	0.19																							
14	0.75	0.22	0.41	0.21	0.56	0.36	0.14	0.55	0.16	0.68	0.48	0.50	0.22																						
15	0.83	-0.08	0.47	0.30	0.67	0.59	0.22	0.56	0.58	0.67	0.38	0.75	0.53	0.87																					
16	0.77	0.08	0.18	-0.05	0.52	0.38	0.31	-0.18	0.44	0.24	0.35	0.78	-0.03	0.52	0.62																				
17	0.45	-0.02	0.61	0.71	0.28	0.62	0.18	0.44	0.60	0.47	0.43	0.55	0.68	0.39	0.59	0.20																			
18	0.76	0.09	0.27	-0.01	0.49	0.33	0.37	-0.08	0.44	0.35	0.37	0.81	0.08	0.59	0.71	0.98	0.28																		
19	0.81	0.26	0.56	0.41	0.45	0.44	0.24	0.59	0.20	0.75	0.66	0.59	0.21	0.96	0.85	0.54	0.53	0.61																	
20	0.42	-0.02	0.54	0.70	0.33	0.67	-0.13	0.71	0.45	0.52	0.30	0.21	0.61	0.49	0.55	-0.12	0.60	-0.07	0.50																
21	0.66	0.38	0.39	0.20	0.42	0.35	0.16	0.58	0.13	0.72	0.43	0.45	0.16	0.96	0.78	0.39	0.39	0.47	0.93	0.50															
22	0.33	-0.05	0.62	0.77	0.04	0.65	0.27	0.20	0.64	0.30	0.45	0.49	0.54	0.03	0.30	0.18	0.88	0.20	0.22	0.44	0.03														
23	-0.35	0.14	-0.07	-0.32	-0.45	-0.66	0.47	-0.39	-0.58	-0.08	0.18	-0.20	-0.44	-0.24	-0.39	0.08	-0.25	0.09	-0.16	-0.81	-0.21	-0.16													
24	0.13	-0.44	-0.28	-0.31	0.08	0.22	0.19	0.21	0.36	0.03	-0.30	0.31	0.03	-0.15	0.10	0.07	-0.07	0.03	-0.16	-0.20	-0.13	-0.04	0.01												
25	-0.02	-0.41	0.04	0.04	0.28	0.04	0.13	-0.26	0.41	-0.16	-0.08	0.30	0.54	-0.14	0.18	0.27	0.54	0.33	-0.08	-0.18	-0.24	0.54	0.22	0.09											
26	0.79	0.04	0.32	0.33	0.52	0.84	0.16	0.53	0.65	0.55	0.33	0.71	0.31	0.64	0.73	0.45	0.60	0.43	0.67	0.56	0.67	0.45	-0.42	0.36	-0.01										
27	0.58	0.48	0.65	0.37	-0.08	0.37	0.67	0.15	0.36	0.66	0.61	0.72	0.05	0.48	0.52	0.62	0.53	0.68	0.61	0.09	0.53	0.52	0.24	-0.04	0.18	0.50									
28	-0.05	-0.03	0.54	0.27	-0.08	-0.02	0.56	0.01	0.33	0.38	0.18	0.26	0.62	0.07	0.28	0.18	0.58	0.32	0.13	0.08	0.07	0.55	0.20	-0.18	0.67	-0.01	0.54								
29	0.12	-0.02	-0.25	-0.36	0.10	-0.10	0.24	-0.61	-0.12	-0.28	0.15	0.13	-0.45	-0.14	-0.19	0.54	-0.21	0.41	-0.09	-0.66	-0.19	-0.02	0.61	0.13	0.24	0.02	0.21	-0.12							
30	0.13	-0.41	-0.01	-0.05	0.14	0.09	0.12	0.76	0.01	0.41	-0.03	0.03	0.21	0.27	0.31	-0.24	0.02	-0.19	0.22	0.22	0.30	-0.21	-0.15	0.67	-0.22	0.36	-0.18	-0.25	-0.35						
31	0.76	0.12	0.39	0.16	0.56	0.48	0.33	0.53	0.38	0.72	0.42	0.66	0.33	0.90	0.89	0.59	0.54	0.65	0.89	0.41	0.90	0.22	-0.14	0.15	0.08	0.82	0.62	0.22	0.02	0.36					
32	0.95	0.25	0.47	0.37	0.43	0.60	0.25	0.39	0.33	0.59	0.68	0.77	-0.02	0.81	0.77	0.75	0.43	0.75	0.89	0.32	0.75	0.28	-0.12	0.02	-0.08	0.73	0.67	-0.04	0.20	0.12	0.79				
33	0.79	0.31	0.36	0.13	0.31	0.56	0.48	0.18	0.52	0.56	0.43	0.85	0.03	0.62	0.68	0.79	0.44	0.79	0.68	0.12	0.65	0.36	0.04	0.25	0.12	0.78	0.85	0.24	0.35	0.04	0.82	0.82			
34	0.71	0.38	0.35	0.12	0.21	0.39	0.49	-0.04	0.33	0.43	0.53	0.77	-0.13	0.53	0.53	0.84	0.38	0.83	0.62	-0.09	0.53	0.36	0.28	0.07	0.20	0.59	0.88	0.26	0.55	-0.19	0.68	0.79	0.94		
35	0.67	0.42	0.49	0.30	0.01	0.35	0.54	0.09	0.25	0.50	0.66	0.76	-0.15	0.48	0.48	0.72	0.44	0.75	0.64	-0.08	0.48	0.43	0.36	0.04	0.19	0.49	0.92	0.30	0.42	-0.13	0.60	0.79	0.85	0.94	

High Low

Fig. 6 The spectrum of the correlation coefficient between responders

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

REFERENCES

[1] Averill, J., Holmberg, D., Vinh, A., & Davis, W. (2009). Building Information Exchange for First Responders Workshop. Proceedings NIST Technical Note.

[2] Boguslawski, P., Mahdjoubi, L., Zverovich, V., & Fadli, F. (2016). Automated construction of variable density navigable networks in a 3D indoor environment for emergency response. Automation in Construction, 72, 115-128.

[3] Brown, G., Nagel, C., Zlatanova, S., & Kolbe, T. H. (2013). Modelling 3D topographic space against indoor navigation requirements. In Progress and new trends in 3D geoinformation sciences (pp. 1-22). Springer, Berlin, Heidelberg.

[4] Burton, G. (2007). How the United States is reducing its firefighter fatalities. Australian Journal of Emergency Management, The, 22(2), 37.

[5] Chen, L.C., Wu, C.H., Shen, T.S., & Chou, C.C. (2014). The application of geometric network models and building information models in geospatial environments for fire-fighting simulations. Comput. Environ. Urban Syst. 45, 1–12.

[6] Choi, J., Choi, J., & Kim, I. (2014). Development of BIM-based evacuation regulation checking system for high-rise and complex buildings. Automation in Construction, 46, 38-49.

[7] NCSS Statistical Software, Chapter 401, (1998). Retrieved from https://ncss-wpengine.netdna-ssl.com/wp-content/themes/ncss/pdf/Procedures/NCSS/Correlation_Matrix.pdf.

[8] Crotty, M. (1998). The foundations of social research: Meaning and perspective in the research process. Sage.

[9] Evarts, B. (2019). Fire Loss in the United States During 2018 (p. 11). Quincy, MA: National Fire Protection Association.

[10] Ezekwem, K. C. (2016). Environmental Information Modeling: An Integration of Building Information Modeling and Geographic Information Systems for Lean and Green Developments (Doctoral dissertation, North Dakota State University).

[11] Gao, X., & Chen, Y. (2016). Research on BIM Technology in Construction Safety & Emergency Management, Advances in Engineering Research. 112, proceeding in 4th International Conference on Renewable Energy and Environmental Technology (ICREET).

[12] Hardin, B., & McCool, D. (2015). BIM and construction management: proven tools, methods, and workflows. John Wiley & Sons. p 354

[13] Headquarters, Firefighting and Rescue Procedures in Theaters of Operations. (1971). Department of the Army, TM, 5-315. Washington D.C.

[14] Holmberg, D.G., Raymond, M.A., & Averill, J. (2013). Delivering building intelligence to first responders. Gaithersburg. National Institute of Standards and Technology (NIST).

[15] Hossain, M. A., & Yeoh, J. K. W. (2018, June). BIM for Existing Buildings: Potential Opportunities and Barriers. In IOP Conference Series: Materials Science and Engineering (Vol. 371, No. 1, p. 012051). IOP Publishing.

[16] Isikdag, U., Underwood, J., Aouad, G., & Trodd, N. (2007). Investigating the role of building information models as a part of an integrated data layer: a fire response management case. Architectural Engineering and Design Management, 3(2), 124-142.

[17] Isikdag, U., Underwood, J., & Aouad, G. (2008). An investigation into the applicability of building information models in a geospatial environment in support of site selection and fire response management processes. Advanced Engineering Informatics, 22 (4). 504–519.

[18] Jones, W. W., Davis, W. D., Evans, D. D., Holmberg, D. G., Bushby, S. T., & Reed, K. A. (2005). Workshop to define information needed by emergency responders during building emergencies (No. NIST Interagency/Internal Report (NISTIR)-7193).

[19] Li, N., Yang, Z., Ghahramani, A., Becerik-Gerber, B., & Soibelman, L. (2014). Situational awareness for supporting building fire emergency

response: Information needs, information sources, and implementation requirements. Fire safety journal, 63, 17-28.
[20] Li, N., Becerik-Gerber, B., Soibelman, L., & Krishnamachari, B. (2015). Comparative assessment of an indoor localization framework for building an emergency response. Automation in Construction, 57, 42-54.
[21] Mahdaviparsa A., McCuen T. (2019). Comparison Between Current Methods of Indoor Network Analysis for Emergency Response Through BIM/CAD-GIS Integration. In: Mutis I., Hartmann T. (eds) Advances in Informatics and Computing in Civil and Construction Engineering. Springer, Cham.
[22] NBIMS, (2006). National BIM Standard Purpose, US National Institute of Building Sciences Facilities Information Council BIM Committee.
[23] OSHA, Occupational Safety and Health Standards, Title 29 of the Code of Federal Regulations (CFR), 2012, 1910.155(c) (28).
[24] Pavan, A., Bolognesi, C., Guzzetti, F., Sattanino, E., Pozzoli, E., D'Abrosio, L., Mirarchi, C., & Mancini, M (2020). BIM Digital Platform for First Aid: Firefighters, Police, Red Cross. In: Daniotti B., Gianinetto M., Della Torre S. (eds) Digital Transformation of the Design, Construction and Management Processes of the Built Environment. Research for Development. Springer, Cham.
[25] Raosoft, EZSurvey, (1996). Retrieved from http://www.raosoft.com/samplesize.html
[26] Rensink, R. A. (2002). Internal vs. external information in visual perception. In Proceedings of the 2nd international symposium on Smart graphics (pp. 63-70). ACM.
[27] Ruppel, U., Abolghasemzadeh, P., & Stuebbe, K.M. (2010). BIM-based immersive indoor graph networks for emergency situations in buildings. Proceedings of the International Conference on Computing in Civil Engineering and Building Engineering. 65–72.
[28] Shino, G. K. (2013). BIM and fire protection engineering: by including all life safety systems in the BIM rendering, engineers improve the building's model as a whole. Consulting Specifying Engineer.
[29] Soegaard, M., & Dam, R. F. (2013). The encyclopedia of human-computer interaction. The Encyclopedia of Human-Computer Interaction.
[30] Tashakkori, H., Rajabifard, A., & Kalantari, M. (2015). A new 3D indoor/outdoor spatial model for indoor emergency response facilitation. Building and Environment, 89, 170-182.
[31] Tavakol, M., & Dennick, R. (2011). Making sense of Cronbach's alpha. International journal of medical education, 2, 53.
[32] Underwood, J., Aouad, G. F., Isikdag, U., & Trodd, N. M. (2007). Investigating the applicability of IFC in a geospatial environment in order to facilitate the fire response management process.
[33] USFA. (2016). Fire-Related Firefighter Injuries Reported to the National Fire Incident Reporting System (2012-2014). Volume 17, Issue 6 (2016).
[34] Vandecasteele, F., Merci, B., & Verstockt, S. (2017). Fireground location understanding by semantic linking of visual objects and building information models. Fire Safety. 91, 1026-1034.
[35] Wu, B., Zhang, S. (2016). Integration of GIS and BIM for indoor geovisual analytics. In XXIII ISPRS Congress, Commission II ; Halounova, L., Li, S., Šafář, V., Tomková, M., Rapant, P., Brázdil, K., Shi, W., Anton, F., Liu, Y., Stein, A., Eds. 455-458.
[36] Zhang, Z., Zhou, Y., Cui, J., & Meng, F. (2011, June). Modelling the information flows during emergency response. In Geoinformatics, 2011 19th International Conference on (pp. 1-5). IEEE.