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The Identification of the Elements Effective on the Resilient Design of Buildings against Fire

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ABSTRACT

The safety of a building against the phenomenon of fire is a stereotype that we, the individual, read, see and sometimes painfully feel its absence. The engineering of a building against fire is one of the architectural infrastructures in the resistance of buildings. Which has been proposed and agreed on the scale of "durable metropolises" since 2015. The present study is based on the method of structural equations and data analysis by SPSS and Lisrel software (version 10 for mac). In this method the data were collected in the form of a questionnaire and in terms of Likert among the heads of stations of the Tehran Municipality Fire and Safety Services and the university elite. Resilient design of the architecture of a building against the spread of fire, design of automatic fire extinguishing systems is also the appropriate coverage of the structure of a building against the heat caused by the flame of the building. Fire has the highest coefficient Impact is among the variables affecting the stability of the building against fire hazard. Also, in the next ranks of effectiveness, respectively, the two variables of automatic fire extinguishing systems in the initial stages of lighting and optimal coverage of the building structure against the heat reflected from the fire.
***Keywords**: Resistance, fire, conflagration, residency of building against conflagration*

1. INTRODUCTION

The Fire is identified as one of the oldest disasters that can endanger people's property and health within a short time. With reference to the related definition, the fire is defined as the burning of the flammable materials or an unwanted and uncontrolled combustible firing, which is usually followed by smoke and heat. Occurrence of fire is considered as a fire that originates from an unintentionally controlled heat source and ignites and expands and developed with its own thermal force.

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(Chapter Third: The National Building Code).A fire can start within a lower period of time and in a small area of a building, and if proper measures are not taken to control and extinguish the danger in the building, it can engulf the whole body of the building after a while, and thus it may challenge the lives and property of those living in the building on one hand, and on the other hand make an end to the useful life of a building by causing irreparable damage to the building structure, facilities, interior architecture and furniture of the building and remove the building from future menstruation (Lawton, C .Kallai, 2012: 389-401).

The phenomenon of fire will cause serious damage to the structure of buildings as well as irreparable loss of life to those present in a building. It should be noted that fire resistance accounts as one of the most important issues that has attracted remarkable attention in the world in recent decades. Fire resistance and the consequences of a large fire is concerned itself as an infrastructure in the architecture of durable buildings that has been proposed since 2015 and presented and agreed as on the scale of durable metropolitan index. The stability and resistance of buildings against the risk of fire have two basic objectives:

Ensuring the safety of lives of those present in a building and the stability of the building against the risk of fire in such a way that the minimum possible damage occurs to the future use of the building after the fire, the architecture, structure and internal facilities of a building. According to the third issue of National Building Regulations, today all buildings in the country should be examined in terms of safety and stability against fire hazards, while the country's architectural research knowledge as the main field of building engineering on fire modeling in a building during a new fire is on its primary stages. The third section of the National Building Code is now compiled sporadically from European and American fire standards.Braxma, Predensky, and Pauls argue that identification factors influencing a building's overall resilience against fire can play a crucial role in managing the save of individuals and survival of a building (SFPE, 2019). It is assumed, as a requirement that the well-thought-out safety measures for the architecture of the building against possible fire will be able to provide suitable conditions for evacuation of occupants in case of fire, and in the longer term, the building will continue to survive after successful firefighting. (V.Gwynne, E.D.Kuligowski and S.M.2008) The American architect and researcher, Koepek, gives an example on the issue of occurrence of fire in a building. Consider a building that has endured an hour of massive fire in its body. A number of users are trapped inside the building, and firefighters are questioning whether the structure, which sometimes stood for hours in the heat of the fire at temperatures in excess of 600 to 900 'F , is still stable and operates the task of transferring weight. Does it work well on building foundations? Are there still communication channels inside the building to help trapped people? (Moore and A.Holledge, 2002: 22-34) Kopek's example shows that fire in the architecture of a building, while having a tangible and well-known nature, has a very complex and effective mechanism and requires a variety of research aspects in order to gain a better understanding of the nature of fire in buildings and stabilize buildings against the risk of widespread fire.

Therefore, the issue of fire resistance of a building can be examined from two main aspects, the first aspect is whether a building can provide the necessary opportunity in the initial stage of the fire to safely leave the burnt body? And second, whether the building has the ability to withstand widespread fire hazards through actual technologies such as fire alarm and extinguishing systems or potential methods such as architectural and structural resilience design of buildings.

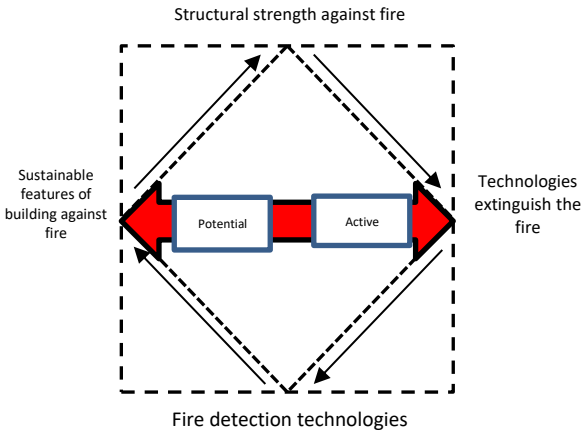


Fig1: The identified component model on the resistance of a building against fire (source: author)

In determining the problem of durable design of a building against fire hazards, a rhombus can be drawn, in four of which, the effective characteristics of fire-resistant architectural design of the building is concerned as well as the degree of fire resistance of the building structure, fire-fighting technologies designed for the building, and the fire alarm technologies used in the building. This article focuses on an area of architecture in which the effects of various components on the durable design of a building against fire are measured. Therefore, the present study raises it's most important questions in these two questions: What are of variables affecting the stability of a building against fire and what is the weight of the impact of each of these components and what is the weight of the impact of each of

these components and their defining sub-characteristics on the stability of a building against fire?

2.Theoretical foundations of research

The framework of theories in the process of durable design of a building against fire is a combination of observations, field reports recorded by fire department personnel present in fire operations and experiments of researchers in construction science research centers around the world. For example, Edward Wood, a firefighting researcher in the United States, has gained insights by interviewing nearly 600 elite firefighters across six states. The results of his research show that the resilience of a building against fire in the most important stage depends on the systems of fire alarm and extinguishing technologies in a building, this point from Wood's point of view is important because in many cases where the architect of a building Has not considered the risk of fire due to its design; The detection of flames by fire alarm and new fire extinguishing systems is of great importance in the early moments of their ignition and before widespread flames. (NFPA101, 2018). There is a long history of writing standard fire codes on a global scale. Table 1 lists the most important fire standards compiled globally.

Tab1: International codes developed to sustain buildings against fire (source: author)

International fire codes			
Description	**Code name**	**country**	
Principal of fire safety engineering – emergency exits –human behavior evacuation strategies	PD794-6	UK	1
emergency exits –human behavior evacuation strategies	C/Mn2	New Zealand	2
Covering the structure against fire –fire detection – fire extinguishing	AU/34-b	Australia	3
Principal of fire safety engineering – emergency exits	Nihon 3/wq-213A	Japan	4
Covering the structure against fire –fire detection – fire extinguishing	INS-TAR34-S	Nordic Countries	5
emergency exits –human behavior evacuation strategies	ISOtr-21	ISO	6
fire detection – fire extinguishing	ISOopi-45	ISO	7
Principal of fire safety engineering – emergency exits – fire extinguishing	ISO9031	ISO	8
emergency exits –human behavior evacuation strategies– fire extinguishing	101-5000	NFPA	9
Principal of fire safety engineering – emergency exits	A34	IBC	10
Principal of fire safety engineering – emergency exits –human behavior evacuation strategies	Di -45/23A	DIN	11

Study and research on the most important global standards in the field of fire, such as SFPA, NFPA and IBC show that the components that from the perspective of researchers compiling these criteria are the criteria for identification of the variables that affect the fire resistance of a building that are, in many cases, similar, and from the point of view of Moll Finn, and different experts around the world, and different versions of this degree of importance of each of these variables, which is different from other variables (Carpman.J.R.Grant MA, 2002: 175-178) Table No. 2 classifies the variables of action criteria in stabilizing buildings against fire hazard (derived from the standards of Table No. 1).

Tab2: Factors affecting fire resistance in buildings (source: author)

Factors affecting fire resistance in buildings				
Source	**Item**	**Sub-Component**	**component**	
Allen, G. Men and Women, Maps and Minds. (Nuallain, Ed.), Spatial Cognition: Foundations and 00Applications.20	Perceptual – Visual – Tactile – Auditory perception	Perception	Flame Power	**Fire Resisting**
	Speed of fire – Flame speed – Heat Generate	Flame	Flame Power	
	The volume of smoke produced – The degree of toxicity of the smoke	Expansion		
ASTM E119, Standard Test Methods for Fire Tests of Building Construction and Materials, 2014.	GAS , Water Extinguishing the fire	Extinguishing the fire	Building features	
	Fire detection system – local – complete – smoke detection	Fire detection	Building features	
	Gypsum base coatings – Mineral base coatings – paint base coatings	Strength of materials		
ASTM E84, Standard Test Method for Surface Burning Characteristics of Building Materials, 2015.	Building Architecture – Building Facilities	Engineering	Technology	
	Focal point – landscape – routing - signs	Architecture	Technology	

According to Table 2, gaining knowledge of durable design of a building against fire requires full knowledge of flame retardant power, building design features and fire control technologies.

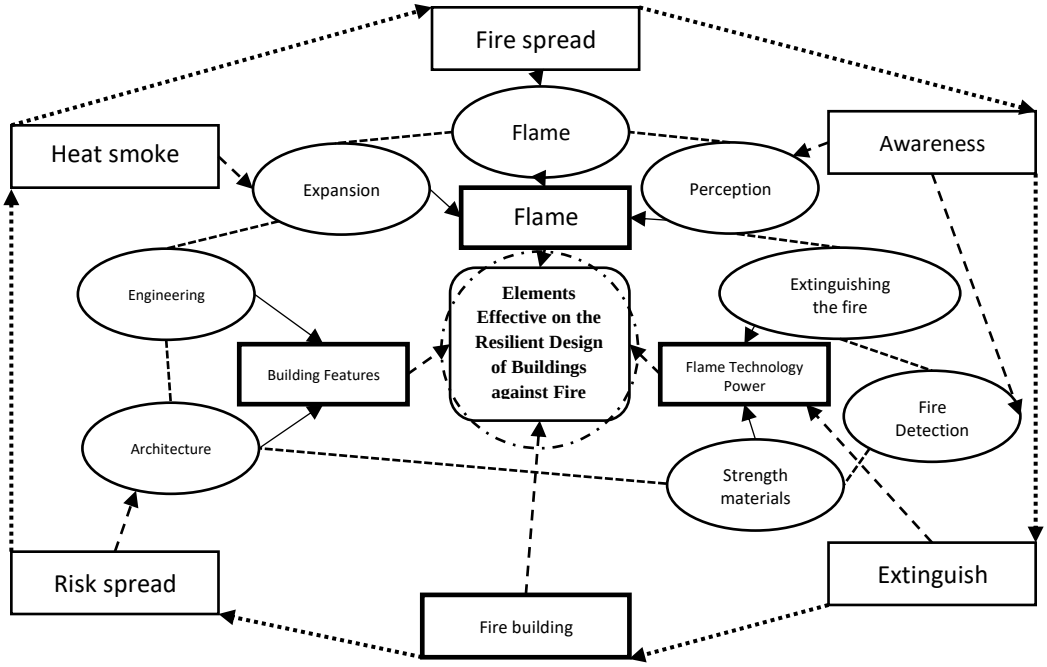


Fig2: resistance model derived from research proposal (source: author)

3- Research method: Data collection in this research is in descriptive-analytical form in terms of combined problem solving and explanatory in terms of results, because it explains the factors and relationships. Thus, after examining the theoretical foundations of research and summarizing variables with the help of logical analysis and rational reasoning, the basic items of factors affecting the variables and thus affecting the stability of buildings against fire are suggested. Then, through interviews with experts of Tehran Municipality Fire and Safety Services using Delphi-Fuzzy method, by preparing a questionnaire according to the Likert spectrum, the initial proposed factors are screened to a questionnaire based on the factors screened to the charges of fire stations in Tehran. Also, students of construction sciences (architecture-civil engineering) should be in postgraduate studies at Shahid Beheshti University and Islamic Azad University, Science and Research Branch of Tehran. This questionnaire has been reviewed and analyzed based on step wise regression method in Spss software and data entry for factor load analysis in LISREL software (Version 10for MAC) and its findings will be discussed in order to explain the conceptual model of the Article.

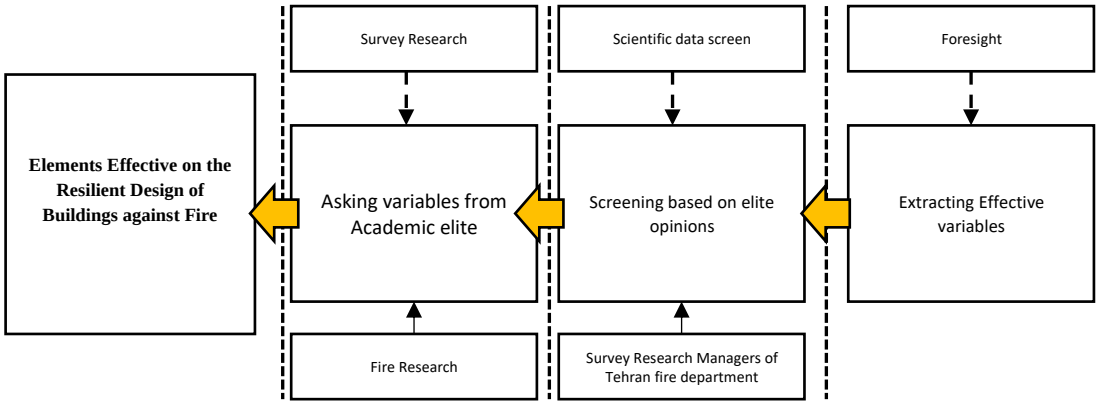


Fig3: Research model derived from interviews (source: author)

Step 1:

At this stage, due to the components identified in the theoretical foundations of research on the stabilization of buildings against the risk of fire are high and scattered, and in order to identify the main variables, integration and screening in order to reduce the components and their localization, we shall apply the weight restrictions . To do this, a questionnaire with 29 questions (each question indicates a factor variable that affects the stability of buildings against fire) was designed and 20 questionnaires that were distributed according to the number of elites working at Tehran Fire and Safety Services (including the organization's CEO, six deputies of organization, the deputy director and the board of directors of the aforesaid organization).All questionnaires were prepared on a qualitative basis and based on a range of 5 Likert options consisting of the very important to less insignificant questions. In the first stage of the survey, the proposed conceptual model with effective sub-criteria was sent to the members of the expert group and their agreement with each of the factors was obtained and their proposed and corrected views were taken into account. Then, the second questionnaire was prepared and sent back to the members of the expert group along with the previous views of each person and the extent of their differences with the views of other experts was considered. In the second stage, the members of the expert group answered the questions again according to the points of view of the other members of the group. According to the views presented in the first stage and comparing it with the results gained by this stage, if the difference between the opinions of experts in the two stages was less than the threshold value of 0.2%, the polling or survey process was stopped. Further, among the mentioned factors, those for whom the non-phase average of experts' opinions was less than 8, were excluded and omitted from the Research Conceptual Model. At this stage, 7 factors were rejected and omitted and 22 factors were remained.

Furthermore, the opinions of experts about 3 average non-phase factors were less than 8, thus they were not accepted. Therefore, there remained 18 elements that were re-evaluated in the third stage, while applying the necessary changes. According to the results of the third questionnaire, the rate of disagreement of experts in the second and third stages was less than the threshold value of 0.2 percent, and therefore the survey of experts was stopped at this stage, and because the non-phase average of expert opinions was calculated and showed to be higher than value of 8, all remained variables were accepted. Therefore, during the 3 stages of the survey, out of 29 elements, 11 elements were removed from the conceptual model under study and the final model had 18 elements.

The result of the first step of the research can be known as the extraction of screened elements according to the opinion of internal experts involved in the problem of fire from the variables affecting the stability of the building against fire.

3-2 Second step:

The formation of a matrix of variables is identified as the second step in explaining effective information and criteria based on the first step of the research. In explaining the variables extracted from the first step, the three elements including the "nature of fire", "building design" and "firefighting technology" were selected as independent variables affecting the dependent variable of "building stability against fire" based on the opinion of experts. Different dimensions were identified for each of these variables, which are shown as their sub-variables in Table 3.

Tab3: Components extracted from data interviews with experts (source: author)

Variables affecting Sustainability of building against fire based on the research progress			
Item		Sub/Com	Com
Separate fire flame temperature	Ignition Temperature	The Nature Of Fire	Fire Resistance
The duration of the fire			
The spread at which the flame moves on the joinery	Speed of spread		
Behavior of materials in case of fire			
Predicted fire travel path	Fire gas products		
Variety of gaseous products emitted by fire			
Fielding of different uses of architecture against fire	Resilient architecture	Building Plan	
Sustainable design of traffic routs in the building			
Classification of building occupation based on fire risk			
Occupancies in the building	Building features		
Building height			
Depth of building			
Intelligent fire alarm systems	Fire detection	Technology	
Intelligent fire alarm systems and locators			
Dry fire extinguishing systems	Extinguish the fire		
Intelligent fire extinguishing systems			
Mineral coating with gypsum	Structural strength		
Fire resistant paints			

Step 3:

In the present study, due to its quantitative-qualitative nature, random sampling method was used using the Cochran's formula. Individuals were selected as the statistical population to assess the importance of variables affecting the design of buildings against fire to complete the questionnaire that have one of the following conditions: 1. Firefighters with multiple attendances in the body of the burnt architecture of buildings 2. The technicians and experts of architecture and structure sciences working as the academic board in University 3- The students of Civil Engineering and Structure sciences in postgraduate degrees -Based on Kokouran formula among the statistical volume of 419 specialists, the research considering the error rate of 0.05% and having one of the 3 mentioned conditions, 200 specialists and experts were chosen to participate in the third step of research. Table 4 details the list of 200 comments delivered by the participants in the measurement part of research.

Tab4: Characteristics of the participants answering the questionnaire questions (source: author)

Orientation			Grade	University Name	Characteristic of the participant
Civil	Urban	Architecture			
-	1	7	Ph.D.	Shahid Beheshti Uni	Science Committee
6	6	6	Ph.D.	Azad Uni	
20	10	40	Ph.D.	Shahid Beheshti Uni	Graduate students
35	8	37	Ph.D.	Azad Uni	
1	2	2	M.A	Fire chiefs	Experts of Tehran Fire Department
9	5	5	M.A	Fire commanders	

Step 4:

One of the first outputs of the structural equation method is the table of commonalities for each variable, which shows the degree of common variance of one variable with the other variables used in the analysis. The higher the value in each index, the more relevant that index is to the other indicators used in the subject.

Step 5:

The extract of the factor load of the variables and check the variance explained between the variables shall be conducted in this step. After the statistical control tests that measure the accuracy of the raw data for entering into the calculations of factor analysis, the preliminary matrix is calculated in which the variance explained by each factor is determined. In other words, in the relevant matrix shown in the model, the result of factor analysis and factor load of indicators or path coefficient and causal relationship coefficient of stability variables are determined and the contribution of each relevant factor in explaining and determining stability is different. The product of this stage determines the weight for each factor.

Tab5: The weights used for each measure (source: author)

Variables affecting Sustainability of building against fire based on the research progress				
Factor load	Item		Sub/Com	Com
0/47	Separate fire flame temperature	Ignition Temperature	The Nature Of Fire	Fire Resistance
0/49	The duration of the fire			
0/51	The spread at which the flame moves on the joinery	Speed of spread		

0/53	Behavior of materials in case of fire			
0/68	Predicted fire travel path	Fire gas products		
0/50	Variety of gaseous products emitted by fire			
0/91	Fielding of different uses of architecture against fire	Resilient architecture	Building Plan	
0/72	Sustainable design of traffic routs in the building			
0/74	Classification of building occupation based on fire risk			
0/65	Occupancies in the building	Building features		
0/67	Building height			
0/69	Depth of building			
0/71	Intelligent fire alarm systems	Fire detection	Technology	
0/73	Intelligent fire alarm systems and locators			
0/88	Dry fire extinguishing systems	Extinguish the fire		
0/84	Intelligent fire extinguishing systems			
0/80	Mineral coating with gypsum	Structural strength		
0/79	Fire resistant paints			

Step 6:

The confirmation of research validity in this step is conducted based on the appropriateness of the questionnaire. At this stage and after determining the factor load of each of the factors explaining fire stability, by assigning points to each of the indicators, in comparison with standard scores, evaluation and fitness test and the significance of the relationship between variables is measured. According to the application of Laser Software in this study, for the mentioned indicators, the factor weight and the fitness index of each variable are determined to identify the relationship between each of the relevant indicators and the relevant factors

Tab6: Component Impact Factors (source: author)

Impact coefficients of components				
Errore rate	Khi-Do	Critical Level	Factor Load	Effective Components
0/00	78/67	4/51	1/41	Technological features
0/00	70/21	4/21	1/37	Building features
0/00	60/21	3/51	1/25	Fire features

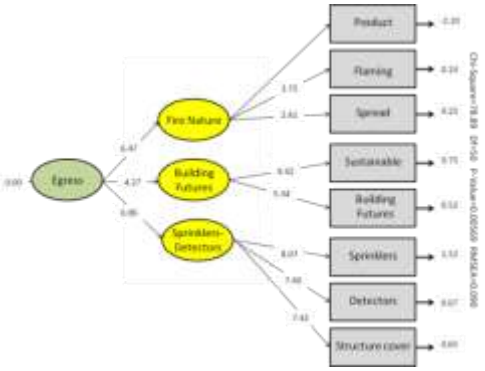
Step 7:

The purpose of path analysis in this step is to obtain quantitative estimates of the causal relationships between the set of variables affecting the stability of buildings against fire. In this study, 18 measures in the form of 8 indicators affecting the stability of buildings against fire are summarized by factor analysis and reduced to 3 main elements (hidden variables) and presented as a combination of significant factors. Then the effect of each of them is entered as a variable in LISREL Software. These variables were analyzed

and processed to explain the impact on the stability of the building against widespread fire and using the output model of multi-criteria decision making and experimental model.

3.Research Findings:

One of the most important requirements of building design is to ensure the safety and stability of the building against fire accidents. The more important a building is socially, politically, culturally, economically or humanly, the more is necessary to ensure the building's resilience in the event of a fire. Figure 5 shows the relationship between variables and indicators in LISREL Software. In this step, the characteristics have been able to explain each element as well, or in the other words, to establish a meaningful relationship between them; in the fitting model (Figure 6), a significant relationship between fire resistance and variables with indicators is shown simultaneously.



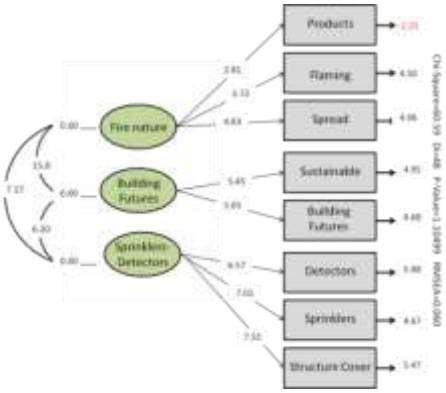
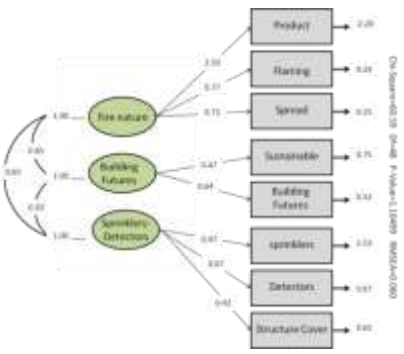


Fig5: Fire Resistance Process Analysis Model and Explanatory Indicators (source: author)

Fig6: Structural Model of Components Affecting Fire Resistance (source: author)

Findings show that in the relationship existed between independent variables and dependent variables, the independent variable is the nature of fire and its constituent micro-dimensions such as ignition rate and heat of combustion have less explanatory power than the other two hidden variables. On the basis of the fitting of the data extracted from the structural model in LISREL Software, the independent variable of building design and the micro-variable of architectural warping design against fire have the highest explanatory characteristic of the dependent variable, followed by the variable of firefighting technology which has more explanatory power. The main difference between the research findings and the theoretical foundations of the research is to determine the priority of designing the resilient architecture of a building against fire over the design of automatic fire alarm and extinguishing systems. In this way, Iranian experts consider as a conditional and dependent issue of fire resistance of a building to the potentially resilient and correct architectural design of a building in phases one and two of the architecture of the building and not on, or regardless to the fire extinguishing technologies used in the building.



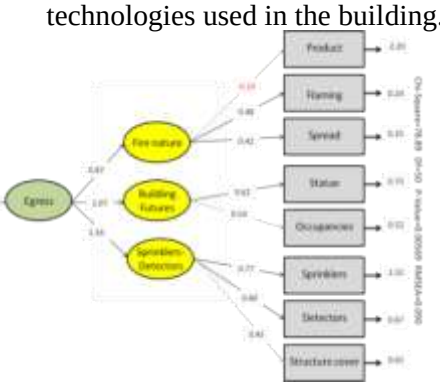


Fig7: Fitting the model of factors affecting fire resistance (source: author)

Fig8: Fitting Structural Model to Factors Affecting Fire Resistance and Explanatory Components (source: author)

Based on the data extracted from the structural equations driven from LISREL Software and their analytical fitness, according to the consensus of experts participating in the field research, the most important threat to the stability of the building after the initial fire, depends neither on the nature, nor is the location and temperature of the flame of fire at the time of the primary source of ignition, but it also relies on the method and power of spreading the fire to other usages and floor levels through communication shafts or installation ducts. The question of which of the architectural resilience design patterns of a building can contain the fire in the early stages of the flame in a certain area until it is extinguished or minimize the possibility of its occurrence, in their view, shall be considered as the most important variable of building stabilization against fire. The findings of the present study indicate that, from the perspective of experts participating in the study, the division of architectural spaces of a building into fire-resistant independent areas with behavior independent of other parts, in order to prevent the possibility of the spread of the fire to other areas of the building for a specified period shall have the most important effect of the fire resistance of a building. Thus, the issue of controlling the spread of fire in the earliest stages of fire through architectural resilient design has the highest importance according the view of experts participating in this study. In the second place, after the resilient design of a building against fire, design of intelligent or smart fire extinguishing systems remains in the initial moments of firing. Contrary to the opinion of European and American researchers who rely heavily on intelligent fire alarm and extinguishing systems to combat the risk of fire in the building, Iranian experts consider the position of technology to be resilient only after the position of design. At this stage, in their view, the correct placement of building fire extinguishing technologies so that the system notices the flame in the first moments of the fire and starts the extinguishing operation is significantly important. However, in many cases, there is a possibility of technical defects of systems located in buildings due to the spend of time and the emergence of culture and technologies of using such devices in the building. In the third place, the importance of the independent variable of building coatings against fire independent technologies. The findings of the present study indicate that if for any reason, the fire is not extinguished in the initial moments of its ignition, after a certain period of time, it will leave an independent choice to leave out the structure according to the architecture of the building. It then engulfs a building by destroying ducts or passing through communication shafts throughout a building. In this case, the structure of the building must withstand the heat caused by the widespread fire until it is extinguished by the forces of the fire department to protect the building from collapsing during the fire (such as Tehran Plasco Structure) and remain stable after the fire is completely extinguished to return the usual loads on it and do not let the building go out of use.

Fig9: Fitting Structural Model to Factors Affecting Fire Resistance and Explanatory Components (source: author)

The lowest coefficients of influence in the evacuation process go back to the nature element of the fire, so research reveals that the inability to extinguish a fire at the initial time of ignition and its unbridled expansion has such a devastating effect that practically identifying the type of fire and its maximum temperature will not have much effects in the eyes of experts. In other words, any kind of fire, with any kind of nature, if it is not identified and extinguished within due time, after its expansion in level and height, will have such a destructive effect on the building that it will not allow its residents to reuse the building after the fire.

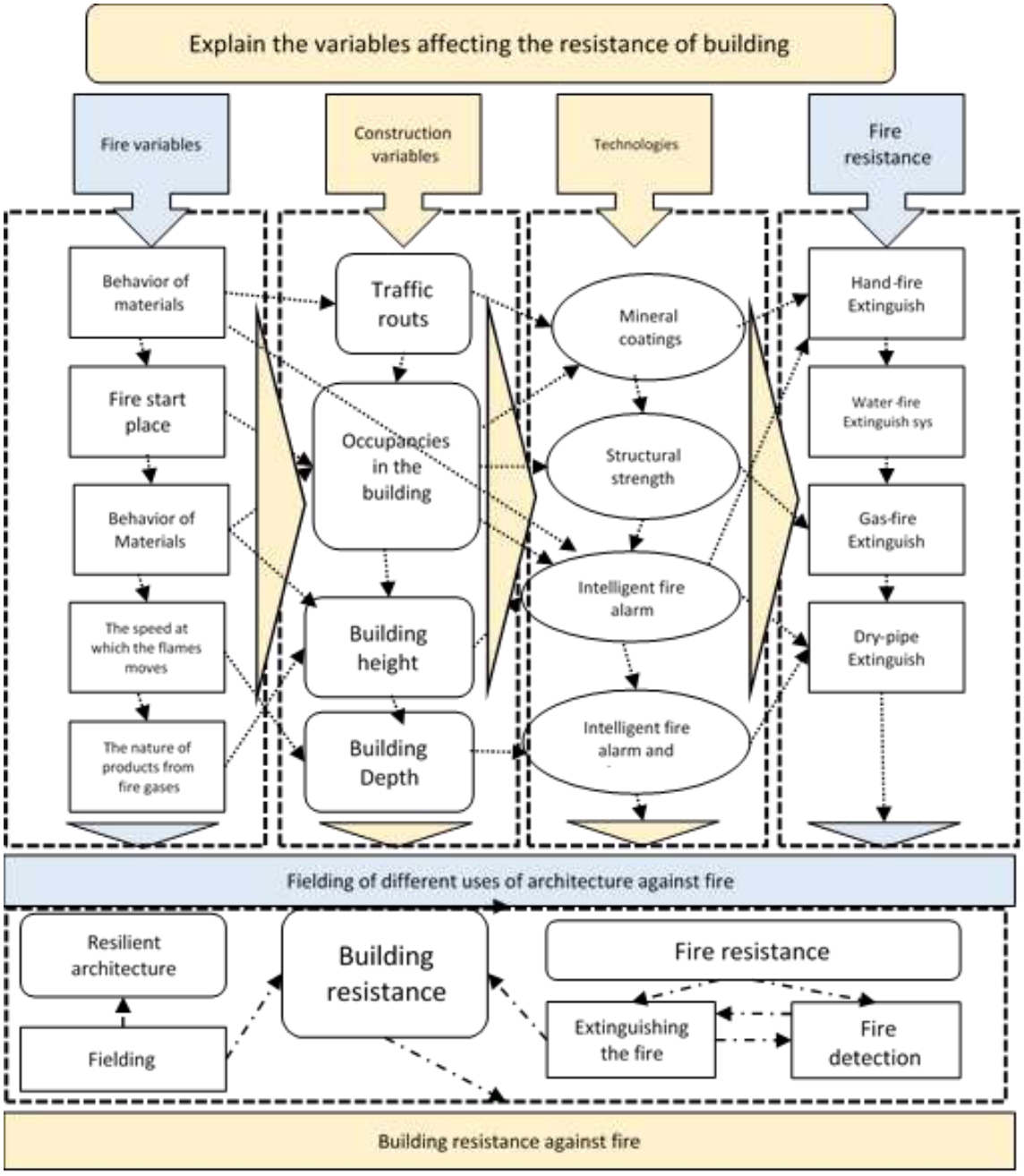


Figure 10. illustrates the conceptual model derived from the phenomena affecting the fire resistance of the building.

4.Conclusion:

According to the main question of the research on identification of the variables affecting the stability of a building against fire hazard, effective elements, based on the consensus of experts of the Tehran Municipality Fire and Safety Services Department by screening several elements derived from the theoretical foundations of the research together with the help of Delphi-fuzzy method in 3 stages, all the dimensions considered by the experts were classified into three sub-variables: "nature of fire", "building design" and "firefighting technologies". Then, by preparing a final questionnaire based on the Likert scale and after obtaining statistical validations, in the LISREL Software, structural equation analysis software, the weights of the effect of each variable on the dependent variable (building resistance against fire) were determined. According to the information obtained from the analysis of structural equations in LISREL Software, it was determined that among the experts of the fire department and the elite students in postgraduate studies in construction and Civil Development sciences, the variable of independent zoning of building uses against fire spread is one of the resilient design element of building architecture. Fire is considered as of the utmost importance in stabilizing a port against the risk of widespread fire. In the next rank we consider the element of intelligent or smart fire extinguishing by rainfall systems of fire alarm and extinguishing technologies, and in the third rank is the element of mineral and gypsum coatings of the same variable. The findings of this study showed that the priority of resilient architectural design of a building against fire from the perspective of Iranian elites and researchers is superior to automatic fire extinguishing and other extinguishing technologies and structural coating. In this way, Iranian experts consider the issue of fire resistance of a building to be potentially dependent on the potentially resilient and correct architectural design of a building in phases one and two of the building architecture, and then the supplement of resilient design, fire extinguishing technologies used in the building. They are known to affect the stability of a building in the event of occurrence of wider fire.

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