ITU A|Z • Vol 20 No 1 • March 2023 • 247-264

An analytical approach to identify design criteria for reducing earthquake risks in residential interiors

S. Banu GARİP[1*], Ervin GARİP[2], Zeynep BİRGÖNÜL[3], Handan GÜZELCİ[4]
[1] baseskici@itu.edu.tr • Department of Interior Architecture, Faculty of Architecture, Istanbul Technical University, Istanbul, Turkey
[2] ervingarip@itu.edu.tr • Department of Interior Architecture, Faculty of Architecture, Istanbul Technical University, Istanbul, Turkey
[3] birgonul19@itu.edu.tr • Department of Interior Architecture, Faculty of Architecture, Istanbul Technical University, Istanbul, Turkey
[4] handanduyar@gmail.com • Department of Interior Architecture and Environmental Design, Faculty of Architecture, Istanbul Kultur University, Istanbul, Turkey

**Corresponding author*
Received: November 2022 • Final Acceptance: January 2023

Abstract
A vital measure to prevent earthquake risks is to retrofit existing buildings or design and construct resistant structures. After increasing the earthquake resistance of buildings, measures taken in building interiors comes to the forefront. In the scope of this study, comprehensive analytical research is conducted to identify the criteria for reducing earthquake risks in the design of residential interior spaces. Reviewing the literature of both national and international publications using the keywords and phrases "Earthquake and Interior Design" "Earthquake and Furniture Design", "Earthquake and Architectural Design", "Earthquake and Materials", "Precautions for Earthquake Damages", "Earthquake Psychology" is employed as a method. In the next step, criteria extracted from the content analysis are categorized, analyzed and evaluated systematically. Together with this research, a set of measures to reduce earthquake risks for the interior design of residential interiors was presented. It also includes risks and strategies related to categorized interior elements, which designers can use in the design process. Many people could be inside residences, where most daily life is spent during an earthquake. This describes the study's widespread impact. The design criteria presented are expected to be a source that includes a set of categorized data with a holistic approach to reduce risks, leading to safe design, and ensuring up-to-date continuity of knowledge for future designs.

Keywords
Earthquake risk reduction, Interior architecture, Secure design, Housing interiors.

doi: 10.58278/0.2023.4

1. Introduction

During history, earthquakes have always carried life-threatening risks. The loss of life and the destruction they have caused in the built environment have always been considered inevitable. Even though such natural disasters are unavoidable and unpredictable, it is possible to take precautions. In this context, studies on the detection and prevention/reduction of earthquake risks have gained significant importance.

Turkey is located in a region prone to earthquakes, but there are different levels of seismic zones. The city of Istanbul is a megacity where a major earthquake is expected in the near future. Besides, it is a fact that several other cities nearby will also be affected by seismic events. Previous experiences and future predictions show that it is of great importance to be aware of this fact and to take necessary precautions. Within the scope of studies aimed at detecting and preventing earthquake risks and reducing its hazards, the most important measures to be taken are the correct placement of buildings, their durability and the earthquake resistance of structures. Assuming that these measures are taken, as a next step, risks can be reduced with design measures in the interior spaces. The fact that a large number of the population would be inside residential buildings during an earthquake, emphasizes the study's importance. In this context, this study aims to identify the design criteria necessary for reducing earthquake risks in residential interiors. A holistic documentation approach to reduce earthquake risks is followed to attain a set of criteria for residential interior design.

Since Turkey is a country located in an earthquake zone, experiences from past events and future projections indicate that developing collective awareness is of great importance by taking all necessary measures to reduce risks. In the case of strong earthquakes, even if buildings do not collapse entirely, destruction in the interior spaces may occur. In circumstances like these, providing earthquake-safe interior design may greatly impact resident safety during such a calamity. With precautions taken indoors, lives may be saved.

In this article, the first phase of the research, which has been conducted as a TUBITAK 1001 (The Scientific and Technological Research Council of Turkey) project with the title "Determining Design Criteria for Reducing Earthquake Risks in Housing Interiors and Developing a Design Model Defining Reduced Risk Areas", is presented. The importance of interior design studies and the limited resources in the interior design discipline are emphasized, focusing on reducing earthquake risks. Following the introduction, we explain our research methodology, which comprises an extensive literature review, analysis and synthesis of the bibliographic resources. Lastly, the outcomes of the literature review are evaluated systematically. We conclude the paper by presenting the limitations and foresight of the research. This research is a holistic documentation study, presenting a set of criteria to reduce earthquake risks in residential interior design. The design criteria include risks and strategies related to categorized interior elements that designers could use in the design process.

2. Earthquake risks and approaches to reducing hazards in interior spaces

Technical indices, including structural strength, maximum story drifts and maximum response acceleration, generally evaluate the seismic safety of buildings. These indices are highly specialized and generally only understood by structural engineers, while there is an increase in the expectation from other professions to understand the seismic performance of the buildings (Hamaguchi et.al., 2013). When the literature is examined, it is seen that most studies are done in the field of civil engineering on the structural aspects. Even though the studies and publications in various fields investigating earthquake risks and effects could be considered bibliographic references for research on interior design, they do not directly explore interior spatial design. These studies, from where the necessary data can be collected, specifically focus on furniture design rather than interior architecture or environmental design. Therefore, there are minimal resources for designing interiors taking earthquake hazards in account. It is observed that the existing studies examining earthquake risks in interior design and focusing on strategies to reduce the undesirable effects of seismic events in interior spaces are limited. It is thus crucial to identify the risks related to interior design decisions and to be able to take precautions in the design process for existing interior spaces to reduce the damage that might be created during an unexpected seismic movement or a greater disaster.

Furniture design studies (Aytöre, 2005; Ahmadnejad & Darbandi, 2015; Chen et.al. 2015; Kaya et.al. 2018; Sweet, 2018; Grimley & Love, 2018) mostly focus on furniture or combination-assembly details rather than holistic solutions regarding the furniture-space relationship recommendations. Studies that take into account earthquake effects within buildings investigate the effects on furniture or non-structural elements (Cimellaro et.al., 2020; Yeow et.al. 2018; Ipek et.al., 2015; Filiatrault & Sullivan, 2014).

Motion analysis of furniture under seismic load is investigated with specific research outcomes. For instance, as a method, within several studies, shake table experiments were revised (Furukawa et.al., 2013; Meguro et al., 2008). In such studies, according to the selected earthquake records, the effect of the vertical acceleration on the non-structural elements was examined with the accelerometers placed in specific places in the building.

Studies focusing on interior design to prevent earthquake risks have generally dealt with the subject within the scope of room scale, user behavior, interior ethics or general precautions to be taken indoors (Demiraslan, 2005; Karamanoğlu & Ulay, 2017; Kaya et.al., 2018; Doğan, 2020). In this context, it is seen that there are different approaches to the subject. Doğan (2020) proposed to adapt ergonomic interior and furniture design principles of mobile spaces, which are defined as places where the action of moving from one place to another for the purpose of transportation or travel, by vehicles such as caravans, boats, trains, and planes takes place, and used them as a reference for the interiors of buildings in earthquake-risk areas. In their study, Ahmadnejad and Darbandi (2015) examined how the earthquake-safe design of furniture could be made based on the idea of creating a life triangle in nurseries. Studies on the precautions to be taken in existing spaces (Alıcı, 2019; Albayrak, 2005; Bernardini et.al. 2016; Hürol, 2014) define the principal decisions as a whole. AFAD (Turkish Ministry of Interior Disaster and Emergency Management Presidency) has published a comprehensive statement on the precautions to be taken before an earthquake (AFAD, 2011-1; AFAD, 2011-2; AFAD, 2011-3; AFAD, 2019). Based on previous experiences, these measures provide critical information for the study of design criteria for reducing earthquake risks.

Within the scope of the study, sophisticated design approaches in countries such as Japan, which are located in earthquake-risk areas, also gain importance (Clancey, 2006; Borland, 2020; JASO, 2021). In Japan, a society that has learned to live with earthquakes, examining their traditional and contemporary houses reveals that a habit of using minimal space and furniture has developed over time (Demiraslan, 2016). It is seen that Japanese architecture has many features that can be examined as an example of interior spaces as well as architectural design.

3. Methodology

National and international publications on earthquake risks and approaches for reducing risks in interior spaces are reviewed. Qualitative data is collected to define the criteria using the content analysis method. Classifications related to the spatial components and component groups in residential interiors are determined and design criteria is researched according to these categories.

Books, theses, articles, papers, research, regulations, publications of institutions related to disaster and emergency management such as AFAD have been systematically examined. Using the content analysis method, the data to define the criteria were collected under the headings of "risks" and "strategies" at this stage. The aim is to enable the designer to use the risks and strategies defined in the literature as a holistic data set within the scope of the determined categories while designing residential interiors. In the context of the evaluation made using the content analysis method, the categories of residential interior components were defined, and the data to be presented as the design criteria in the context of these categories were determined. In Figure 1, the methodology steps are presented.

3.1. Literature analysis

Content analysis is a method used to analyze the content of various data, such as visual and verbal data, allowing facts or events to be reduced to defined categories in order to analyze and interpret them systematically (Harword & Garry, 2003). White and Marsh (2006) describe the method as a very flexible research method that is widely used in library science and information science studies. This method uses a wide variety of analytical techniques to generate and contextualize qualitative, quantitative and sometimes, mixed findings.

In this study, the existing literature was reviewed by a group of six scholars. The literature review team consists of architects, interior designers and a civil engineer. The initial step was to decide on the scope of the literature review, therefore, an initial bibliographical scan was made. As a result of this step, the main categories and keywords were defined. Those keywords and phrases are listed as; "Earthquake and Interior Design" "Earthquake and Furniture Design", "Earthquake and Architectural Design", "Earthquake and Materials", "Precautions for Earthquake Damages", "Earthquake Psychology". This definition depends on the availability of the existing references in qualified indexes and databases, the context's relatability and, last but not least, the conformity of the publications and their benefit.

Consecutively, those keywords and phrases are scanned severally via Web of Science (WOS), Scopus and Google Scholar databases. As a result of this scan, over 200 related articles, proceedings, thesis and reports are obtained. Due to the necessity of a more refined review, another election has been made through this content. Consequently, 68 documents are chosen as the publications to be examined within the scope of the research (Figure 2).

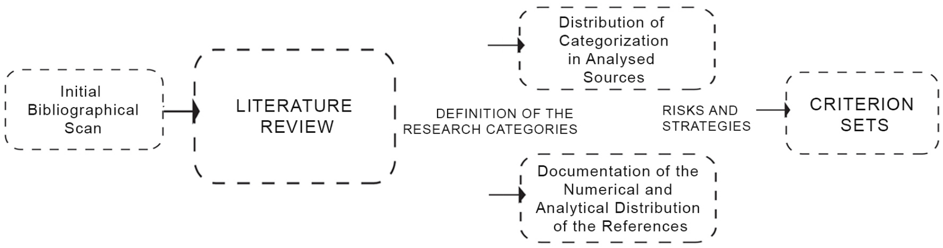

Figure 1. *Research methodology diagram.*

Figure 2. *Publications examined within the scope of the research.*

3.2. Categorization of the criteria

Following the initial bibliographical scan, in relation to the literature analysis, the components that can be used in the residential interior design process were categorized as, "fixed furniture", "mobile furniture", "objects", "non-structural elements", "electrical appliances", "technical equipment" and "lighting fixtures". Table 1 shows the numerical values showing the distribution of these categorization titles in the analyzed sources. Accordingly, it is seen that the studies mainly focus on "fixed furniture" and "non-structural elements" (Table 1).

The primary purpose of creating these category sets is to make a qualitative analysis and synthesis of the subject in the residential indoor areas and define the problems within this framework. The categorization of the criteria is defined regarding the interdisciplinary research analysis, within a range of fields such as architecture, interior design, furniture design, psychology, civil engineering and earthquake engineering.

3.3. Analysis and evaluation of data

As a result of the research analysis, a set of risks and strategies for earthquake hazards documented in the literature is created. "Risks" define situations that may cause damages or danger in interior spaces during an earthquake,

Table 1. *Distribution of categorization in analyzed sources.*

Category	Count of Involvement	Sources
FIXED FURNITURE	23	AFAD (2011-1), AFAD (2011-3), Alıcı (2019), Ayrılmış et.al. (2015), Aytöre (2005), Cimellaro et.al. (2020), Demirarslan (2016), Doğan (2020), ECA (2011), ECA (2016-1), FEMA (2020), Filiatraut & Sullivan (2014), Galloppo et.al. (2019), Karamanoğlu & Ulay (2017), Lewis et.al. (2018), Meguro et.al. (2008), Pietroni et.al. (2021), Spagnoli (2020), Sweet (2018), Taymaz & Sarı (2017), Ulay & Bekiroğlu (2016), Yeow et.al. (2020)
MOBILE FURNITURE	11	Akhand (2018), Ayrılmış et.al. (2015), Chen et.al. (2015), Galloppo et.al. (2019), Isobe et.al. (2018), Kaya et.al. (2018), Lewis et.al. (2018), Pietroni et.al. (2021), Spagnoli (2020), Sweet (2018), Yeow et.al. (2018)
OBJECTS	11	AFAD (2011-3), Akut (2009), Chen et.al. (2015), Demirarslan (2016), Doğan (2020), ECA (2011), ECA (2016-1), FEMA (2020), Karamanoğlu & Ulay (2017), Kaya et.al. (2018), Yeow et.al. (2020)
NON-STRUCTURAL ELEMENTS	14	AFAD (2011-1), AFAD (2011-3), Ertaş Beşir & Dereci (2021), FEMA (2006-2), FEMA (2020), Filiatraut & Sullivan (2014), Hurol (2013), Rodgers et.al. (2021), Sweet (2018), Yeow et.al. (2020), Yeow et.al. (2018), Zaryoun & Hosseini (2019), Zhang & Huang (2017)
ELECTRICAL APPLIANCES	6	AFAD (2011-1), AFAD (2011-3), ECA (2011), ECA (2016-1), Ertaş Beşir & Dereci(2021), FEMA (2020)
TECHNICAL EQUIPMENT	2	AFAD (2011-1), AFAD (2011-3)
LIGHTING FIXTURES	11	AFAD (2011-1), AFAD (2011-3), ECA (2011), ECA (2016-1), Ertaş Beşir & Dereci (2021), FEMA (2006-2), FEMA (2020), Kaya et.al. (2018), Rodgers et.al. (2021), Ulay & Bekiroğlu (2016)

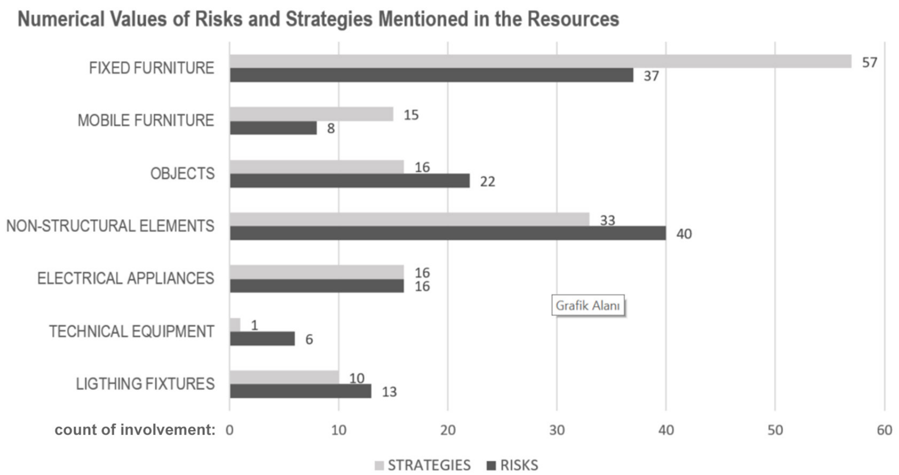

Figure 3. *Numerical values of risks and strategies mentioned in the resources.*

and "strategies" define proposed solutions to prevent these damages. All the risks and strategies mentioned in selected references are compiled in a chart. Figure 3 presents the numerical values of the defined risks and strategies. The analysis reveals that risks and strategies are mainly discussed within the scope of "fixed furniture", "non-structural elements", and "objects" categories. In addition, "electrical appliances" are discussed with an average amount. Lastly, the least discussed elements are the "lightning fixtures" and the "technical equipment" categories.

Some references address only one category specifically, while others consider more than one category. In the previous table (Table 1) the distribution of the categories was documented. Following the compilation of resources, further documentation is created by defining the criterion sets per each category. The data was evaluated with an analytical study, and a table was created that summarizes how risks and strategies are defined within the scope of the categorization (Table 2). Thus, the analysis has become a set of criteria for defining risks and strategies. Table 2 is the compilation of the literature reviews' outcomes that can guide the designer and the occupant through earthquake awareness.

3.4. Synthesis of category results derived from the literature review

In this section, the detailed documentation of each category is explained, and the results are discussed through graphical representations. The numerical values presented within the graphics give information about which criteria and how often they are considered in the references.

3.4.1. Fixed furniture

The literature review on fixed furniture category outcomes is summarized, and numerical values of the sources in which the criteria titles are mentioned are presented in Figure 4. The principal risks related to fixed furniture are defined as "tumbling", "breaking", "blocking the escape route" by falling and pulling the structural elements. The most frequently proposed strategy for reducing risks are "fixing" and related with the use of "material". Since one of the most discussed risks in kitchen cabinets is the spillage of objects they contain, it is often recommended to install a cabinet lock.

In the study by Meguro et. al. (2008) the effects of furniture tipping prevention devices were analyzed, and their effectiveness was evaluated by shaking table tests. It aims to increase people's awareness of dangers and risks through animations and visualizations produced from numerical simulations of the dynamic behavior of furniture at the living room scale when an earthquake occurs, using virtual reality tools. As a result of the study, based upon the results for a 20-story building case, three possible solutions were suggested: to decrease the structural response using building vibration control systems, to use more efficient overturning prevention systems, or to use only built-in type of storing spaces so that potential overturning objects are not used at all (Meguro et.al., 2008). Alıcı (2019) mentions that there are risks of tumbling or overturning of furniture in the event of an earthquake. Fixing and locking measures to be attached to different furniture types that may prevent loss of life are possible solutions (Alıcı 2019). Galloppo et.al. (2019), investigate the possibilities to innovate and transform, from a structural and functional perspective, the design of furniture and mobile equipment in intelligent safety systems that can contribute to the protection of life within their study. In this context, a series of data collection activities of patents and anti-seismic furniture products and interdisciplinary research is carried out. Three levels of project intervention have been identified for safety: Light: anticipates the use of anti-tip devices in common wall-mounted storage systems. Intermediate: includes the development of furniture and protection devices resistant to dynamic and static loads. Heavy: refers to the installation of systems able to collaborate and improve the anti-seismic capacity of the building through the realization of partially modular reinforcements and structures for the development of bunker type protection spaces (Galloppo et.al., 2019).

Aytöre (2005) defines furniture tumbling and breaking risks and suggests that the location, production methods and furniture placement in the face of a great earthquake have effects that can save, as much as they can harm people. Using lightweight materials, fixing, locking, and placing the center of gravity to the underside of the furniture will be beneficial in taking precautions against earthquakes (Aytöre, 2005; Filiatrault & Sullivan, 2014; Ayrılmış et.al., 2015). Karamanoğlu & Ulay (2017) describe the risks of furniture falling, opening and tipping over and they underline the necessity of using light materials for manufacturing furniture and fixing them to the building elements. Akhand (2018) proposes curvilinear finishes to decrease the risks of injuries in the case of crushing.

A study conducted in New Zealand (Sweet, 2018) under the title of "Earthquake Resilient Furniture", examines the psychological impact of furniture as well as its functionality in manufacturing. It demonstrates the necessity of creating new designs that prioritize and support not only the function but also the psychological resilience of the de-

Table 2. *Criterion sets and categorization.*

	RISKS	STRATEGIES
FIXED FURNITURE		
STORAGE ELEMENTS (Wardrobe, Closet, Dresser)	Tumbling	Fixing
	Breaking	Material
	Pulling	Placement
	Blocking the Escape Route	Modularity / Flexibility
		Height Limit
		Design that Provides Psychological Support Against Seismic Events
		Universal Design
		Linking / Locking
		Anti-seismic Design
SHELVES (Bookcase, Glass-door Cabinet, Open Shelves)	Tumbling	Material
	Discharge	Fixing
	Incorrect Arrangement	Modularity / Flexibility
	Causing Injuries	Height Limit
		Closing
		Design that Provides Psychological Support Against Seismic Events
		Linking / Locking
		Hiding Shelves and Drawers
		Load-bearing
KITCHEN CABINETS	Discharge	Lightweight Material
		Cabinet Locks
MOBILE FURNITURE		
CHAIRS	Crushing (Human)	Integrating Protective Structure
		Integration to Structural System
COFFEE TABLES, SIDE TABLES	Negative Psychological Effect on Seismic Events	Material
		Design that Provides Psychological Support Against Seismic Events
TABLES	Negative Psychological Effect on Seismic Events	Material
	Discharge	Design that Provides Psychological Support Against Seismic Events
	Tumbling	Load-bearing
	Breaking	Integration to Structural System
CHAIRS	Replacement	Material
BED	Crushing (Human)	Resistance
		Load-bearing
		Adding an integrated sheltering unit
OBJECTS		
DECORATION, ACCESSORIES, DANGEROUS GOODS	Falling	Fixing
	Slipping	Avoid the Usage
	Causing Injuries	Simplification
	Fire, Explosion etc.	
POTS	Falling	Fixing
	Causing Injuries	Avoid the Usage
MIRRORS / FRAMES / ARTWORK	Falling	Placement
		Hanging with Hooks

Table 2 (continued). *Criterion sets and categorization.*

NON-STRUCTURAL ELEMENTS		
WALL PARTITIONS	Fire-resistance	Material
	Negative Psychological Effect on Seismic Events	Design that Provides Psychological Support Against Seismic Events
	Bending	Fixing with Braces
	Breaking	Strong Construction
	Causing Injuries	Infill Wall
	Cracking	Integration to Structural System
		Flexibility
SUSPENDED CEILING	Downfall	Reinforcement
	Swinging	Swing and Crash
	Falling	Ceiling Support / Wall Distance
	Breaking	Fixing
	Causing Injuries	New Material Research
PLUMBING	Explosion	Correct Calculation
	Pipe Breaking	Material
DOORS	Bending	Seismic knuckle
	Blocking the Escape Route	Planning the Arrangement
	Breaking	
WINDOWS	Glass Breaking	Material
	Explosion	Mobile Windows
		Laminated / Double-glass
		Planning the Arrangement
FLOOR COVERINGS	Slippery - Shifting (Human)	Alternative Material Research
ELECTRICAL APPLIANCES		
TV	Tumbling	Fixing
REFRIGERATOR	Tumbling	Placement
		Fixing
COMPUTERS	Slipping	Fixing
		Non-slippery Material
OVEN - STOVE	Explosion	Flexible Joinery
TECHNICAL EQUIPMENT		
WATER BOILER	Falling	
	Fire	
GAS HEATER	Tumbling	Fixing
	Falling	
	Fire	
RADIATORS	Falling	
LIGHTING FIXTURES		
LAMPS	Falling	Material
	Breaking	Fixing

signs. Sweet (2018) suggests that while seismic design at the architectural scale targets the mitigation of physical hazards, furniture offers unique opportunities to address factors beyond physiological needs. With its human-scale and inherent relationship to the body, furniture invites meaningful tactile and emotional connections in the interactions elicited through its essential function as an interface (Sweet 2018).

3.4.2. Mobile furniture

The literature review on mobile furniture category outcomes is summarized, and numerical values of the sources in which the criteria titles are mentioned are presented in Figure 5. The risks of mobile furniture in residential spaces are documented as, crushing of the occupants, breaking, tumbling (Ayrılmış et.al., 2015; Kaya et.al., 2018; Chen et.al., 2015; Yeow et.al., 2018; Sweet, 2018; Akhand, 2018), replacement and wrong placement (Lewis et.al., 2018), discharge of the objects stored inside cabinets that might cause injuries, and negative psychological effects of seismic events (Galloppo, 2019). In general, the recommendation to avoid tumbling is mainly coined as fixing. Moreover, reconsidering the density of use, using light materials and using modular furniture can be considered as measures to prevent possible hazards of a seismic event. Also, mobile furniture could block the escape route and prevent the mobilization of the occupant, which is considered a significant risk factor.

Sarı & Aktar (2017) state the importance of implementing universal design principles to prevent escape route

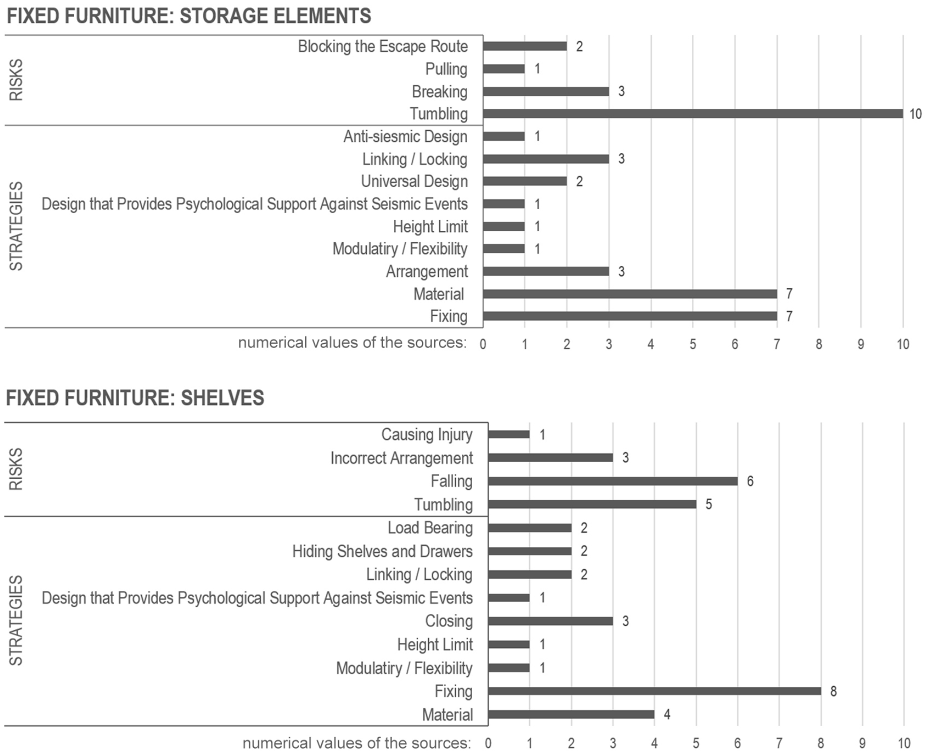

Figure 4. *Fixed furniture: numerical values of the sources in which the titles of the criteria are mentioned.*

blockages. Therefore, mobile furniture that may fall and block the escape routes must be secured, locked or fixed to the walls. If the furniture has shelves or doors, they must be fixed to prevent the spilage of items which could clock escape routes or cause injuries. Likewise, Karamanoğlu & Ulay (2017) state the importance of material selection strategies, using light materials for mobile furniture manufacturing and fixing the furniture to the building elements. Additionally, providing flexible and ergonomic solutions for mobile furniture should be considered (Spagnoli, 2020). Doğan (2020) proposed concealing shelves and drawers and integrating with the structure to reduce risks.

Ulay & Bekiroğlu (2016) conducted a survey to investigate the effects of specific furniture in a seismic event. This study confirms that the overturning and tumbling of cabinets, the spilling of shelves, the opening of kitchen cabinets, damage to furniture, the obstruction of escape routes, and the falling and breaking of lamps can be prevented. This can be done by fixing shelves, locking and securing cabinets, using light materials, and choosing lamps with light materials (Ulay & Bekiroğlu (2016).

The risks of injury and crushing caused by large moving furniture such as beds are mainly the injuries caused by the falling of other elements on the beds' occupants. Therefore, a protective system proposal has been developed by Zhang & Huang (2018) that has a bedside table with earthquake self-rescue function of 12 seconds. In the same study, the fixing of furniture and objects are proposed. Similarly; Pietroni et. al. (2021) discuss the low strength of the tables under load; therefore, they do not offer a protective function in case of earthquake (in case of using the table as a protective surface or a hiding area). They also study innovative furniture design proposals in horizontal and vertical planes that will provide protection during earthquakes, which could increase the material strength and can carry loads. Also, Kaya et. al. (2018) state integrating protective structures into furniture as a strategy.

On the other hand, Demiraslan (2005) investigates the cultural effects on the usage of furniture and examines the habits of interior arrangements from a cultural perspective. In this study, minimalizing the amount of furniture and the hazards caused by overdesign is discussed in line with earthquake awareness creation.

Due to the fact that mobile furniture, by their function, cannot be fixed to a structural element on a daily basis, the optimal proposals for hazard prevention strategies could be summarized as using appropriate, lightweight materials, minimal details and oval corner solutions are suggested for furniture design (Doğan, 2020).

In a study by Isobe et. al. (2018), the movement of furniture is modeled with DEM (Discrete Element Method). However, furniture is considered a rigid element in modeling with DEM, and furniture's effect on the environment (stresses and deformations) is not modeled. Modeling with FEM (Finite Element Modeling) was used in this study; therefore, friction between the contact surfaces was also considered in the model. According to the experiment's results, they defined the movement of the furniture. Three different placements with office furniture were considered: the furniture's motion should change depending on the input wave, friction coefficient of the contact face, and furniture configuration (Isobe et.al., 2018). A single item of furniture would make rocking or translational motions and eventually tumble. Overlaid furniture such as separated cabinets, would exhibit very complex behavior; the whole cabinet could fall in one piece, or the upper cabinet may tumble after making rocking and translational motions on the lower cabinet. Furniture with casters would generally slide along the floor (Isobe et a 2018).

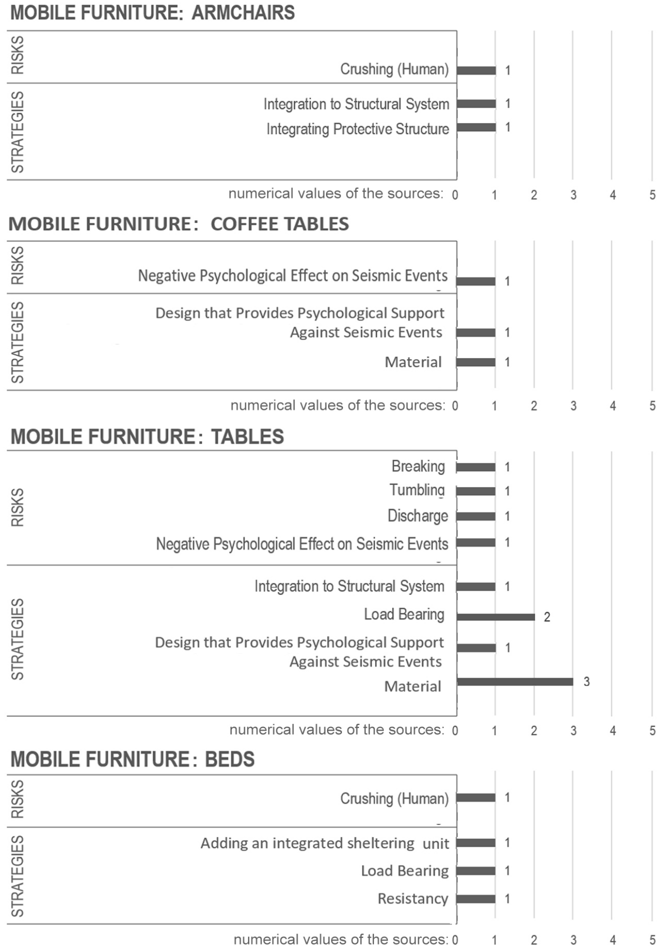

Figure 5. *Mobile furniture: numerical values of the sources in which the titles of the criteria are mentioned.*

3.4.3. Objects

During an earthquake, objects such as books, files, medicines in hospitals or pharmacies, laboratory materials in schools and workplaces, various chemicals, products for sale or storage in commercial units, and museum artifacts may fall. Financial losses and injuries, as well as the risk of fire, may occur as a result of falling objects (AFAD, 2011-3). The literature review on object category outcomes is summarized and numerical values of the sources in which the headings of the criteria mentioned are presented in Figure 6. Many researchers emphasize the importance of placing storage systems (cabinets, shelves, etc.) in appropriate parts of buildings and connecting them to structural elements such as walls and/or slabs in this context (ECA, 2011; ECA, 2016; Chen et al., 2015; Doğan, 2020; Karamanolu & Ulay, 2017). The type of precaution varies according to the size of the object. For large books, a wooden mechanism at the bottom of the shelf and durable straps in the middle are recommended (AFAD, 2011-3).

The primary precaution to reduce the risks of non-structural damaging earthquakes is to reduce the number of movable objects (Demirarslan, 2016). Another critical precaution for this type of earthquake is to organize and place moving objects from the heaviest to the lightest, from the bottom to the top (ECA, 2011; FEMA, 2020).

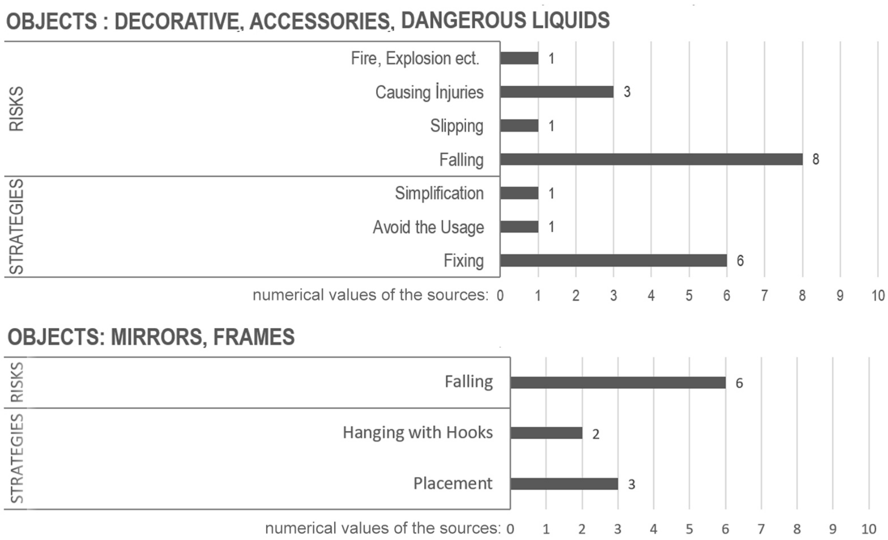

Figure 6. *Objects: numerical values of the sources in which the titles of the criteria are mentioned.*

Lock elements must be installed on the doors of cabinets where fragile objects are stored, and these objects should be stored in cabinets that are fixed to the building elements (ECA, 2011). It is recommended to apply putty, clear quake gel, or microcrystalline wax to the base parts of objects that rest on shelves to prevent slippage and breakage of objects of high value (vases, bottles, etc.). Another precaution is to fix such objects or to place them on non-slip pads (AFAD, 2011-3; Chen et. al. 2015; ECA, 2011; FEMA, 2020).

Other strategies for reducing earthquake risks in kitchen cabinets include installing lock systems on cabinet doors and creating slots in shelves for individual objects (Doğan, 2020; ECA, 2011). Toxic and flammable materials used in laboratories and residential units should be removed from the main circulation routes, and to ensure safety, their quantities should be limited (FEMA, 2020).

It is recommended to use hanging hook screws suitable for the object's weight when hanging objects (chandeliers, flowerpots, frames, mirrors, etc.) (AFAD, 2011-3; ECA, 2011; ECA, 2016). When hanging objects such as picture frames on a wall, it is recommended to use soft materials (rubber, felt, etc.) on the back surfaces of the objects; frames can be attached to walls with adhesives such as putty, clear quake gel, or microcrystalline wax (AFAD, 2011; ECA, 2011). Furthermore, objects placed on the walls near beds should be light and soft to prevent them falling and causing injury during an earthquake (ECA, 2011).

According to research done by AFAD (AFAD, 2011-3) tempered glass should be used for interior design elements and objects made of glass in residential areas. Materials such as transparent plexiglass with a negligible shattering risk should be used instead of regular glass in framed pictures/paintings (AKUT, 2008; Doğan, 2020). It is also advised to avoid objects and materials that might fall or break and to practice the "Drop, Cover, And Hold" movement in previously determined safe places (AKUT, 2008). A general recommendation against the risks posed by all objects: is "L+I+", and is explained as following; "L": Limit; do not keep more than you need, "I" Isolate; keep in a place where everyone can easily access and control, "D": Dispose; give excess potentially dangerous materials to others in need or dispose of them properly, do not accumulate unnecessarily, "S": Separate; Store hazardous substances in separate places (ex, saline and bleach) that would pose a risk if together (AKUT, 2008).

3.4.4. Non-structural elements

The literature review on the category of non-structural element outcomes is summarized, and the numerical values of the sources in which the headings of the criteria are mentioned are presented in Figure 7. The risks caused by non-structural elements were primarily defined as "breaking" and "cracking" of interior wall partitions and "downfall" and "swinging" of suspended ceilings. Studies mainly focus on the risk of glass breaking while examining windows of residential interiors. The most frequently proposed strategies are related with "strong construction", "flexibility" and "materials" for wall partitions, "reinforcement" for suspended ceilings and "materials" for windows.

Ertaş Beşir & Dereci (2021) examined the breaking of interior walls and surfaces or the deformation and collapse of suspended ceilings in their study. Although heavy interior walls are advantageous in fire and sound insulation, they do not have vertical steel reinforcement; their strength is thus low. According to Ertaş Beşir & Dereci (2021), heavy interior walls must have horizontal and vertical steel reinforcing.

Filialtraut & Sullivan (2014) researched and collected information on the seismic design, analyzing and investigating the seismic performance of non-structural building components in actual earthquakes (the 2010 Maule Earthquake in Chile and the 2001 Nisqually-Seattle Earthquake in the United States). In their study, Filiatrault & Sullivan (2014) note that the failure of non-structural components can become a safety hazard or hamper the safe movement of occupants evacuating buildings or rescue workers entering buildings. The most common non-structural component failures observed following the Nisqually earthquake were related to suspended ceiling systems, the cracking of interior partition walls, and the breaking of glass windows (Filiatraut & Sullivan 2014).

For Ertaş Beşir & Dereci (2021), to ensure rigidity and to prevent risks that may occur because of suspended ceilings used in residential interiors, putting cross elements between the brackets could be one of the solutions. The use of tempered or laminated glass, which is known as safety glass, essentially prevents seismic hazards. Furthermore, safety or solar heat plastic

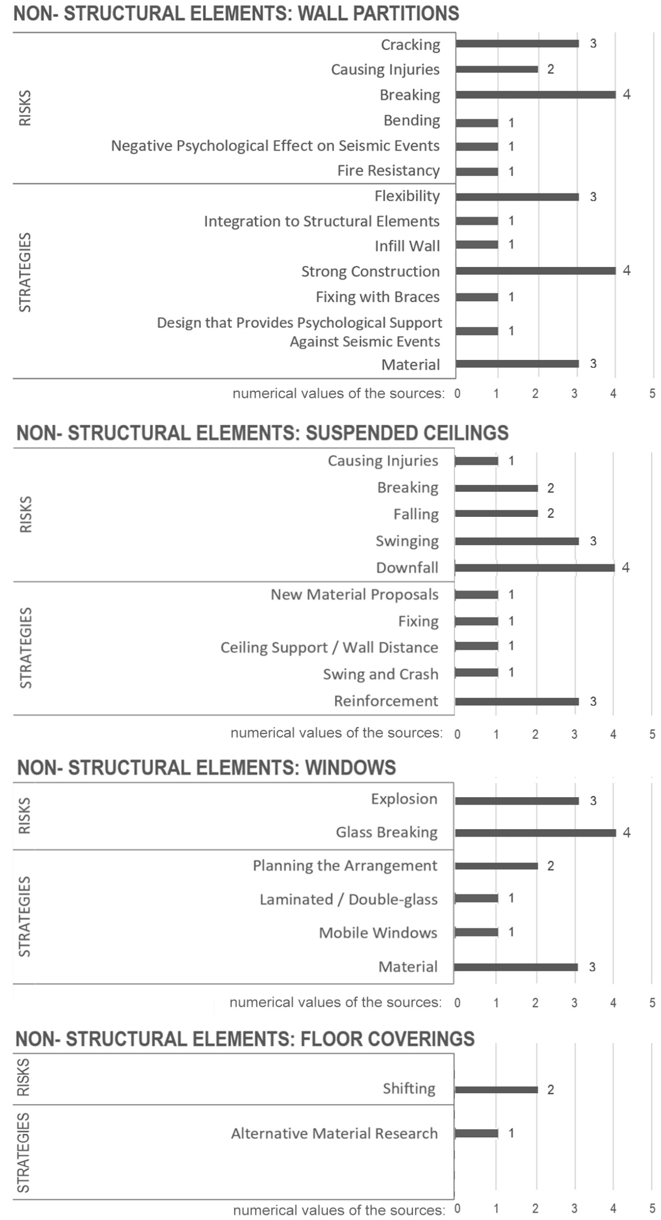

Figure 7. *Non-Structural elements: numerical values of the sources in which the titles of the criteria are mentioned.*

films used for other purposes help reinforce existing glass sheets by holding them together (Ertaş Beşir & Dereci 2021).

Static and kinetic friction tests, and shake-table tests using sinusoidal floor motions of office-type furniture on carpet and vinyl flooring were performed in the study of Yeow et al. (2018). It was found that there were differences in the sliding of furniture on different floor materials (Yeow et.al., 2018). Zaryoun & Hosseini (2019) proposed new material alternatives for non-structural elements and investigated sustainable architecture's role in increasing buildings' resilience against disastrous events. A new natural-based, low-cost, eco-friendly and lightweight fiber-reinforced clay (LFRC) material with high heat, sound and moisture insulation capabilities is introduced. Its employment can remarkably increase the resilience of buildings against earthquakes. A series of tests to measure the bending, shear and compressive strengths was done to discover the mechanical properties of the proposed LFRC material. Test results showed that the proposed material has much higher strengths than plain clay. This material can be used to create movable partitions or floors/ceilings as well as smart furniture to achieve flexible architecture or as the main body of masonry elements, such as load bearing walls in small rural houses (Zaryoun & Hosseini, 2019).

3.4.5. Electrical appliances, technical equipment and lighting fixtures

Since electrical appliances can overturn or slide during an earthquake, they should be the first to be fixed (AFAD, 2011-3). One method for avoiding possible threats is to remove or lock the wheels of heavy domestic appliances such as refrigerators with wheels (ECA, 2011; ECA, 2016). Another method used to reduce the risk during an earthquake is to place objects that are sensitive to overturning or moving, such as refrigerators and copy machines, in an area surrounded by partitions (Ertaş Beşir & Dereci, 2021). During an earthquake, electronic devices such as televisions, computers, stereos, and printers slide and fall, causing significant damage (AFAD, 2011-3). Fixing lightweight electrical appliances with L fasteners, straps, plastic clip strips, double-sided tapes, or non-slip pads helps prevent earthquake damage (AFAD, 2011-3; ECA, 2011; ECA, 2016; FEMA, 2020; FEMA, 2016) (Figure 8).

Heating boilers and water heaters, which are non-structural objects, can fall during an earthquake and injure nearby individuals. Such technical equipment should be of adequate size to prevent it from collapsing during an earthquake. To avoid fires, they must have a circuit that disconnects from the power supply when it falls (AFAD, 2011-3). Small electric heaters that can be displaced during an earthquake should not be placed on high levels such as tabletops, but rather on the ground to reduce the risk (AFAD, 2011-3). It is critical to keep heaters away from flammable objects such as curtains, armchairs, and carpets (AFAD, 2011-3). Furthermore, smoke detectors, fire extinguishers, avoiding connecting multiple electrical appliances to a single electrical socket, and turning off technical equipment that works with gas when not in use are all critical (AFAD, 2011-1). Securing tanks used for heating water to the wall with metal strips or placing them in the gaps created between building elements helps to prevent the risks such as overturning or fire during an earthquake (ECA, 2011; ECA, 2016; FEMA, 2020; FEMA, 2016). Technical equipment that uses solid fuel, such as stoves, should be placed near chimneys, and the flue connection pipes should be secured to the building's ceiling/slabs with hanging clamps. The stove doors should be closed and placed inside the space so that they do not obstruct escape routes in the case of an earthquake (AFAD, 2011-3; FEMA, 2016). During an earthquake, residential-type gas cylinders used for heating and cooking, oxygen cylinders used as healthcare equipment in hospitals, and industrial-type gas cylinders used in workplaces may fall or slide. These cylinders can potentially cause gas leaks, fires, and poisoning (AFAD, 2011-3). Thus, cylinders should be strapped to the nearest surface with two straps (AFAD, 2011-3) (Figure 8).

Lighting fixtures, which are defined as non-structural immovable items (glass chandeliers, fluorescent lamps, surface mounted and recessed spots, lampshades, floor lamps, etc.), can cause physical damage, injury, and fire during an earthquake by falling, detaching, or overturning (Figure 8). Precautions vary depending on the type of lighting element to reduce the risks caused by lighting fixtures. Securing lighting systems to the ceiling or steel structures in the slabs with special hooks or closed chain systems can

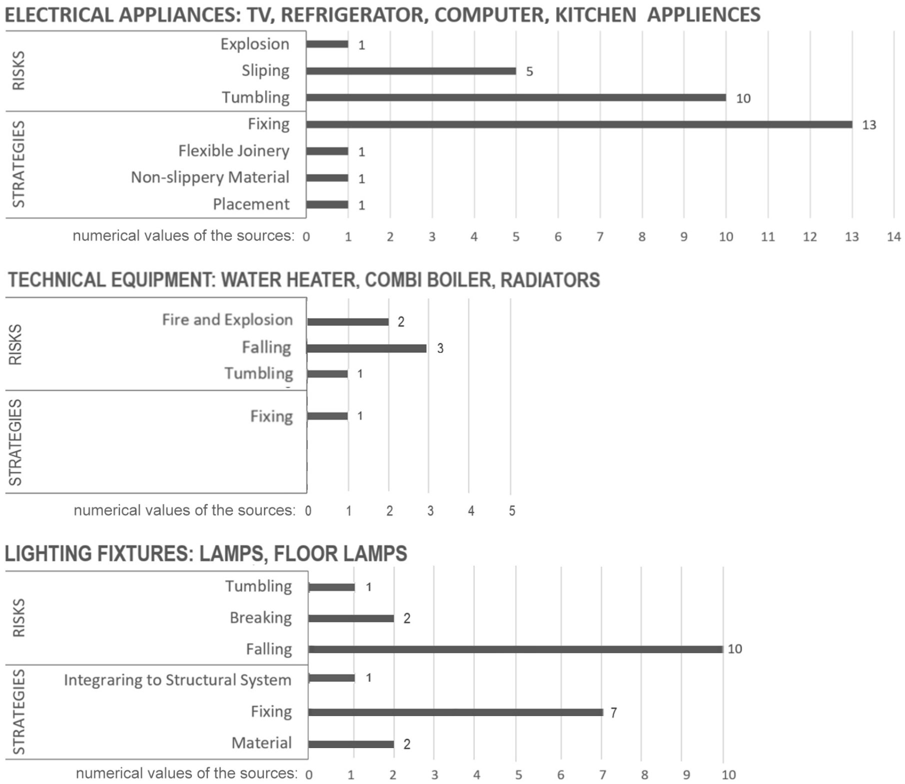

***Figure 8.** Electrical appliances, Technical equipment and Lighting fixtures: numerical values of the sources in which the titles of the criteria are mentioned.*

help to avoid injuries (AFAD, 2011-3; ECA, 2011; ECA, 2016; FEMA, 2020).

There should be enough space between heavy and side-by-side hanging lighting elements to prevent them from colliding. It is critical to secure the fluorescent lamps in linear lighting fixtures used in schools, offices, and hospitals. Because these lamps have the potential to fall out of their sockets during an earthquake and cause injuries (AFAD, 2011-3; Rodgers et al., 2021). High-energy bulbs in floor lamps and lampshades should be placed away from flammable materials, as they can cause fires due to high temperatures on the bulbs. These lighting fixtures should be attached to a nearby wall or table with metal elements to reduce fire risk (AFAD, 2011-3). Moreover, movable lighting fixtures should not be placed on or near earthquake escape routes (Ertaş Beşir & Dereci, 2021). Lighting elements are treated with different precautions according to their location in interior spaces. When suspended from the ceiling, they must be connected to the carrier system of the ceiling; if embedded in the suspended ceiling, they must be secured with links (Ertaş Beşir & Dereci, 2021).

4. Results and discussion

As a result of research analysis, the definition of strategies and risks documented in literature according to the categorization has revealed a set of criteria for reducing earthquake risks in the design of residential interior spaces (Table 2). The synthesis of results derived from the literature review is presented through numerical values of the sources in which the criteria headings are mentioned for each category. The analyzes made within the scope of the defined categorization present that risks and strategies are mostly handled within the scope of "fixed furniture", "non-structural elements" and "objects" categories. The most defined risk for "fixed furniture" (store elements, shelves) was "tumbling"; and the most defined strategies were related with "material" and "fixing". "Falling" was the most underlined risk for "kitchen cabinets" while "locking" was the most proposed strategy.

In scope of the studies which focused on "non-structural elements", the most defined risks for "wall partitions" were "breaking" and the studies proposed "strong construction" as a design strategy. The most important risk that is defined for "suspended ceilings" was "downfall" and the strategies related with the defined risks were on "reinforcement".

"Objects" such as books and decorative accessories mostly define a risk of falling, and the most proposed strategies are related with "fixing" and "placement".

As further research of this comprehensive literature review, the derived results will be compiled by an interior design point of view. Therefore, a design guide containing all data supported by visual scenarios will be created. This guide has created a holistic directory for reducing earthquake hazards by design, for the use of both interior architects and designers, as well as the wider community. The fact that large numbers of people use residential interiors during earthquakes and that daily life takes place on a large scale in residential interiors defines the widespread impact of the study. The residential interior design criteria to be determined within the scope of the study is expected to be a source for raising social awareness. Furthermore, as a "Design Guide for Reducing Earthquake Risks in Residential Interiors", it can be used in different design phases, as well as for taking individual measures by residential users. However, even though this guide will focus on residential interiors, the measures and directories could be applied to other interiors, such as schools, offices and hospitals. This study can further impact and promote earthquake awareness for future studies in the interior design discipline.

5. Conclusion

It is clear that an earthquake is unpredictable, and its damage is unmeasurable beforehand. Therefore, it is difficult to predict the exact extent of the hazards or outcomes of accidents related to seismic events. It is a fact that even if buildings do not collapse, damage within the interior spaces may occur. In this context, the precautions to be taken in the interiors might be life-saving. Consequently, in the interior design process, taking appropriate measures to combat earthquake damage is essential for users' safety.

This research is a documentation study that comprise a profound literature review, analysis and synthesis of the bibliographic resources. The study's primary outcome is compiling a set of design criteria with a holistic approach for residential interior design in earthquake zones. It is crucial to prevent the damage caused by earthquakes by taking measures in the interiors of buildings, and it is of great importance to develop collective awareness of this fact. The presented residential interior design criteria set is expected to be a source that includes a holistic set of categorized data to reduce risks, lead to safe design, and ensure up-to-date continuity of knowledge for future designs.

Acknowledgement

The research project discussed in this article titled "Determining Design Criteria for Reducing Earthquake Risks in Housing Interiors and Developing a Design Model Defining Reduced Risk Areas" is funded by TUBITAK (The Scientific and Technological Research Council of Turkey) with project number: 221M188.

The authors would also like to acknowledge the contribution of the project team including researchers, scholars and consultants.

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