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How design decisions change fall from heights in reinforced concrete structures?

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Abstract

Prevention through Design (PtD) and Design for Safety (DfS) are now being considered in relation to occupational health and safety and building design. A recent collection of studies suggests that certain decisions made by designers during the design process are at the root of many risks. A study was undertaken to relate falls from height to the conventional design process for reinforced concrete buildings. This was achieved by dividing the building design process into stages. During the design phase, input was gathered from architects and engineers working in the sector. Accident types were identified based on studies of occupational accident investigation reports from the Ministry of Labor. Of the 15 types of fall from height accidents studied, 12 were attributed to design decisions. Of these, 6 different accident types were associated with 5 or more design decisions, while 2 of these were associated with 3 or 4 design decisions. The remaining 4 types were linked to only 1 design decision.

Keywords: *Design Decisions, Design for Safety, Occupational Health and Safety, Prevention through Design, Reinforced Concrete Structures.*

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Betonarme yapılarda tasarım kararları yüksekten düşmeyi nasıl etkiler?

Öz

Tasarım Yoluyla Önleme (PtD) ve Güvenlik için Tasarım (DfS) artık işçi sağlığı ve iş güvenliği ile bina tasarımını bir araya getiren kavramlar olarak değerlendirilmektedir. Yakın zamanda yapılan bir dizi çalışma, tasarım sürecinde tasarımcılar tarafından verilen bazı kararların birçok riskin temelini oluşturduğunu göstermektedir. Bu çalışmada betonarme binalarda yüksekten düşme ile geleneksel tasarım süreci arasında ilişki kurulmaya çalışılmaktadır. Bina tasarım sürecinin aşamalara ayrılması ve ardından tasarım aşamasında, sektörde çalışan mimar ve mühendislerden görüşleri çalışmanın temellerini oluşturmaktadır. Keza bu temele ek olarak kullanılan kaza türleri, Çalışma Bakanlığı'nın iş kazası inceleme raporları temel alınarak belirlenmiştir. İncelenen 15 tür yüksekten düşme kazasından 12'si tasarım kararlarına bağlanmıştır. Bunlardan 6 farklı kaza türü 5 veya daha fazla tasarım kararıyla ilişkilendirilirken, 2 tanesi 3 veya 4 tasarım kararıyla ilişkilendirilmiştir. Kalan 4 kaza türü ise sadece 1 tasarım kararıyla ilişkilendirilmiştir.

Anahtar kelimeler: *Tasarım Kararları, Güvenlik İçin Tasarım, İş Sağlığı ve Güvenliği, Tasarım Yoluyla Önleme, Betonarme Yapılar.*

1. Introduction

The construction industry poses a high risk of accidents within its work environments due to the nature of the sector [1-5]. In numerous countries, the construction sector ranks among the top industries in terms of fatalities, injuries, and financial losses [6-8]. Numerous studies have indicated that certain decisions made by designers during the design process can be a source of multiple risks in the construction process [9, 10]. In light of the occupational accidents that occur in the construction sector, it is possible to attribute some of the hazardous environments and risks causing accidents to specific design decisions made at the beginning of the process [11].

However, certain techniques including Prevention through Design (PtD) and Design for Safety (DfS) have contributed towards the integration of design within the field of Occupational Safety and Health (OSH) [12-18]. This has facilitated the elimination of design-based risks and hazards. Nevertheless, the association between design decisions and risk assessment should be established at the outset of the process to ensure that PtD and OSH strategies are jointly contemplated.

This study aims to correlate design decisions with construction site risks and hazards. Pilot building types examined were multi-story reinforced concrete buildings. Construction techniques in Northern Cyprus and developing nations in the Middle East were also evaluated to identify accident types. As a result of our assessment, this study has focused on accidents involving falls from heights, which have been identified as one of the most frequent types of accidents [19-24].

2. Materials and methods

2.1.Data Acquisition

The literature review highlights that certain design decisions may increase the risk of occupational accidents [25]. On the other hand, other studies suggest that incorporating small-scale design changes into the design process can significantly reduce the number of such accidents [26].

With the assistance of professional designer architects and engineers, the design process has been divided into phases, taking into account these findings. An expert panel was convened, comprising 12 architects and 8 civil engineers, with the mandate to divide the design process into distinct phases. The experts participating in the study are all actively working architects and engineers with 5-30 years of experience. They also have at least one certificate related to occupational health and safety. A total of 20 studies were eventually incorporated, drawing on the combined expertise of the panel participants. For the composition of the panel, Turoff (1970) suggests a range of 10-50 participants, while Adler and Ziglio (1996) recommend a smaller number of 10-15 experts for a homogeneous group [27, 28]. It is generally acknowledged that a larger number of members enhances the reliability of a composite judgement [29]. To ensure that panelists possess the necessary level of expertise, they must exhibit high levels of objectivity and rationality, have a strong track record in their field, commit to participating for the entire program duration, and be willing to invest significant time and effort into their involvement [14]. Moreover, the panel members' level of expertise is a vital consideration. Expertise in building safety, construction, and design was deemed necessary for this study. Furthermore, all panel members were educated on health and safety practices in the construction industry and the restoration of industrial heritage. Rule-based data creation requires inputting material data and corresponding work items into the model. The variables being evaluated are the material type, which pertains to whether the factory roof requires removal or replacement and is brittle in nature; the material location that includes its position on the site and altitude; and the associated risks and work item, namely the brittle material and the hazard of falling from a height with the possibility of the roof light breaking. As a result of these efforts, the design process was successfully structured into distinct phases.

The study identified the types of accidents that occur in multi-storey reinforced concrete buildings in developing countries. A total of 793 occupational accidents in the construction sector, which occurred between 1994 and 2014 in the northern part of Cyprus, were analyzed in order to identify related accidents. The analysis followed a logical flow of information with causal links between statements and the language used was clear, objective and value neutral. Accident records were obtained from the Occupational Accident Investigation Archive of the Ministry of Labour and Social Security, which is responsible for occupational safety and health in the country. Information from the studies by Tözer [11] and Tözer et al [26] was also used.

In the final stage of the study, the design phases that emerged from the expert panel's practice were linked to accident types. The study examined the relationship between design decisions and accident types and convened a panel of 10 OSH experts to analyze the design process phases and their correlation with accident types from the outset. The study examined the relationship between design decisions and accident types and convened a panel of 10 OSH experts to analyze the design process phases and their correlation with accident types from the outset. The study aimed to determine whether there was a causal relationship between the matched design phases and accident types.

2.2.Methodology

The process of dividing the design process into phases began with a review of the literature. Expert opinions were sought to ensure correct division. The expert panel was made up of 12 architects and 8 engineers. Prior to the panel, the invited experts were asked to conduct a comprehensive literature review on the design process. The authors also conducted a literature review. During the panel, each designer was asked to explain their respective design process while the other participants listened and evaluated. The results of the study are presented in the results section.

During the three-day panel session, which totaled eight hours, the designers were instructed to work collaboratively, explore implications, and precisely define each phase of the design process. Subsequently, records of occupational accidents in the building industry were scrutinized to determine design decision-related incidents. First, 793 occupational accidents at the construction site were classified according to the International Code of Disease, ICD-10 format. However, as the same classification had already been conducted for these accidents in a previous study by Tözer et al. using a similar method, we decided to utilize the findings of that study after reviewing it. The results section presents the findings of the classification process, which identified the most widespread accident types.

Within the scope of this study, 10 experts participated to an expert panel. The panel aimed to determine whether each accident type could be associated with design decisions, drawing on the OSH experts' experiences. Each accident type was examined for its associated risks and the sources of these risks. Based on this assessment, the type of accident that is associated with design decisions was identified as a source of design-related accidents. The results of this analysis are presented in the results section. The steps followed to complete the study are outlined in Figure 1.

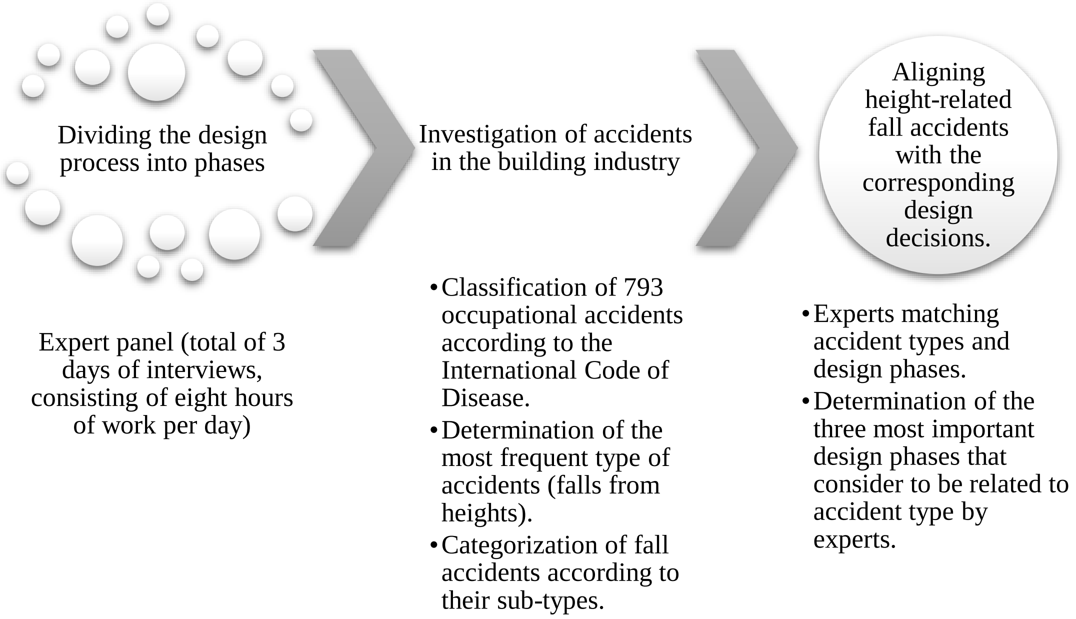

Figure 1. Flowchart of the applied methodology.

3. Results

Firstly, the design process is divided into phases, as shown in Table 1, resulting from the collaboration of 20 professional designers. The views of designers were gathered through a three-day series of interviews, with each day consisting of eight hours of work. Brainstorming was employed in the study. As a result, the process consists of four main components, as shown in the left-hand column of the table, which were identified by the panelists as Site Selection and Preliminary Survey, Determining Requirements, Plan and Section Settlement, and Material Selection. Names are assigned on the basis of the issue or decision that the designer is focused on making during that phase. The right-hand column of Table 1 divides the four main sections into sub-sections in a detailed and orderly manner.

Table 1. Phases of Design Process [26].

Main Sections of Design Process	Sub-Sections of Design Process
Site Selection and Preliminary Survey	1-Construction Site Selection
	2-Survey of Physical & Geographic Conditions
	3-Survey of Public Work (Zoning) Regulations
Determination of Requirements	4-Ground Floor Area and Total Area Definition
	5-Definition of Number of Stories
	6-Definition of Settlement in the Lot
Plan and Section Settlement	7-Identification of Space Requirement
	8-Identification of Facades and Openings
	9-Identification of Level Dynamism
	10-Identification of other Details
Material Selection	11-Material Selection of Structural Elements
	12-Wall Material Selection
	13-Material Selection of Mechanical Systems
	14-Material Selection of Electrical Systems
	15-Floor Covering Material Selection
	16-Material Selection for Siding
	17-Material Selection for the Roof

Initially, 793 occupational accidents were classified according to the ICD codes. Then, each code's accidents were separated into fatal and non-fatal incidents. According to occupational accident records, the most frequent type of accident resulting in death, injury, and loss of workdays was falls from heights, which occurred in both fatal and non-fatal cases (Table 2). The research conducted by Tözer et al. [26] and Tözer [11] has been utilized to determine the most frequent type of accidents, which is falls from heights. Furthermore, Tözer et al. [26] and Tözer [11] further classified these falls into sub-groups. The research conducted by Tözer et al. [26] and Tözer [11] has been utilized to determine the most frequent type of accidents, which is falls from heights.

Table 2. Type of Construction accidents with ICD-10 Codes [11,26].

Causes of Accidents	ICD-10 Codes	Fatal		Non-Fatal		Total	
		No.	%	No.	%	No.	%
Building & Construction Collapse	W20	2	4.76	4	0.5	6	0.757
Cave-in	W20	1	2.38	5	0.7	6	0.757
Contact with Chemical Substances	T52-T59		0	4	0.5	4	0.504

Contact with heat or hot substances	X10-X19		0	23	3.2	23	2.9
Crashed, Jammed in or Between Objects	W23	3	7.15	84	11	87	10.97
Explosives	W36-W40		0	6	0.9	6	0.757
Exposure to Electric	W85, W86	10	23.8	9	1.3	19	2.396
Fall on Same Level	W1, W3, W10		0	62	8.3	62	7.818
Falling Objects	W20	2	4.76	57	7.7	59	7.44
Falls	**W12, W13**	**21**	**50**	**278**	**37**	**299**	**37.7**
Sharp Object İnjury	W25-W29		0	63	8.5	63	7.945
Striking against or struck by objects	W22		0	8	1.1	8	1.009
Struck by thrown, projected object	W20		0	86	11	86	10.84
Traffic Accident	V00-V60	3	7.15	54	7.2	57	7.188
Unknown			0	8	1.1	8	1.009
Total		**42**	**100**	**751**	**100**	**793**	**100**

While Tözer and colleagues [26] and Tözer [11] have categorized fall accidents according to their sub-types, Table 3 illustrates their classification into three main categories: fall from Scaffold, fall from Structural Elements, and Other Type of Falls, based on their respective workplace environments. Each sub-group is then internally detailed. The respective types of falls are analyzed from the perspective of their fatal and non-fatal outcomes.

Table 3. Detailed analysis of falls [11,26].

Type of Falls (W12, W13)	Fatal	Non-Fatal	Total
Falls from scaffolds			
1- Scaffold giving in-breaking-falling	3	24	27
2- On the scaffold (stepping on air)	1	9	10
3- On the scaffold (while going up-down)	0	7	7
4- On the scaffold (setting up-dismantling)	0	5	5
5- On the scaffold (slipping, loss of balance etc.)	1	36	37
Sub. Total	5	81	86
Falls from structural elements			
6- Falls from structural element (from threshold)	3	28	31
7- Falls from structural element (from the roof)	0	10	10
8- Falls from structural element (flight of stairs)	1	6	7
9- Falling through opening on the floor	2	7	9
10- Falls from structural element giving in	1	1	2
Sub. Total	7	52	59
Other type of falls			
11- From the moulding system	2	18	20
12- Moving ladder	4	54	58
13- Into a canal, hole etc.	0	13	13
14- From a vehicle, machine	2	35	37
15- Going up on unsuitable object	1	14	15
Other	0	11	11
Sub. Total	9	145	154
Total	**21**	**278**	**299**

The objective of this study's final segment was to align height-related fall accidents with the corresponding design decisions listed at each phase. Amongst the 15 identified types of fall accidents, 12 were linked to specific design choices based on the expertise of OSH professionals, while for 3 accident types, no design phase association was found (Table 4. The outcomes obtained from the association activities, specifically the link between design phases (and consequently, the design choices made in these phases) and different types of accidents, are extensively presented in detail in Table 4 and Figure 2. Table 4 and Figure 1 present the stages of the design process and fall type accidents paired by the experts. Table 4 shows how the experts associate design phases with types of accidents, without frequency information. In Figure 2, the three most important design phases that experts consider to be related to accident type are presented diagrammatically.

Table 4. Association of design phases (and hence the design decisions in the phases) with the types of accidents.

Type of Accident (type of Fall)	Design Stages (Related with Design Decisions) *
Scaffold giving in – breaking - falling	5, 8, 11,12, 16, 17
Stepping on air (on scaffold)	5, 8, 11,12, 16, 17
Going up – down (on scaffold)	5, 12, 16, 17
Setting up – dismantling (Scaffold)	5, 8, 11, 12, 16, 17
Slipping – loss of balance etc. (on scaffold)	5, 8, 11, 12, 16, 17
Fall from threshold	5, 8, 9, 11, 12, 17
Fall from the roof	10, 11, 17
Fall from the flight of stairs	10,
Fall through the opening on floor	10
Fall from the structural element (Giving-in)	11
Fall from the moulding system	11
Fall from moving ladder	13, 14, 16, 17
Into a canal, hole etc.	-
From a vehicle, machine	-
Going up on unsuitable object	-

* Number explanations are presented in table 1.

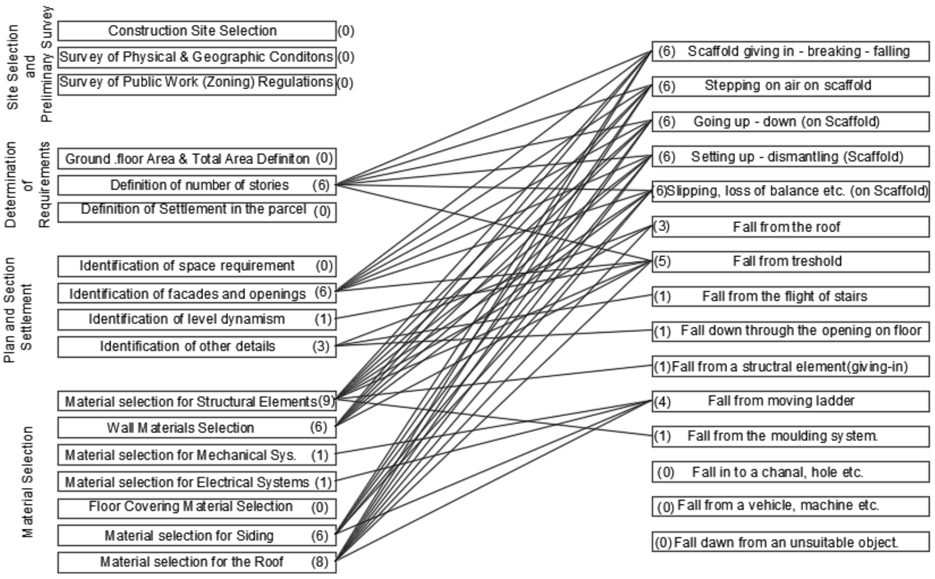

Figure 2. Diagram showing the association of design phases (and hence the design decisions in these phases) with the types of accidents.

When experts were asked to match 15 accident types with the design criteria, they were requested to select the top 5 choices. The choices were numbered 1 through 5 respectively, and the experts wrote down the ones they deemed most crucial as number 1. Therefore, opinions were gathered from specialists, with a few preferring to associate four design criteria. Through analyzing Table 5, it has been predicted which design decisions concerning falls from height are of greater or lesser importance. It has been observed that design criteria numbered 5 (Definition of Number of Stories) and 8 (Identification of Facades and Openings) are prominent, while design criteria numbered 11 (Material Selection of Structural Elements) and 17 (Material Selection for the Roof) are frequently influential. The distribution of other design criteria in order of importance is presented in Table 6.

Table 5. Association of matrix of accident type and design criteria according to expert opinions

Type of Fall*	**E1***	**E2**	**E3**	**E4**	**E5**	**E6**	**E7**	**E8**	**E9**	**E10**
1	5 (1)	8 (2)		12 (5)	16 (4)	17 (2)			11 (2)	
2	11 (3)	5 (1)	17 (2)	16 (4)			8 (1)	12 (4)		
3			5 (1)		12 (3)				16 (3)	17 (2)
4				5 (1)	8 (1)	11 (4)	12 (5)	16 (3)	17 (1)	
5	8 (2)	11 (3)	12 (3)				16 (4)	17 (2)		5 (1)
6	9 (5)			11 (2)	5 (2)	8 (1)	17 (3)		12 (4)	
7	17 (4)						11 (2)			10 (4)
8		10 (5)								
9			10 (4)							
10					11 (3)					
11								11(1)		
12		13 (4)		17 (3)		16 (3)				14 (3)
13										
14										
15										

*The type of accident to which the numbering corresponds is available in table 3.
**E (Expert).

Tablo 6. Distribution of design criteria in order of importance (1 to 5)

Sub-Sections of Design Process	**1**	**2**	**3**	**4**	**5**
5-Definition of Number of Stories	xxxxx	x			
8-Identification of Facades and Openings	xxx	xx			
9-Identification of Level Dynamism					x
10-Identification of other Details				xx	x
11-Material Selection of Structural Elements	x	xxx	xxx	x	
12-Wall Material Selection			xx	xx	xx
13-Material Selection of Mechanical Systems				x	
14-Material Selection of Electrical Systems			x		
16-Material Selection for Siding			xxx	xxx	
17-Material Selection for the Roof	x	xxxx	xx	x	

4. Discussion

The following information was presented in the results section. When examining the types of falls classified under the category 'Type of fall', six different design decisions were associated with falls on scaffolding. These types of falls included 'Scaffolding giving way - breaking - falling', 'Stepping on air (on scaffolding)', 'Going up - going down (on scaffolding)', 'Setting up - dismantling (scaffolding)', 'Slipping - loss of balance etc. (on scaffolding)'. Abbreviations of technical terms are explained the first time they are used. The accident type 'Fall from height', in particular the subtype 'Fall from sill', was found to be associated with five different design decisions. On the other hand, the accident type "fall from a moving ladder" was associated with three different design decisions, and "fall from a staircase", "fall through an opening in the floor", "fall from a structural element" and "fall from a moulding" were each associated with one design decision. Finally, accidents such as 'falling into channels, holes, etc.', 'falling from a vehicle' and 'falling from an unsuitable object' were not associated with any design decision.

However, accidents involving falls from heights were associated with the design phases listed. Out of fifteen different types of falls, twelve (80%) were associated with at least one design decision, while the other three (20%) had no connection to any design decisions.

Analysis of the findings shows that the decisions made during the "Material selection for structural elements" phase of the design process were linked to nine different types of accidents. Additionally, the decisions made during the "Material selection for the roof" phase of the design process were linked to eight different types of accidents. In contrast, the decisions made during the "Definition of number of storeys", "Identification of facades and openings", "Wall material selection", and "Material selection for siding" design phases were linked to 6 distinct types of accidents. This is opposed to the decisions made during the "Identification of other details" phase, which were associated with only 3 accident types. The decisions made during the 'Identification of floor level dynamism', 'Material Selection for mechanical systems' and 'Material Selection for electrical systems' stages of the design process were exclusively linked to a single type of accident. Where the decisions made during the phases of "Construction Site Selection," "Survey of Physical & Geographic Conditions," "Survey of Public Work (Zoning) Regulations," "Ground Floor Area and Total Area Definition," "Definition of Settlement in the Lot," "Identification of Space Requirement," and "Floor Covering Material Selection" did not result in any accidents.

Therefore, when the design process is divided into 17 phases, out of the total of 17 design phases (referring to design decisions made in these phases), 10 (58.82%) were linked to at least one type of accident, while 7 (41.18%) were not associated with any design decisions (thus with any design decision). After evaluating the relative significance of the different design criteria, it is clear that the two most important design criteria are number 8 (identification of facades and openings) and number 5 (definition of number of storeys). Furthermore, design criteria number 11 (choosing the materials for structural elements) and number 17 (choosing the materials for the roof) are often important.

5. Conclusions

Due to the high rate of injuries and fatalities in the construction industry, it is imperative that all stakeholders, including owners, designers, contractors, subcontractors and suppliers, work together to reduce these figures. It is also important to recognize that preventive measures aimed at reducing injuries have an impact not only on workers but also on other stakeholders. The list of basic objectives for a construction project, which currently includes low cost, high quality and fast delivery, should be extended to include a reduced accident rate. Without exception, designers recognize that their decisions have an impact on the cost, quality and schedule of the project.

This article poses an elementary question to designers: shouldn't they also acknowledge that their design choices have an impact on the intrinsic hazard to the workers undertaking the project? A sustainable building project must not harm the environment during its construction and must be socially acceptable to avoid harm or injustice to any group. General contractors and subcontractors carrying out their work have practical reasons as well as moral obligations to support DfS. Reducing the possibility of construction accidents, which can cause delays in project completion, is beneficial to all owners. In particular, members of design-build teams should benefit financially from reduced construction accidents. In addition, lower workers' compensation insurance rates and increased project productivity are results of such measures. The aim of this study is to improve cooperation between structural engineers, site engineers and architects in order to minimize the impact of construction accidents.

In future studies, it is aimed to determine the importance levels of the decisions made using design decisions and the relationship levels of the design stages matched with fall from height accidents.

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