Evaluation of Different Building Structural Systems: The Case of Turkey

Esra Bostancioglu
Assoc.Prof.Dr., Department of Architecture, Istanbul Kultur University, Istanbul, Turkey
esrabostancioglu@hotmail.com

Abstract
A building structural system is evaluated by using several parameters such as cost, construction time, fire resistance, lifetime, maintenance and repair frequency and environmental impacts. This study aims to evaluate buildings constructed with different structures in Turkey. Existing building stock in Turkey is assessed in terms of structures and number of stories. For the economic evaluation of the structures, a two-storied residential project is selected as an example. For the assessment of construction cost, structural cost and the other cost components for different structures, the selected project is designed with three different structures. Selected structures are; masonry, reinforced concrete framed and wood framed structures. These structures are evaluated in terms of economic features as well as other features for providing investors with tips on how to choose the structure in future. The current situation of structures in Turkey is also examined.

Keywords
Building Structures, Masonry Structure, Reinforced Concrete Framed Structure, Wood Framed Structure, Construction Cost, Structural Cost.

1. Introduction

The assessment of a structural system involves several parameters such as cost, construction time, fire resistance, lifetime, maintenance and repair frequency, and environmental impacts. Different structures have different characteristics. Some cannot be used in multi-storey buildings because of their load-bearing capacities, some take shorter time to construct and some have lesser impacts on the environment. Hence, they can be evaluated from many perspectives. Cost is one of the most important parameters in evaluating a structure. It can be said that the main objective for each project is economic efficiency. Economic efficiency means the benefit of a designed building is larger than the cost it involves. Building production in Turkey makes up a large share of the construction sector and national investments, hence it is vital to meet the need for building through the most economical way.

This study aims to evaluate buildings constructed with different structures in Turkey. Some structures cannot be used in multi-storey buildings, hence buildings in Turkey are primarily assessed in terms of structures and numbers of stories. Then, an assessment is made of construction costs, structural costs and other cost components for a selected 2-storey residential building if it is constructed by using three different structures. In addition, these three different structures are evaluated in terms of other characteristics, providing investors with information about various characteristics of the structures they may choose, to help them to make the right decisions. After three different structures are assessed, the current situation of structures in Turkey is examined.

2. Building Structures

Masonry structures refer to systems where numerous and relatively small building materials such as stone, brick, block, wood, adobe and gasbeton are placed one on top of other to form a load-bearing wall with their own weight or with a binder / adhesive material. Load-bearing walls formed transfer the loads placed on them to the ground via the foundation. The foundation has to be continuous where there is the load-bearing wall. In masonry systems, openings for doors and windows can be created on load-bearing partitions and external walls as much as permitted by regulations for given locations; walls are connected with horizontal and vertical elements called beams based on tensile strength.

Reinforced concrete framed structures refer to systems in which dynamic and static loads exerted on structures are born by supporting elements such as columns, beams and vertical loads are transferred to the foundation system via columns. All walls only carry their own load and transfer their load to the slab whatever their floor, whilst the slabs convey the loads exerted on them to the columns through the beams or directly. In this structure, walls do not bear loads (except shear walls), hence they can be replaced or removed whatever the floor, thus providing flexibility in the use of spaces. Reinforced concrete framed structures can be constructed with different construction technologies, such as cast-in place and prefabricated, allowing the construction of multi-storey buildings. In reinforced concrete framed structures, elements of the structure take a small place in the slab, providing flexibility in interior space use and facade design.

One dimensional wood component assumes the role of structure in wood framed structures. The gaps between the studs are filled with a component such as adobe, brick, gasbeton. Plaster can be applied on the wall surfaces or the outward facing surfaces of the laths and studs may be covered to provide desired insulation and protection against external factors.

Researchers compared different building structures in literature. Hemström, Mahapatra and Gustavsson used a web-based questionnaire to assess Swedish architects' perceptions, attitudes and interest towards steel, concrete and wood frames in multi-storey buildings (n = 412). Results indicate that the responding architects find concrete the most suitable frame material in buildings of 3–8 storeys, mainly because of the performance of concrete with regards to the engineering aspects (e.g. stability and fire safety) that were considered important in the choice of frame material. Although wood is considered the least suitable frame material, the overall attitude towards, and interest in, using wood is positive and related to the perceived environmental benefits of wood. This may derive from an increased discussion of and information about the environmental impact of buildings. Wood may be perceived as new and innovative while not considered as adequately proven as steel and concrete with regards to engineering aspects (Hemström, et.al., 2011).

Börjesson and Gustavsson calculated primary energy use and carbon dioxide (CO_2) and methane (CH_4) emissions from the construction of a multi-storey building, with either a wood or a concrete frame, from life-cycle and forest land-use perspectives. The primary energy input (mainly fossil fuels) in the production of building materials was found to be about 60-80% higher when concrete frames were considered instead of wood frames. The net greenhouse gas (GHG) balance for wood materials will depend strongly on how the wood is handled after demolition of the building. The net GHG balance will be slightly positive if all the demolition wood is used to replace fossil fuels, slightly negative if part of the demolition wood is re-used, and clearly positive if all wood is deposited in landfills, due to the production of CH_4. If concrete frames are used, the net GHG emissions will be about those when demolition wood from the wood-framed building is deposited in landfills and no biogas is collected. If forest biomass is used instead of fossil fuels, the net area of forest land required to supply both raw material and energy for the production of building materials, will be about twice as high when wood frames are used instead of concrete frames. However, the GHG mitigation efficiency, expressed as CO_2 equivalents per unit area of forest land, will be 2-3 times higher when wood frames are used if excess wood waste and logging residues are used to replace fossil fuels. The excess forest in the concrete frame alternative is used to replace fossil fuels, but if this forest is used for carbon storage, the mitigation efficiency will be higher for the first forest rotation period (100 yr), but lower for the following rotation periods (Börjesson and Gustavsson, 2000). Xing, Xu and Jun compared the environmental effects of two different building structures, steel and concrete. The results show that the steel framed building is superior to the concrete framed building on the following two indexes, the life cycle energy consumption and environmental emissions of building materials. It is found that the life cycle energy consumption of building materials per area in the steel framed building is 24.9% as that in the concrete framed building, whereas, on use phase, the energy consumption and emissions of steel framed building are both larger than those of concrete framed building. As a result, lower energy consumption and environmental emissions are achieved by the concrete framed building compared with the steel framed building on the whole life cycle of building (Xing et.al., 2007).

3. Review of Existing Building Structures in Turkey (Case Study)

The assessment of existing buildings in Turkey in terms of structures, numbers of buildings provided by the Turkish Statistical Institute based on occupancy permits have been used in the review. (https://biruni.tuik.gov.tr/yapiizin). By the year 2016, the distribution of the existing buildings in Turkey by their structures shows that reinforced concrete framed structures are the most commonly preferred structures with 93.24%. As shown in the Table 1 and Figure 1, out of the existing structures, the masonry structures make up 2.76%, steel framed structures 1.77%, prefabricated structures 1.43%, composite structures 0.62% and wood framed structures 0.18%. The masonry structures, the wood framed structures and the prefabricated structures cannot be used in multi-storey buildings in terms of load bearing properties. Existing statistics show that steel framed structures and composite structures are not very common in multi-storey buildings in Turkey. As of 2016, the distribution of existing buildings in Turkey in terms of number of stories is as follows: 15.85% are single storey, 17.65% 2-storey, 16.35% 3-storey, 12.77% 4-storey, 15.02% 5-storey, 11.22% 6-storey, 4.69% 7-storey, 1.47% 8-storey, 1.24% 9-storey and 3.73% are 10-storey or more. (Table 1, Figure 2). 45.48% of existing structures are 1 to 3 storey buildings. In order to compare different structures in the study, a residential building has been chosen as an example. The building to be evaluated has been designed as a two-storied structure, since it is the most preferred number of stories in the existing buildings and it can be constructed with all the alternative structures. As of 2016, the distribution of the existing two-storied buildings by structures shows that 2-storey buildings are indeed the most commonly preferred type. In 2-storey structures, the reinforced concrete framed structures are the most common structures with 89.53%. In the existing 2-storey buildings, the masonry structures make up 6.50%, steel framed structures 1.31%, prefabricated structures 1.63%, composite structures 0.66% and wood framed structures 0.37% (Figure 3). When we examine the distribution of the structures in the existing 2-storey buildings between 2011 and 2016, reinforced concrete framed structures seem to be dominant (Table 2, Figure 4). The distribution does not change much in 2016.

Table 1: Number of the different structures according to their number of stories in Turkey (2016)
Source: Turkish Statistical Institute (https://biruni.tuik.gov.tr/yapiizin)

	1-storey	2-storey	3-storey	4-storey	5-storey	6-storey	7-storey	8-storey	9-storey	10+ -storey
masonry	1,497	1,361	410	6	3					
steel framed	1,731	275	49	13	14	6	1	3		7
wood framed	94	77	40							
reinforced concrete framed	13,902	18,759	18,745	15,088	17,760	13,263	5,550	1,744	1,470	4,387
composite	294	139	90	51	51	52	19	2	4	36
prefabricated	1,289	341	68							
total	**18,807**	**20,952**	**19,402**	**15,158**	**17,828**	**13,321**	**5,570**	**1,749**	**1,474**	**4,430**

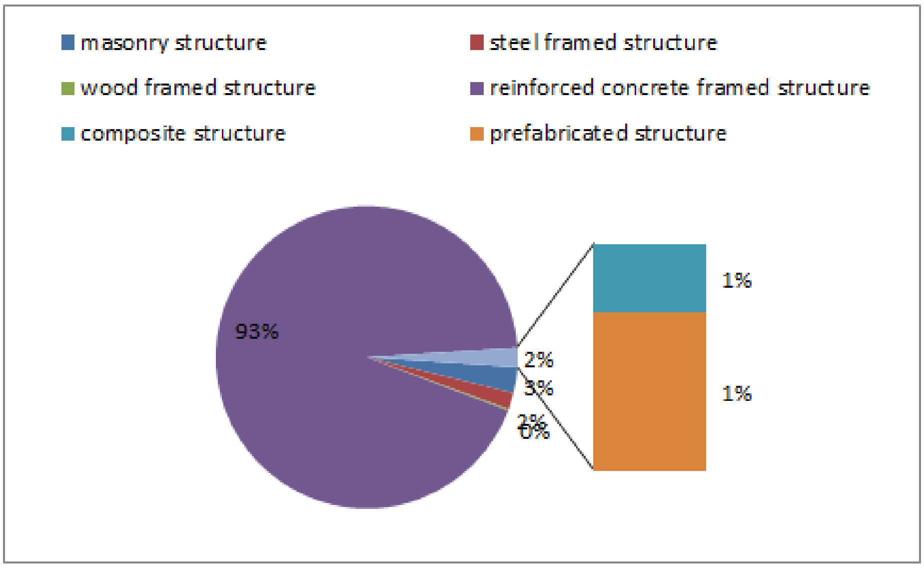

Figure 1: Distribution of existing structures in Turkey (2016)
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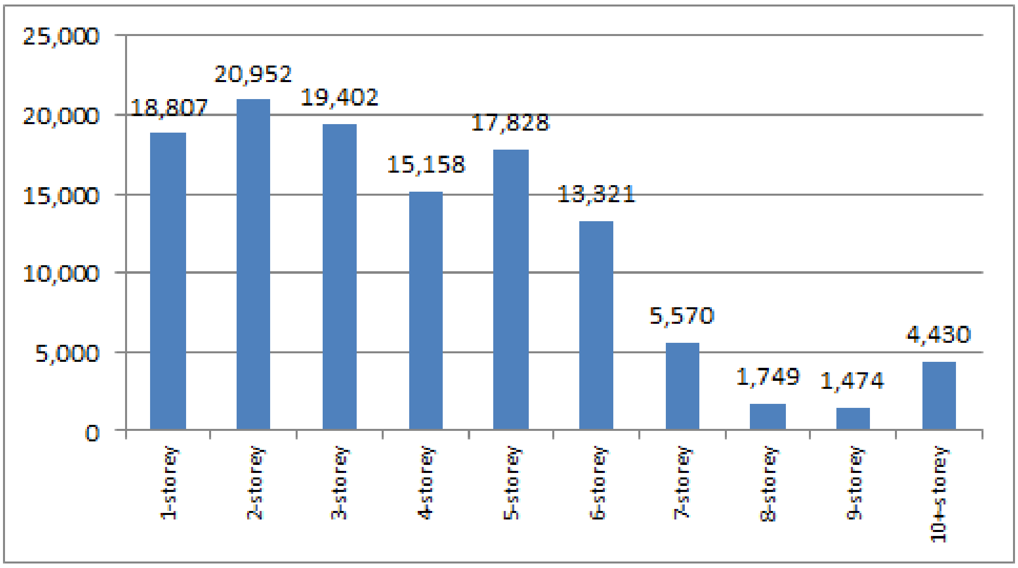

Figure 2: Distribution of existing buildings according to their number of stories in Turkey (2016)
Source: Turkish Statistical Institute (https://biruni.tuik.gov.tr/yapiizin)

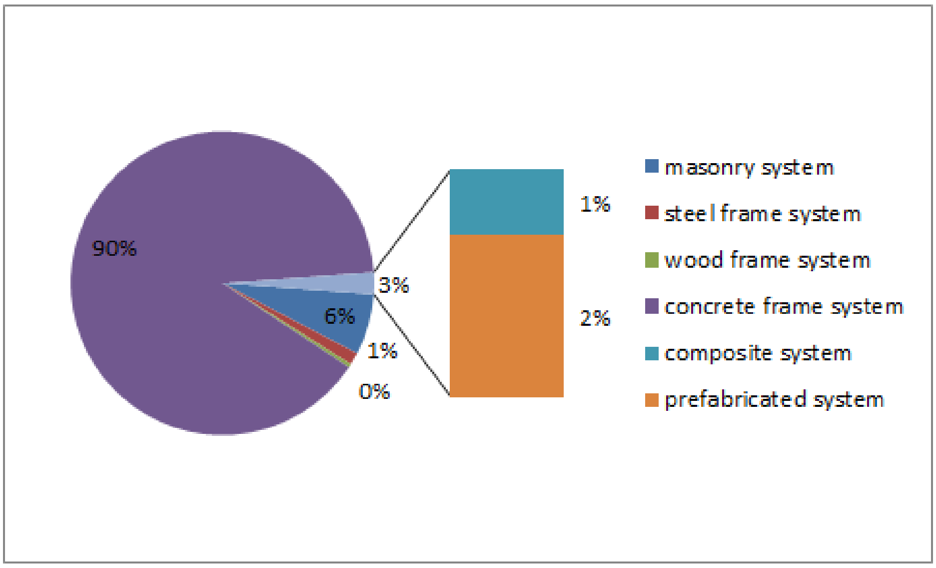

Figure 3: Distribution of existing 2-storey structures in Turkey (2016)
Source: Turkish Statistical Institute (https://biruni.tuik.gov.tr/yapiizin)

Table 2: Number of the different structures in Turkey between 2011 and 2016
Source: Turkish Statistical Institute (https://biruni.tuik.gov.tr/yapiizin)

	2011	2012	2013	2014	2015	2016
masonry structure	2,279	2,117	2,484	2,115	1,659	1,361
steel framed structure	218	252	287	308	262	275
wood framed structure	102	91	88	150	54	77
reinforced concrete framed structure	20,910	20,155	22,076	23,002	18,002	18,759
composite structure	95	126	245	217	165	139
prefabricated structure	191	205	303	353	493	341
total	**23,795**	**22,946**	**25,483**	**26,345**	**20,635**	**20,952**

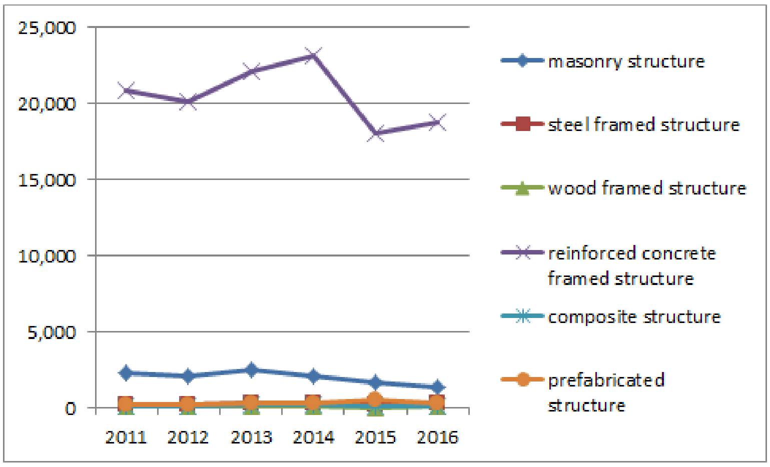

Figure 4: Distribution of existing 2-storey structures in Turkey (2011-2016)
Source: Turkish Statistical Institute (https://biruni.tuik.gov.tr/yapiizin)

4. Economic Evaluation of Building Structures (Case Study)

The study assesses different structures from an economic perspective, it examines the economic differences that would emerge if a 2-storey residential building is constructed with different structures. The selected structure is a 2-storey residential building with four sides open with a total floor area of 148 m^2. In terms of the structures, it has been considered that the 2-storey residential building may be constructed with masonry structure, reinforced concrete framed structure and wood framed structure. Only the characteristics relating to the structure have changed in these buildings, with all the other variables being kept the same. The three residential buildings have been considered to have the same plan characteristics, gross area and qualities.

4.1. Methodology

Projects for each residential project with different structures have been prepared. Necessary measurements have been made on the prepared projects, with quantity surveys determining the quantity of each work item. The quantities determined have been multiplied by the unit prices of the Ministry of Environment and Urbanization for the year 2017, allowing for a calculation and assessment of construction and structural costs (https://birimfiyat.csb.gov.tr).

In the second stage; by using the bill of quantities used in the calculation of the construction costs of the residential buildings to be constructed with three different structures; costs related to infrastructure, structure and finishes works which are the basis of CI / SfB Construction Information classification and indexing system adopted in European countries as well as their shares in construction costs have been determined and evaluated.

Construction information classification systems can be used to support this information management process. The classification structure in a construction information classification system defines concept hierarchies that can be used for document classification, providing a common framework for document organization and management among project organizations. These classification frameworks can be embedded in inter-organizational information systems, like project websites, project management software, and document management systems. Examples of CICSs include: the CSI MasterFormat, CSI UniFormat, CI/SfB, Uniclass, and the Overall Construction Classification System (Caldas, and Soibelman, 2003). CI/SfB is the Construction Index/ Samarbetskommitten for Byggnadsfragor, a Scandinavian classification system for libraries set up in 1959 and intended for the construction industry. This system has been used worldwide for technical and trade literature in the construction sector. In recent years it has been gradually superseded by Uniclass, which has a much wider coverage and is able to encompass new building types and concepts involving energy and environmental issues. However, many architectural libraries are still organised according to the CI/SfB system. An index of subjects organised by CI/SfB assists with company and/or product selection. Main groups in element category of CI/SfB are substructure, structure, finishes, fittings, external works. Classification of building system is seen in Table 3.

Table 3: Classification of building system (https://www.ribaproductselector.com)

Substructure	Structure	Finishes
(11)Ground works	(21)External walls	(41)Wall finishes: external
(13)Floor beds, ground floors, basements	(22)Internal walls, partitions	(42)Wall finishes: internal
(16)Foundations, retaining walls	(23)Floors, including beams	(43)P Floor finishes: jointless
(17)Pile foundations	(24)Stairs	(43)S Floor finishes: rigid tiles, slabs, mosaic
	(27)Roofs, including beams	(43)T Floor finishes: flexible sheets, including rubber, plastics
	(28)Building frames	(43)T Floor finishes: carpets
	(29)Patent glazing	(43)X Floor finishes: wood systems
	(31)External & entrance doors/screens	(43)Y Floor finishes: finishes, accessories
	(31.4)Windows	(44) Stair finishes
	(31.49)Windows, parts, accessories	(45) Ceiling finishes

(31.5)Doors: industrial (31.5)Doors: general (31.59)Doors: parts, accessories (31.9)Lintels, sills, weatherbars, other window/door parts (32)Room dividers, internal grilles etc. (33)Access floors (34)Balustrades (35)Suspended ceilings (37)Rooflights	(47) Roof finishes

This study has been based on this classification, but since the study only covers the construction costs, the cost assessments considered the infrastructure, structure, and finishes.

4.2. Findings

As can be seen from Table 4 and Figure 5, the masonry structure seems to be the most economical alternative according to the assessment of construction costs of the residential buildings to be built with three different structures. It is observed that the construction cost of the reinforced concrete framed structure is 7.40% higher than the masonry structure and 22.17% more than the wood framed structure. As all the properties of the selected buildings are assumed to be the same except for the structures, the analysis of Table 3 shows that the variations in the construction cost arise from the structural cost. Figure 5 assesses infrastructure, structure and finishes costs and the share of within the total construction cost. In the masonry structure; infrastructure makes up 6.00% of the construction cost, structure 63.31% and finishes cost 30.39% of the total costs. In the reinforced concrete framed structure; 5.80% of the construction cost belongs to infrastructure, 66.01% to structure and 28.19% to finishes costs. In wood framed structure; 4.91% of the construction costs belong to infrastructure, 70.71% to structure and 24.38% to finishes costs. As can be seen, the structure costs have the largest share in construction costs in all the three structures. In the wood framed structure, the share of the structure cost within total construction cost is higher than the other systems.

Table 4: Evaluation of construction costs for different structures

	substructure cost ($)	structure cost ($)	finishes cost ($)	(total) construction cost ($)	relative construction cost
masonry structure	1,996.28	21,157.14	10,106.38	33,259.80	100.00
concrete framed structure	2,070.49	23,581.76	10,069.54	35,721.89	107.40
wood framed structure	1,996.28	28,729.92	9,905.99	40,632.19	122.17

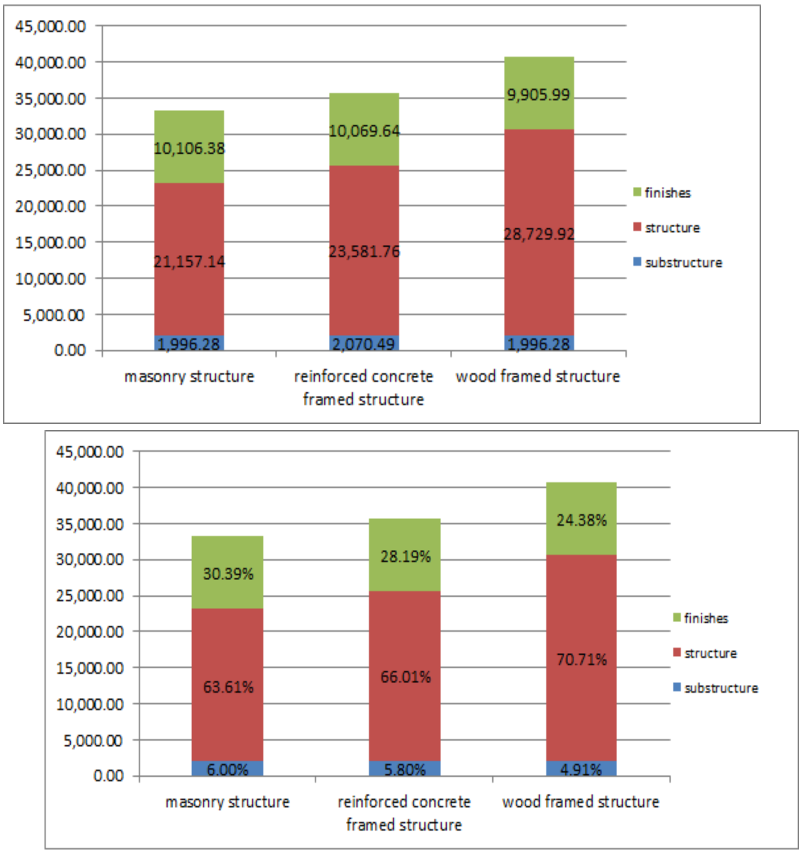

Figure 5: The costs for infrastructure, structure, finishes and the share of within the total construction costs

Structural costs are compared in Table 5 and Figure 6. The lowest structural cost belongs to the masonry structure. The structural cost of the reinforced concrete framed structure is 11.46% higher than the masonry structure, with the wood framed structure 35.79% higher. Out of the three structures, the wood framed structure has the highest structural cost.

Table 5: Evaluation of structural costs for different structures

	structure cost ($)	relative structure cost
masonry structure	21,157.14	100.00
reinforced concrete framed structure	23,581.76	111.46
wood framed structure	28,729.92	135.79

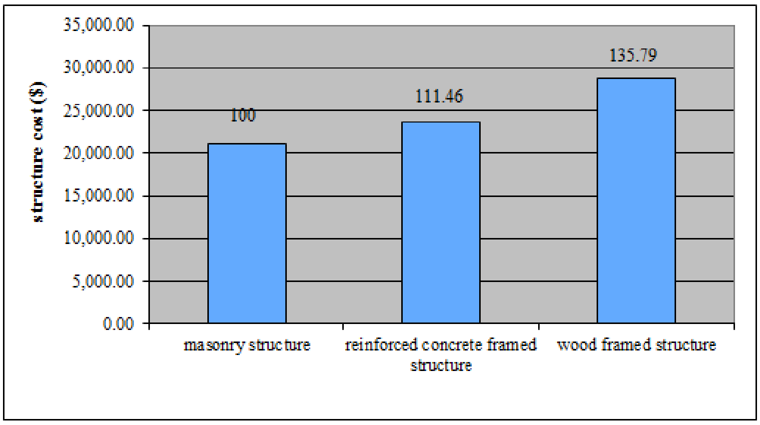

Figure 6: Structural costs for different structures

5. Results and Conclusion

The economic assessment made for buildings built with three different structures in Turkish context suggests that the most economical structure for the selected 2-storey residential project is the masonry structure. However, the construction costs of reinforced concrete framed and masonry structures are similar to each other. The construction cost of wood framed structure is 22.17% more than the masonry structure and 13.75% more than the reinforced concrete framed structure. In the comparative exercise, since all the variables of the buildings have been taken the same except the structure; it has been observed that the variations in the construction cost result from the structural cost. Therefore, in terms of the evaluation of the structural costs; the highest structural cost is observed in the wood framed structure and the lowest structural cost is observed in the masonry structure.

The assessment of buildings with these three different structures shows that the masonry structure has some disadvantages compared to the other structures, in that it is heavier than the other structures, it has some problems in terms of creating openings as compared to the reinforced concrete framed structure, it does not allow for transparent façades and multi-storey buildings. At the same time, the walls are bearing systems, so wall thicknesses increase. The elements of the structure occupy more space and the useful space decreases in a building with the same floor area. Reinforced concrete framed structure is lighter compared to masonry structure and allows for multi-storey construction. It does not have any limitations in creating openings for doors and windows, it allows for creating any opening on internal and external walls. The walls may be removed completely and it allows more flexible design. On the other hand, although wood framed structure is the most expensive alternative, it is built with a natural material, so its impact on the environment is less than that of the other two structures. It can be constructed in a shorter time, and the wood has much better thermal insulation properties than the reinforced concrete. However, the fire resistance is less than the masonry and reinforced concrete framed structures and wood framed structure requires more frequent maintenance and repair. Although the destruction of masonry and reinforced concrete framed structures result in a rubble pile, recycling is possible in the destruction of the wood framed structures.

The assessment on the distribution of the existing 2-storey buildings in Turkey by the type of the structures shows that reinforced concrete framed structures are the most commonly preferred structures with 89.63% to 86.53% between the years 2011 to 2016. The masonry structures make up 6.50% to 9.75% and their share has gradually diminished up to date. The wood framed structures make up 0.26% to 0.57%. It is thought-provoking to see that the masonry structures are preferred too little although they are more economical than the reinforced concrete framed structures; the same applies to the wood framed structures, which are used too little although they have some advantages in that they use a natural material, they have lesser impact on the environment and can be recycled. In the future, it is predicted that these two structures, which are superior to the reinforced concrete framed structures in some respects, would be preferred more in building production in Turkey.

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