The Role of the Layered Wooden Beam Construction System in Space Making and Form Making in The Middle and Far-Eastern Architectural Culture

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Abstract

A layered beam is a structural system that is known in various cultures, particularly those that employ a wooden frame structure. It is referred to as 'tumpang sari' in Java, Indonesia, 'bindirmeli kiriş' in Turkey, and 'dougong' in China. Essencially, a layered wooden beam consists of two or more layers of wood logs functioning as a composite beam system. The arrangement of these layers can be expanded vertically or maintained in a straight orientation. This layering system is intended to increase the stiffness of the wooden frame while enabling the creation of extended and cantilevered roofs or eaves. The layered wooden beam system plays a significant role in space-making and form-making in architecture. In the architectural traditions of Southeast Asia, East Asia and Anatolian Turkey, the layered wooden beam system tends to expand upwards, forming an inverted pyramid shape that results in pyramid, dome, or vault-like interior spaces. It can be employed in both interior or exterior settings, configured in full or half arrangements with varying heights.

This paper aims to investigate the utilization of the layered wooden beam system in Middle and Far-Eastern cultures including Indonesia, Turkey, and China, and examine its role in space-making and form-making. Through an exploration of relevant literature, this study seeks to provide a descriptive analysis of how similar construction systems help shaping the space on various architectural contexts. Additionally, this paper discusses the space produced by the implementation of layered wooden beams from both the formal aesthetics and symbolic perspectives.

Keywords: Layered beam, traditional architecture, wooden beam, wood construction

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1. INTRODUCTION

Layered wooden beams are found in various architectures and cultures. In the Javanese culture of Indonesia, this system is known by the name ‘tumpang sari’ (Saragih, 1987). In Anatolian Seljuk mosques and traditional Turkish houses, the system is called ‘bindirmeli kiriş’ system, which means overlapping beam technique (Eser, 1997). In China, the similar system known as ‘dougong’ system is employed (Rian and Sassone, 2014). Visually, this system can be recognized by the feature of the wooden beams stacked on top of each other in a perpendicular manner. This system clearly is the part of the main structure that transfers the load, but in addition it also produces unusual shape and spatial characteristics.

The emergence of layered wooden beam system presents an intriguing subject of investigation. This paper seeks to eludicate and analyse both the similarities and differences, in formal, functional, and symbolic aspects, to comprehensively grasp their significance in form-making and space-making.

2. METHODOLOGY

This paper utilizes a literature review followed by a comparative analysis. The properties and characteristics of layered wooden beams in various architectural contexts and cultures are explored through previous research and scholarly references. The Indonesian ‘tumpang sari’ system is selected as an example of layered wooden beam application in Southeast Asia, the Turkish ‘bindirmeli kiriş’ system represents its application in Anatolia, and China’s ‘dougong’ system exemplifies its application in East Asia. The various applications of layered wooden beams are then analysed using the theory of form-making and space-making, considering both formal attributes and symbolic meanings. Through this approach, the formal and spatial role of layered wooden beams in each culture will be understood.

3. THE FORM- AND SPACE- MAKING IN TRADITIONAL ARCHITECTURE

The built form or shape in architecture can be defined as a physical appearance architecture (Hasgül, 2015). The built shape normally composed of the vertical and horizontal surfaces that define the division of space and shape the spatial configuration (Peponis, 1997). However, spatial configuration is not only concerned with the physical arrengement of space, it also has social and cultural meanings.

According to Ching (2007), to create spaces with certain characteristics and qualities, designers can apply vaious ordering principles -such as axis, hierarchy, symmetry, rhythm, datum- and proportion and scale. These principles are inherent in every building unit. In traditional architecture, the application of these principles is often not only related to physical form, but also to its perceptual meaning. For instance, in Mongolian culture, the dome on the yurt’s roof represents the sky, and the hole at the top symbolizes the sun or the eye of heaven (Hasgül, 2015). For the Javanese, the peak of the pyramidal roof at the center of the house serves as a connecting axis between the sacred realm in heaven and the human realm on earth (Frick, 1997). Both are examples of the application of hierarchies and axes which are not only formal, but also closely related to perceptual and symbolic meaning.

The application of layered wooden beams in various cultures cannot be separated from the symbolic meaning. From a formal perspective, the layered wooden beam functions as a load-bearing element that defines the spacial boundaries, specifically as the top surface. It is a clear embodiment of hierarchy, rhythm, proportion, and scale. However, the way in which

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the wooden beams are stacked results in a certain quality of space, so it is -definitely- not just a technical consideration. In the discussion section, the role of layered wooden beams in form making and space making will be further explored and examined.

4. APPLICATION OF THE LAYERED WOODEN BEAM SYSTEM IN VARIOUS REGIONS AND CULTURES

4.1. 'Tumpang sari' system in Java, Indonesia

The layered wooden beam system named 'tumpang sari' is a fundamental part of the roof structure in Javanese joglo houses in Indonesia. 'Tumpang sari' is a system of wooden beams are arranged in an overlapping technique (Figure 1). This system supports the weight of the roof and transfers it to the four main wooden posts. The number of beams arranged is always an odd number. The beams are locked vertically with a peg system to avoid sideways shifting due to the push from the roof (Saragih, 1987). The 'tumpang sari' system is known to have been used since the 8th century in Central Java, Indonesia (Trisulowati, 2003).

The 'tumpang sari' system consists of two main sections. The first one is the wing section named 'elar', which is shaped like an inverted pyramid. The second one is the inside of the center named 'uleng', which has a shape resembling a regular pyramid. The inverted pyramid system (elar) bears the weight of the entire roof and perimeter of the building. On the other hand, the regular pyramid system (uleng) tends not to bear the load (Saragih, 1987). The 'tumpang sari' system is a transitional element between the roof structure and the four main posts of the building (Sudarwanto and Murtomo, 2013). The section of 'tumpang sari' system can be seen in Figure 1.

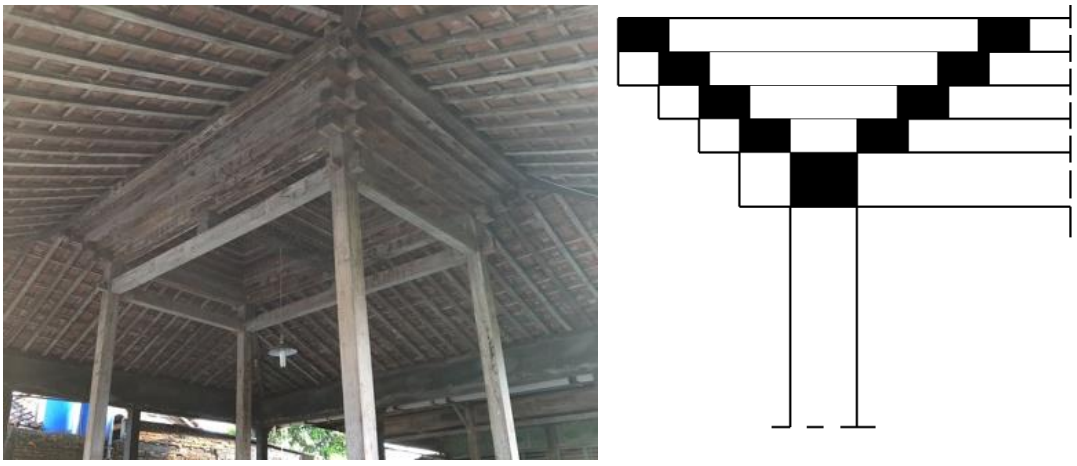

Figure 1. 'Tumpang sari' and Tumpang sari section (right) (Johanita Anggia Rini, 2021; section modified from Saragih, 1987)

Several researchers have proposed hypotheses about the reasons behind the arrangement of wooden blocks in overlapping layers to form a pyramid. Santosa et al. (2020) stated that the 'tumpang sari' system incorporates the principle of stereotomics. The number of wooden beams stacked and forming a pyramid result in a heavy weight and becomes a load for the joints between the beam and the wooden column. This weight exerts downward compression force, thereby reducing lateral forces during seismic events.

The configuration of conical 'tumpang sari' wooden beams forms a pyramidal space with a central impression. This spatial effect is the same as that found from inside the temple which refers to the mandala concept. Consequently, it can be inferred that the space formed

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beneath the ‘tumpang sari’ of the joglo house holds asacred significance, as it also refers to the same mandala principle (Santosa et al., 2020).

From a cultural and spiritual standpoint, Frick (1997) also argued earlier that the highest point of the roof of the joglo house represents the vertical axis between the earth realms and heaven. Therefore, the central structure beneath this point becomes the most sacred space within the house.

4.2. ‘Bindirmeli kiriş’ system in Turkey

Layered wooden beams are found in Turkish Anatolian architecture, such as mosques and houses. This system is called the ‘bindirmeli kiriş’ system which means overlapping (Eser, 1997). The wooden beams are stacked on top of one another.

Mosques utilizing this system are referred to as ‘wooden-columned Anatolian Seljuk mosques’ and were built during the Anatolian Seljuk period (1077-1308 AD). Examples of these mosques can be found in Ankara (Arslanhane Mosque), Konya (Sahip Atâ Mosque), Beyşehir (Eşrefoğlu Mosque), Kastamonu (Candaroğlu Mahmut Bey Mosquein Kasaba Village), and Afyon (Afyon Grand Mosque) (Erarslan, 2021). The mosques of this era share a structural similarity with traditional houses in the region, to the extent that, if the minaret were removed, the mosques would resemble regular Anatolian houses (Yüksel, 2016).

The layered wooden beam system employed in the mosque ceilings was constructed without the use of nails (Parlar and Arslan, 2003). As the stacking height increases, the length of the wooden beams also increases, resulting in the formation of cantilevers. These wooden cantilevers not only elevate the ceiling height, but also contribute to its stepped appearance (Eser, 1997). The layered wooden beam system is also applied to the upper gallery or ‘mahfil’. which is supported by wooden posts and interlacing wooden beams. The construction of floor joists of the upper gallery is similar to that of the mosque ceiling (Aydın and Perker, 2017). The upper galleries of Ahi Elvan Mosque, Arslanhane Mosque, and Eşrefoğlu Mosque also employ the same system. This system emerged in the 12th century and persisted until the early 20th century (Yüksel, 2016).

In contrast to the closely arranged layered wooden beams of the ‘tumpang sari’ system, the layered wooden beams in the Anatolian Turkey architecture exhibits gaps between the beams with gaps reaching up to 1.5 meters. Typically, the principal beams are situated perpendicular to the ‘mihrab’ (prayer niche), while the secondary beams run above it, parallel to the ‘mihrab’. The principal beams bear the load of the entire upper structure and transfer it to the columns (Erarslan, 2021).

The configuration of the layered wooden beam system on the ceiling is closely related to the spatial division within the mosque. In general, the interior space of a mosque is divided into multiple rows based on the arrangement of the wooden posts, ranging from three rows in smaller mosques to seven rows in larger ones. These rows are oriented perpendicular to theqibla wall where the ‘mihrab’ is located. The layered wooden beams on the ceiling typically follow this row division.

In the case of Kasaba Village's Candaroglu Mahmut Bey Mosque (Figure 2), for example, the ceiling is divived into three rows. The central ceiling is higher than the side ceilings. Various overlapping patterns are created with wooden elements on the middle and the side ceilings (Aydın and Perker, 2017). In the case of the Eşrefoğlu Mosque, the main

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prayer hall is divided into seven rows, with the central row being wider and higher than the others (Erarslan, 2021).

A section illustrating 'bindirmeli kiriş' system can be observed in Figure 2. Upon examination of the section, the configuration of the layered wooden beam system reveals an arch-like structure with a subtle curvature, resulting from the extension of each beam on the apex of the supporting posts. Spatially, the resulting formation is closer to a vault rather than a dome, owing to its elongated shape rather than circular form.

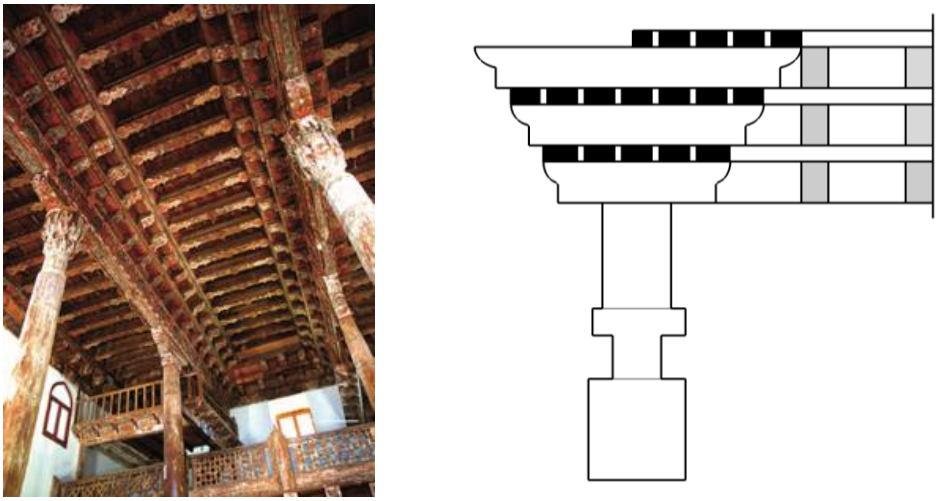

Figure 2. 'Bindirmeli kiriş' system, Kasaba Village's Candaroğlu Mahmut Bey Mosque, Kastamonu (right) (Kastamonu İl Kültür ve Turizm Müdürlüğü, 2022), and the section on the left (modified from Karaseki, 2007)

The layered wooden beam system is also used in overhanging projection on the facades of Turkish traditional houses, such as the Kaleiçi houses in Ankara. In general, the cantilevered wooden beams extend approximately 60-100 cm from the facade, occasionally with supoort of a secondary beam (Öztank, 2018). The beams are all stacked perpendicularly. In addition to expanding the interior space of the upper floor, this layered wooden beam system also functions as an eave for the ground floor's facade.

4.3. 'Dougong' system in China

The layered wooden beam system can also be observed in Chinese architecture (Figure 3), although the wooden beams are more accurately called wooden blocks due to their relatively short size. This layered wooden beam system is found in the transition between the roof beam system and the wooden posts, known as 'dougong' (Zhao et al., 2020). 'Dougong' has been widely used and reached its mature stage during the Han dynasty from 206 BC to 220 AD (Liu, 1982). A section of 'dougong' can be seen in Figure 3.

The term 'dou' means a wooden block or piece while 'gong' refers to a wooden bracket (Rian and Sassone, 2014). In the 'dougong' system, a number of wooden blocks are placed on top of the column and arranged on top of each other in a perpendicular manner to form a cantilever-like formation. The length of the wooden block on the top layer is almost twice the length of the block below it. This proportional pattern is repeated until the desired height and length of the cantilever are achieved.

The overall shape of the cantilevers resembles an inverted pyramid. These cantilevers serve to support the primary roof beam and transmit the load from the beam and roof to the

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columns. The ‘dougong’ system is found in numerous Chinese temples and palaces (Rian and Sassone, 2014).

‘Dougong’ can be found both in the interior and exterior of buildings. The ‘dougong’ located within the interior is called the ‘inner eave dougong’, whereas the one located in the exterior is called the ‘external eave dougong’. Furthermore, the ‘external eave dougong’ can be divided into an intermediate set, a column set and a corner set (Ma, 2003). Within the external eave dougong, the extended wooden beams provide support for the weight of the overhanging eaves (Li et al., 2014).

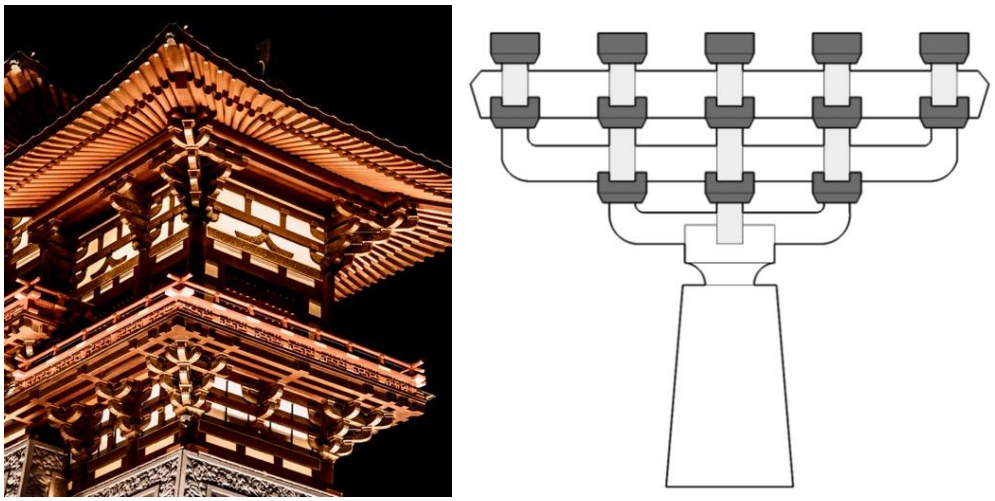


Figure 3. ‘Dougong’ system (left) and ‘Dougong’ system, section (rigt) (Tyler, 2020; section modified from Rian and Sassone, 2014)

According to Li et al. (2014), there are several main functions of ‘dougong’ in terms of structural, mechanical, and aesthetic aspects. The main function of ‘dougong’ is to transfer the load from the roof evenly to the post and to the foundation, while strengthening the overall structural integrity, particularly in seismic events. Wooden blocks that extend in various directions technically shorten the span of the roof beams, thereby reducing the stress they experience. From a climatic standpoint, the ‘dougong’ system allows for a wider eaves which offer protection to the walls and windows against heavy rainfall, considering that traditional Chinese windows are only covered with paper. The arrangement of ‘dougong’ wood blocks with interstitial gaps also allows for the daylight to penetrate into the terrace even though the eaves are quite wide. Moreover, culturally, the significance of the building itself and the owner's socioeconomic status is reflected in the style and coloration of the ‘dougong’.

5. DISCUSSION

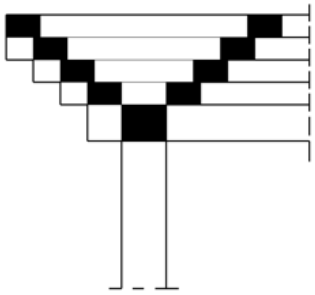
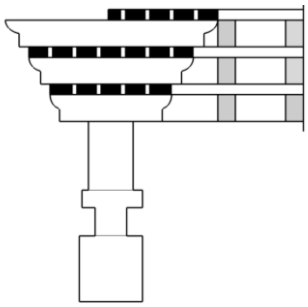
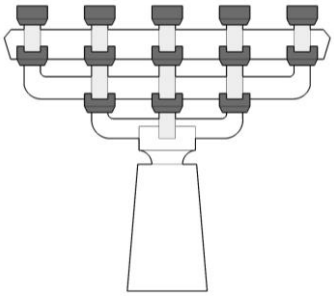
5.1. The role of layered wooden beams in form-making

From a formal perspective, the entire layered wooden beam system described in this paper forms a configuration that widened upwards to resemble an inverted pyramid. This inverted pyramid shape is generated by the need for load distribution, which all three systems have in common. The ‘tumpang sari’ system aims to increase the compressive load to stabilize the structure, as well as widen the reach of the beam to the perimeter of the roof (Saragih, 1987). The ‘bindirmeli kiriş’ system in the Anatolian Seljuk mosques transmits the load from the roof system to the wooden posts. It is mentioned in the reference that there are wooden-columned Anatolian Seljuk mosques that originally utilized earth roof (Erarslan, 2021), thus it

is appropriate if the wooden beams had to be stacked in layers because they received a direct load from the heavy earthen roof. The 'bindirmeli kiriş' system in traditional cantilevered houses aims to withstand the load from the wider upper floor due to the projection of the facade (Öztank, 2018). In the case of 'dougong' system, its upward extension serves to broaden the range of load distribution for the wide eaves (Li et al.,2014). It can be concluded that technically, the shape of the layered wooden beam system tends to widen upwards to broaden the load-bearing range.

Analyzing their placement within a building, the 'tumpang sari' system is positioned in the interior of the building and concealed from the external view. The 'bindirmeli kiriş' system in Anatolian Seljuk mosques is located both on the interior and exterior, while in traditional Turkish houses, it is located on the exterior. The 'dougong' system, on the other hand, can be located both on the interior and on the exterior. Notably, no specific pattern emerges regarding the location of the layered wooden beams among the three examples. The location can be different in each cultural context.

Table 1. Stacking configurations in various types of layered wooden beams

'Tumpang sari' system	'Bindirmeli kiriş' system	'Dougong' system
		

Regarding the stacking technique of the layered wooden beams (Table 1), all three examples utilize a perpendicular arrangement. The difference, however, is found in the configuration of the stacked beams. The 'tumpang sari' and 'dougong' systems are characterized by a centralized configuration, whereas the 'bindirmeli kiriş' systems in Anatolian Seljuk mosques and Turkish houses have a linear configuration. This configuration is in line with the space formed. The layering steps in the 'tumpang sari' system, the 'dougong' system, and the 'bindirmeli kiriş' system in Turkish houses, are more visible. Conversely, the steps in the 'bindirmeli kiriş' system on the ceiling of Anatolian Seljuk mosques tend to be more subtle, as they are aligned along a single axis, further combined with the gigantic scale of the space.

5.2. The role of layered wooden beams in space-making

The configuration of upward expansion of layered wooden beams produces various spatial formations such as pyramids, domes, or vaults. In the 'tumpang sari' system, the pyramidal space called 'uleng' is centrally formed with a prominent apex (Figure 4). This characteristic is aligns with the Javanese spiritual understanding that the center of 'tumpang sari' which is the peak of the roof is the most sacred space in the house, since it symbolizes the axis connecting heaven and earth (Frick, 1997, Santosa et al., 2020).

The space created by the 'bindirmeli kiriş' system in Anatolian Seljuk mosques resembles an elongated vault. The space tends to be linear rather than centralized, as the 'bindirmeli kiriş' system continuously extends through the wooden posts modules (Figure 5). Although not directly forming an arch, the capitals and consoles on the columns draw attention

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in terms of profiled structures and architectural plastics and animate the view of the ceiling (Eser, 1997). This plastic impression makes the vault effect appear. This could be one of the reasons behind the row configuration that is perpendicular to the qibla wall. This direction allows the curvilinear spatial effect produced by the layered wooden beam arrangement to be directly seen and experienced by people entering the mosque from the front door.

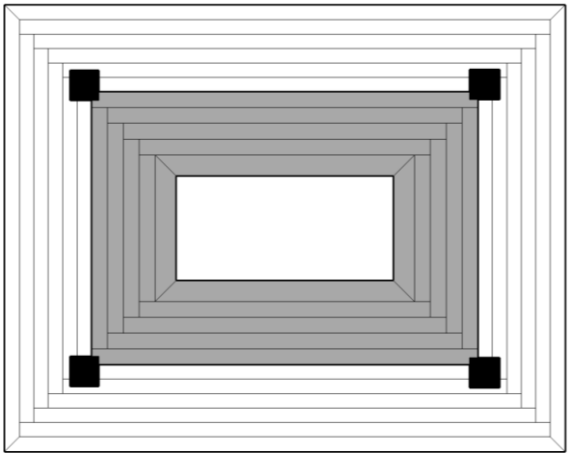

Figure 4. 'Tumpang sari' configuration, top view (Johanita Anggia Rini, 2022, modified from Saragih, 1987)

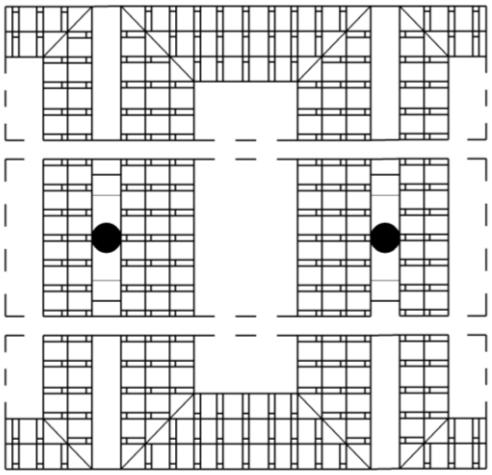

Figure 5. 'Bindirmeli kiriş' configuration, top view (Johanita Anggia Rini, 2022, modified from Karaseki, 2007)

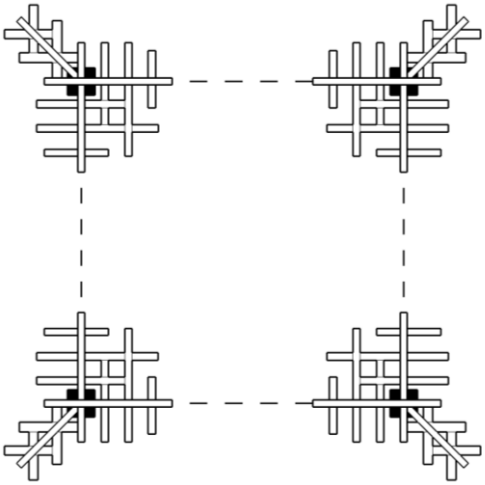

Figure 6. 'Dougong' configuration, top view (Johanita Anggia Rini, 2022, modified from Ziyin Yao et al., 2019)

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Symbolically, the relation between arches, domes or vaults with religious spaces is quite familiar; a curvilinear roof is a symbol of the sky, while the space beneath it, is the personification of the earth (Alami, 2001). In some Anatolian Seljuk mosques like Eşrefoğlu Mosque, there is even a void in the center of the roof and a pit in the ground, which reinforces the symbol of the relationship between heaven and earth (Erarslan, 2021). The central row or the ceiling is wider and higher than the side rows, further enhancing the arch or vault impression throughout the interior space, as well as emphasizing the impression that the center of the mosque is the most important zone.

The vault-like space created by the 'dougong' system is relatively subtle due to the extended distances between the 'dougong' elements, but the pyramidal effect remains notable as the wooden blocks in the 'dougong' branch to four or more directions (Figure 6). This branching system aptly resembles a tree, which served as the original inspiration of the 'dougong' system (Rian and Sassone, 2014).

Table 2. Curved spaces produced by various types of layered wooden beams

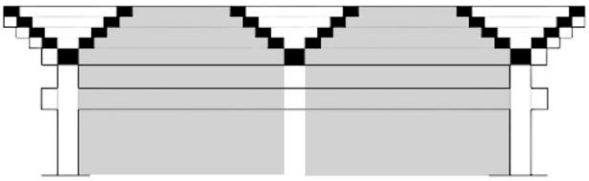
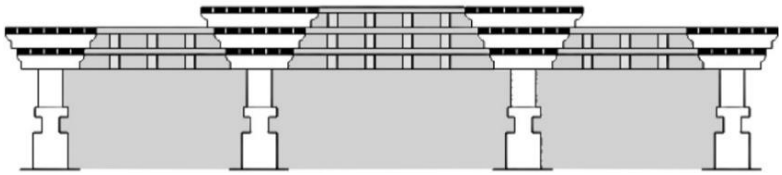
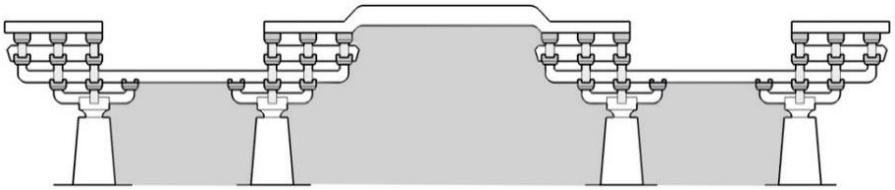
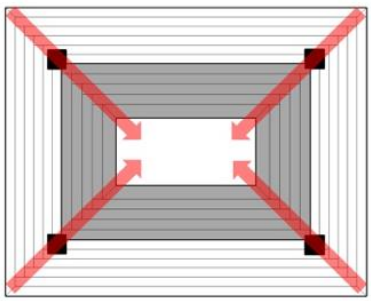
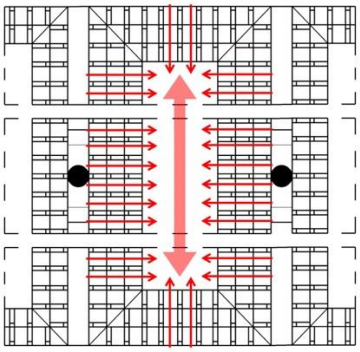
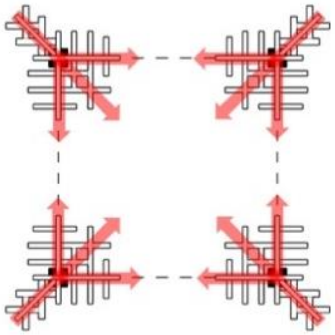
Layered wooden beam system	Overview of Sectional Views
'Tumpang sari' system	
'Bindirmeli kiriş' system	
'Dougong' system	

Table 3. Spatial characteristics created by various types of layered wooden beams

Centralized space produced by the 'tumpang sari' system	Linear space produced by the 'bindirmeli kiriş' system	Centralized space produced by the 'dougong' system
		

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The comparison of curved spaces produced by the three types of layered wooden beams is shown in Table 2. The comparison of the spatial characteristics is shown in Table 3.

The layered wooden beams in the three systems discussed also exemplify Ching's (2007) principles of ordering systems, namely axis, hierarchy, rhythm, and dimensional manipulation. With the entire system taking the shape of an inverted pyramid and resulting in a pyramid/dome/vault-like space, the layered wood beam system clearly establishes a strong vertical axis within the space. The repetition of wooden beams of a specific size and spacing embodies the rhythmic quality evident in both the system and the overall space. The formal hierarchy corresponds to the symbolical hierarchy, where the pinnacle of the pyramidal space holds greater significance than the lower portions. Dimensional manipulation is achieved in the 'tumpang sari', 'bindirmeli kiriş' and 'dougong' systems, through the arrangement of wooden beams, creating an ascending step pattern. The progressively rising cantilever or beam perceptibly reduces the distance between opposing walls providing technical convenience, while enhancing the plasticity effect of the ceiling (Eser, 1997). Consequently, the resulting ceiling exhibits a curvilinear impression, giving the sense of increased height, and making the users feel relatively smaller.

The comparison between the formal and spatial characteristics of the layered wooden beam and the space created by the application of it can be observed in Table 4.

Table 4. Comparison between the formal and spatial characteristics of the layered wooden beam and the produced space

	'Tumpang sari'	**'Bindirmeli kiriş'**	**'Dougong'**
Origin	Indonesia – South East Asia	Turkey - Anatolia	China – East Asia
Stacking configuration	Widened upwards, without gaps	Widened upwards, with gaps	Widened upwards, with a small gap
Original function	Supporting conical roof	Supporting flat or shield roof	Supporting sloped roof and eaves
Location	Interior	Interior and exterior	Interior and exterior
Sectional form of generated spaces	Pyramid-like	Vault-like	Arch-like
Spatial characteristics	Centralized	Linear	Centralized

6. CONCLUSIONS

Layered wooden beams are found in various architectural styles and cultures. Its applications include the 'tumpang sari' system in Javanese houses in Indonesia, the 'bindirmeli kiriş' system in Anatolian Seljuk mosques and traditional Turkish houses, and 'dougong' system in China. The layered wooden beam system can be utilized in both the interior or the exterior spaces.

The wooden beams are stacked perpendicular to each other serving as a transitional element to transfer the load from the roof system to the wooden posts. Formally, the layered wooden beam system described in this paper expands upwards, resembles an inverted pyramid, to broaden the load-bearing range. This configuration creates an interior space with a pyramid, dome, or vault-like appearence. The 'tumpang sari' and 'dougong' systems tend to produce centralized spatial arrangements, while the 'bindirmeli kiriş' system produces a more linear space.

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Layered wooden beams create spaces characterized by a strong axis, rhythm, hierarchy, and dimensional manipulation. The formal hierarchy aligns with the symbolic hierarchy embedded in each culture. Dimensional manipulation is achieved through the stacking of wooden beams which creates increasing steps on the capitals of the posts that shorten the horizontal distance and give a sense of height to the space. The final effect is a ceiling with a curvilinear impression creating an enhanced perception of height, and making the users feel relatively smaller.

This study focuses primarily on the aesthetic and spatial aspects of layered wooden beams, serving as a preliminary exploration. Further research can expand to encompass other dimensions including structural performance, specific materials, and socio-cultural considerations. Likewise, the research methodology can be expanded to include quantitative calculations, ethnological studies, and other approaches, moving beyond solely descriptive qualitative methods.

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This article complies with research and publication ethics and there is no potential conflict of interest in this article.

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Author Contribution Statement

The initial idea, object, and research scope were contributed by the second author. Refinement of methods, processing, and analysis of data carried out by the first author. Both authors contributed to the writing.

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