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Properties and Application Potential of Shoji Screens: An Overview and Outlook

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Abstract: Historically, most modern residential buildings were designed as permanent and solid objects. However, many highly developed and populated contemporary cities have revealed emerging needs for more mobile, comfortable, economical, multi-functional, and aesthetic residences. One of the architectural styles contemporary architects can derive inspiration from is Japanese architecture, a unique architectural style well-known for its sophisticated building techniques, material selection, and aesthetics. Due to frequent natural disasters, the high forest cover rate, the limitations on space, and the dense population, most Japanese buildings (residences, temples, and palaces) developed high mobility, intricate functionality, and unique aesthetics. In previous research, very few scholars focused on a comprehensive discussion of one fundamental component of traditional Japanese architecture—the shoji screen—and how this component influences Japanese residences in multifaceted ways including the optical, ventilated, aesthetic and spatial ones. To address this research gap, this paper analyzed the properties of the materials composing the shoji screens and elucidates the reasons why the Japanese appreciate and utilize shoji screens. This paper approves the potential advantages in improving people's living quality, endorses the applications of shoji screens in small residences, and proposes further refinements on shoji screens on materials.

Keywords: Japanese architecture, Japanese traditional houses, Japanese residences, shoji screen, windows and walls

1. Introduction

The shoji screen, composed of translucent paper sheets adhering to a lattice frame made of wood or bamboo, was a cultural icon in Japanese history and played a fundamental role in traditional Japanese life.

The origin of the shoji screen can be traced back to China in the Zhou Dynasty (approximately 300 AD) when the predecessor of the shoji screen—the Chinese folding screen—was still heavy and non-portable. Then, in the Nara Period (710-794 AD), folding screens with various Chinese furniture, standardized measurements for size, and architectural techniques from the Tang Dynasty were transported to Japan by Chinese architects and Buddhists (618-904 AD). In this period, the folding screens were merely utilized in the dwellings of the upper class [1]. Then, shoji screens became widespread in Japan from the Heian Period (794-1185 AD). At the beginning of the Period, they were made of people's clothes and were still heavy and not as portable and removable as the later

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shoji screens. They served chiefly as partitions of space. Also, they couldn't diffuse and filter light [2].

Later on, the shoji screens started to possess more versatility. With the paper becoming more accessible for craftsmen, the covers on the shoji screen were replaced by the translucent paper processed from mulberry trees in the late 12th and early 13th centuries. These shoji papers were called "akari-shoji," which meant illuminating shoji. Enabled by the translucency and the light weight of paper, shoji screens derived their versatility. They became a light filter with mobility and attractive aesthetics. In Japan, shoji screens are well adapted to the local mild climate, dense population, small residences, religion, and people's appreciation. The shoji screens shaped Japan's cultural and aesthetic appearance [3].

Today, citizens in cities and highly-populated areas seek more comfortable and aesthetic residences. Since shoji screens have prominent advantages in moderating light, saving and visually enlarging indoor space, and improving the setup of indoor space, this author believes the traditional shoji screens possess the potential to be reapplied in modern residences, especially in some populated areas. Furthermore, this paper has also considered the deficiencies of the traditional shoji screens and attempts to point out the solutions to refine shoji screens.

2. Method

This research paper studies both primary and secondary sources to study the properties of Japanese shoji screens and its architectural functions and explore their potential uses. The primary sources are mainly photos and hand-painted illustrations on traditional Japanese houses and shoji screens. These sources were collected during the author's field trip study in Japan. These sources help clarify shoji screens' spatial, optic and aesthetic values. Other secondary sources allow the analysis of the properties of shoji materials to evaluate the acoustic and thermal performances and their existing applications in architecture.

3. Thesis statement

While traditional shoji screens have poor thermal insulation and sound insulation and only mitigate the potential physical harm caused by insect pests and high moisture, they can prominently moderate indoor light, save space and visually extend space, curtail the distance between people and natural views, and refine the existing setups of space in residences by their mobility. Examining the pros and cons, this paper affirms the shoji screen's potential to be refined through strengthening their waterproof capacity and insect resistance, and benefit the modern residences in highly populated cities.

4. Various materials for traditional shoji screens and their properties

4.1. Sheet materials and their properties

Most sheet materials for Japanese to make shoji paper are mitsumata (Edgeworth chrysantha) fibers and kōzo (Japanese mulberry trees) fibers, manila hemp, rice pulp, straw pulp, and wood pulp. With these materials, Japanese craftsmen created various paper types by combining one or up to three of these materials with certain ratios. Consequently, the papers' original colors, opacities, and textures changed, forming the famous shoji papers that the Japanese frequently utilize—kinwashi, ginwashi, rice paper, mozō paper, and kōzo paper.

Due to a special type of biopolymer in the cellulose fibers, the amount of wood fibers determines the warmth of the lights filtrated from the shoji papers. Lignin, existing in the rinds of trees, absorbs blue wavelength most strongly, eventually leaving wood fibers with yellowish colors [4]. This

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explains why many shoji papers can filtrate the warm color and impede the entrance of the cold colors. For instance, kōzo paper, a Japanese paper mainly added with kōzo fibers and little pulp, exhibits a stronger capacity to impede the transmission of blue waves than this mozō, a paper mainly added pulp but with little kōzo fibers. Therefore, kōzo paper appears a yellower color than mozō paper under the circumstance that they are of the same thickness and under the same lighting.

Another determinant of shoji paper's appearance is opacity, which is affected by the length of fibers and the amount of fillers. Like many other papers, shoji papers made out of longer fibers exhibit more opaque, and vice versa. Also, larger numbers of fillers will influence the capacity of light transmission. One of the definitions of opacity is a material's capacity to hide an object behind it [5]. Since higher opacity ensures higher visual privacy, architects can choose shoji papers with different opacities to meet the various functions of different rooms. Though other factors, such as coatings of papers, can affect the opacities of shoji papers, since most Japanese architects cherish the original appearance of shoji papers and abandon the needless decorations due to both the dogma of Buddhism and the scarcity of materials, this paper doesn't take coatings into on of reason influencing shoji papers' opacities.

Last but not least, the level of the roughness of the shoji paper's surface also influences the lights passing through the shoji screens, creating various visual effects. When incident lights approach the paper surface, the diffuse reflectance will happen. Light will first touch with one side of the paper. Then, some of the light will be absorbed by the substances in the paper, just as mentioned above, and some of the light will be reflected in all directions due to the roughness of the paper [6]. With a higher level of roughness, the shoji paper tends to reflect more uniform lights. In this circumstance, though people's angles to the shoji screen can vary, the shoji paper's brightness always tends to be the same.

4.2. Frame materials and their properties

The most usable traditional shoji screen frame materials are Hinoki (Japanese cypress), Akamatsu (red pine), Tsuga (Japanese hemlock Spruce), Sugi (Japanese cedar), and Kiri (Japanese paulownia).

Hinoki is a Japanese cypress widespread in the temperate northern hemisphere. It's a timber with medium hardness, which empowers its potential to be reshaped and carved. Since it possesses high flexibility and high resistance to moisture, it's a suitable material for building dwellings, palaces, and furniture in moist areas like Japan. Moreover, its exquisite textures and aroma make it an ideal ornamental material, such as in shoji frames. However, due to its high cost, it tends to be utilized more by the elite class in ancient times.

Akamatsu, also known as red pine, exhibits high elasticity and good resistance to corrosion. So, this resinous timber is frequently used for beams and foundations of dwellings to prevent these load-bearing parts from decaying. However, compared with other woods, it's not as stable and resilient to warping, so it's not frequently used to make shoji frames.

Tsuga, a kind of hemlock spruce, has a straight and dense trunk. This property promotes it to become a commonly used construction material for Japanese houses. Also, its fine grain allows it to become a decorative material to produce shoji frames.

Sugi, a type of Japanese cedar, contains a high percentage of water and relatively low hardness compared with Hinoki and Tsuga. However, because of its high workability, soft texture, and reddish color, it's a high-quality material for decorative fabrics and indoor construction. Therefore, it's common to see this material for sculptures in tearooms and niches in living rooms. Also, it's the most commonly used material to make shoji frames.

Kiri, a Japanese paulownia, is famous for its straight and elegant body shape. Since it's relatively hard and highly resistant to moisture, it's a very good choice for architects to build houses and produce

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ornamental structures. However, due to its unaffordable prices, most Japanese only utilize it to produce furniture. So, it's less used in the production of shoji frames.

Despite the diversity of wood types employed, the materials utilized in the construction of shoji screens exhibit common characteristics, including moderate durability, beautiful textures, superior workability, and notable resistance to moisture and warping. Within the context of traditional Japanese practices, the selection of materials for shoji frames is predominantly influenced by economic considerations. This economic rationale elucidates the preeminence of hinoki (cypress) and sugi (cedar) among the five viable materials, and these species are more frequently adopted in the production of shoji screens.

5. Advantages of shoji screens

5.1. Removability and space saving

Shoji screens are slideable. Due to the local ample resource of wood, the wooden beams and the wooden columns are the only supporting members of the Japanese houses. A large amount of space between columns enables people to install the panel-like units set on the track—shoji screens. Architects designed an above track, called shikii, and a below track, called kamoi, to regulate the track of the slidable shoji screens. The kamoi is always deeper than shikii. People can firstly lift the shoji screen, and infix the upper part of the shoji screens aslant into the kamoi. Then, they let the bottom of the shoji screens aim at the shikii and fall into the shikii. During the whole installation process, slidable shoji screens require no pulleys, screws, or nails, providing people with the high flexibility of dismantling and installing.

Most common doors and windows in Western countries are swinging doors. These doors and windows need people to push them to open. So, these swinging doors and swinging windows require an additional fan-shaped space to guarantee their normal operations. Also, the opened swinging doors only offer limited space for people to pass through. In contrast, Japanese slidable shoji screens only move on their straight tracks, which almost don't employ any additional space. Moreover, since Japanese houses are supported by wooden beams and very few solid walls, the shoji screens can be installed in any place between two beams, replacing the position of the walls. Therefore, the installation of shoji screens provides dwellings with highly flexible walls. When dwellers open all these slidable shoji screens, the shoji screens can be gathered with the size of one piece of the shoji screen, thus offering a large-scale open space. This flexibility of shoji screens cultivates an enormous aesthetic potential.

5.2. Light moderation

One of the fundamental effects of the shoji screens is to moderate sunlight. In traditional Japanese houses, most outside walls near the gardens and the windows are all shoji screens (sliding doors and windows). Due to both the light diffusion ability and light absorption ability, most shoji screens can only allow approximately 50% of sunlight to pass through. The first benefit is the shoji screens can serve as a shading device. Japanese people can utilize shoji screens to reduce the brightness in their rooms and reduce solar radiation. In summer, when the sunlight becomes stronger, they can utilize more than one shoji screen to shade sunlight more efficiently. Since the shoji screens are easy to install and dismantle, they can adjust the number of overlapping shoji screens based on the strength of the sunlight. Secondly, the shoji screen can also unify the indoor light. As mentioned in the previous paragraph, the surfaces of the shoji screens are rough, which provides them with the capacity for diffuse reflection. So, the sunlight passing through the shoji papers can transmit through lines to all the rooms' corners. As a consequence, the indoor light can be more uniform.

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5.3. Ventilation

Strong ventilation of shoji screens is another advantage. Since Japan is an island nation with a temperate oceanic climate, it withstands high humidity brought by ample rainfalls. According to a study on Japanese environment-friendly houses from Kanto Gakuin University, shoji screens have a prominent effect in increasing the amount of passing air in the house. This capacity of shoji screens can help houses maintain strong ventilation [7]. Therefore, when the indoor heat become excrescent, dwellers can open the shoji screens to exclude heat. Besides, when humidity inside rooms becomes high, dwellers can also utilize shoji screens to reduce the humidity. As a consequence, dwellers' living environment can be more comfortable.

5.4. Affinity to nature

One of the vital reasons for using shoji screens is to strengthen the connections between people and natural beauty. Most traditional Japanese houses construct a niwa, a Japanese private garden. It is an area composed of trees, stones, water, and decorations. In Buddhism, everything in nature shares the same status. Therefore, people can never conquer or exploit nature. Largely influenced by this philosophy, the Japanese consider gardens as the same important part of houses, which reveals the Japanese's respect for both humans and nature. So, gardens are also one part of architecture.

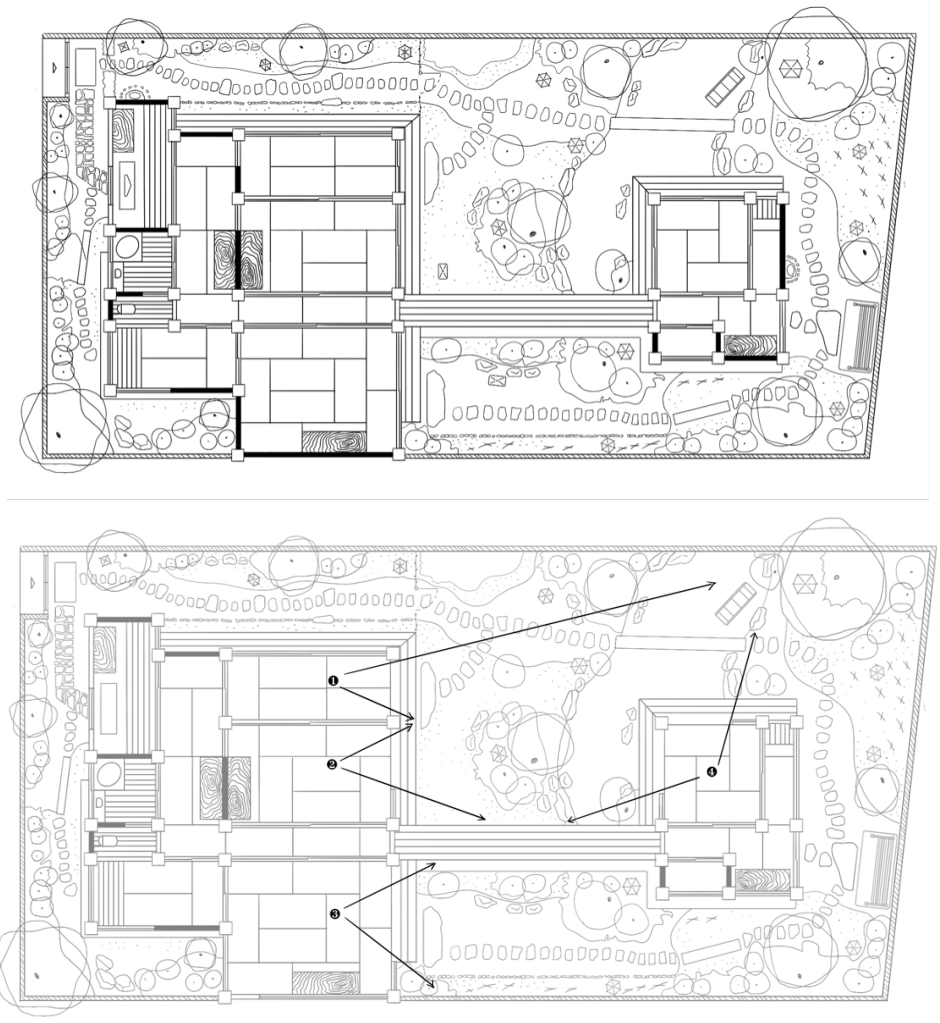

Figure 1: Sketch ontypical Japanese residence and notes & analysis on Dwellers' views through shoji screens (huang, 2024)

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When architects design the whole dwelling, they hope the dwellers in rooms can relish the garden views anytime without stepping out of the rooms. So, the meaning of shoji screens is to enable people to see the whole garden inside rooms. When shoji screens are opened, shoji screens serve as frames to capture the beauty of certain areas with certain morals in gardens. For example, in Figure 1, people in the living room position 1, can see trees, a bridge, a pool, a water wheel, and stones. They utilize stones and little pine trees as the symbol of mountains and large pine trees. In the frame of shoji screens, these natural elements compose a picture of people's harmonious relationship with nature. In Figure 1, standing at point 2, people can enjoy the view of the trees, the stones, the stone lantern, and the bosk. People utilize these natural elements to compose an epitome of the natural landscape. In position 3, people can enjoy the scene of a stone pavement and bamboo. The stone pavement leading to the surrounding trees, stones, and houses reflects Buddhism's endless circulation of life. The most important room for the Japanese is the tea room, in position 4, which shares the widest view of the whole garden. Through the shoji screens in tea rooms, the hosts and guests can discuss and appreciate the setup of the garden and the specific scenes.

Though Niwa, the large gardens, are always exclusive to the upper class and the wealthy Japanese family, the poorer families also have their gardens called tsubo-niwa. It's a small open-air area surrounded by the dwelling in three or even four directions. Since it's especially precious, architects always place tsubo-niwa near the entrance and the porch, where guests and dwellers will most frequently pass through. The rooms in the other two or three directions are installed with shoji screens, aiming to spread the beauty of the tsubo-niwa to the largest degree.

Moreover, thorough blending the boundary between interior and exterior space, shoji screens can visually extend space. When all shoji screens adjacent to niwa and tsubo-niwa are opened, the outside view can make the indoor space more visually spacious. Living in houses with traditional shoji screens, even though the sizes of the houses are not large, people won't feel crowded and oppressive.

5.5. Capacity to change the setup of rooms

Figure 2: Original setup and two variants (huang, 2024)

In most Western countries, rooms are divided by solid walls based on their functions. However, in Japan, shoji screens empower the dwellers with the flexibility to change the setup of rooms. When shoji screens are closed, each room remains separated and plays its original role. Since they only allow light to pass through and prevent the view, they can give each room a sense of privacy. After some shoji is opened, the partitions of the residential space have been changed. In Figure 2, the reception room and living room is connected to form a large space—room 2, and so do room 3. Moreover, the third picture exhibits another possible setup for space. People can flexibly change the setup of space and endow them with various functions.

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Applied in modern architecture, shoji screens can provide houses or apartments with more flexible space and the chance to restructure space. In small dwellings, people can develop more functions of their houses.

6. Limitations of shoji screens

The widespread of shoji screens benefits from Japan's geographical features, architectural features, and adequate wood resources. However, these features also bring the drawbacks of shoji screens in the thermal insulation, sound insulation, waterproof capacity, and control of insect pests.

Though shoji screens can resist high humidity, they can not withstand the rains. From a geographical perspective, Japan is an archipelago consisting of thousands of islands in the Pacific Ocean. So, it appears with a temperate oceanic climate. Its summer is cool, and winter is relatively mild, which enables the Japanese to install shoji screens as their walls instead of other heat-insulated walls. From an architectural perspective, most traditional Japanese have wide and solid eaves so most rain won't fall onto the shoji paper. So, Japanese craftsmen don't use waterproof materials to produce shoji screens when designing shoji screens. Though shoji screens can endure the high humidity, it's not waterproof. So, the large-scale use of traditional shoji screens is limited to Japan.

Moreover, shoji screens can't efficiently save energy and protect dweller's privacy due to their low heat insulation and sound insulation. A study conducted by Dr. Mohammad, a professor of the Architectural Engineering Department at King Fahd University of Petroleum and Minerals, demonstrated that paper composed of cellulose has high heat conductivity and low sound absorption [8]. Since papers generally have low thermal insulation, it will can not sustain the indoor warmth efficiently. Moreover, because of its bad sound insulation, it can not provide dwellers with enough sense of privacy. So, traditional Japanese shoji screens made up of paper have a conspicuous limitation in energy saving and protecting dwellers' privacy.

Last but not least, insect pests are a potential issue for the long-term use of shoji screens. Because shoji screens are mainly processed from wood frames and papers, they will be damaged by insect pests, especially termites. Termites will gnaw the wood frame and even the paper. The structure of shoji screens will be destroyed, which will deprive shoji screens of functions.

7. Conclusion

This paper analyzes the removability, optical effect, aerial value, nature aesthetic, and spatial advantage through studying the shoji screens. Shoji screens can be installed and removed easily, moderate the indoor light of houses, strengthen the ventilation, capture the natural beauty, and increase the flexibility of indoor space. These advantages of the shoji screens can effectively help the young generations to create more comfortable, convenient, and multi-functional residences. Since shoji screens have a deficiency in heat insulation, waterproofing, sound insulation, and insect pests, it's a more optimal choice to install shoji screens as the partitions of the interior space. If architects want to use shoji screens as windows and doors, it requires further refinements of on-screen materials and structure to adapt to harsher environments and specific purposes.

8. Discussion

8.1. Method to refine shoji screens

Though shoji screens have disadvantages in insulating heat, waterproofing, insulating sound, and preventing insect pests, these disadvantages can be addressed with modern technologies to enable their uses as windows and facades. For instance, craftsmen can design a shoji screen with empty space between two translucent papers. They can fill this empty space with heat-insulated materials,

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such as fiberglass, cellulose, and cotton [8]. These light-weight materials can not only absorb sound efficiently and insulate heat but also guarantee the removability and translucency of the shoji screens. Moreover, diatomaceous earth, a natural power without harm to humans and wood structure, has a prominent effect in preventing insect pests [9]. By sprinkling the diatomaceous earth on the shoji screens, people can effectively prevent termites and other harmful pests from damaging the screen paper and wood frames. Also, some natural essential oils, such as oils from cedar wood and orange trees, can prevent wood-boring insect pests from damaging shoji screens [10]. Sprinkled on the surface of shoji screens, it can also leave pleasant odors.

8.2. Existing applications of shoji screens

The transparency, nebulous atmosphere, and light-weight traditional Japanese shoji screens provide modern architects with plentiful inspiration. Architects want to utilize the shoji screens' light moderation capacity and spatial partitioning function. To improve the shoji screens' qualities, the architects will simplify the structure of shoji screens and update the materials.

The winner of The 1993 Pritzker Architecture Prize, Fumihiko Maki's works offer an excellent application of shoji screens for a large pavilion. Fumihiko Maki designed an exhibition pavilion for new technology, the TEPIA building. He derived the inspiration from traditional Japanese shoji screens, refined them, and designed a large veiled panel to cover the surface of this pavilion. This device moderates the sunlight. It also filters both the exterior street views and the interior view of the foyer, providing visitors with a sense of security [11].

Moreover, architect Hiroshi Nakamura from the NAP Design Office provides an application and also refinement on shoji screens in a residence building. In his work--optical glass houses--he wanted to separate exterior noisy streets and interior private gardens and, meanwhile, ensured the transmission of ample light to the garden between two tall buildings. Eventually, he chose the glass bricks to build a translucent screen in front of the garden for the sake of its durability and optical performance. [12]

Not exclusive to shading devices, many architects also utilize the prototype of shoji screens to create modular and movable partitions. In a case study from California Polytechnic State University on commercial houses, they studied the modular panel partitions and tested their properties. [13] While these panel partitions remain highly moveable and light, they can insulate the heat and sound efficiently because of their material—glass, and polypropylene. Also, these materials are economical and can meet the demands of the dwellers in some developing and populated areas.

8.3. Suggestions on future applications

Despite the numerous contributions made by architects and researchers towards the refinement and reinterpretation of shoji screens, their designs and studies often prioritize either the shading effect or the spatial partitioning function. This limitation arises from the inherent challenge of achieving an optimal balance among light-weight construction, light modulation, thermal insulation, and other functions. Consequently, future research should concentrate on the development of durable and translucent materials that exhibit effective thermal and sound insulation properties while also demonstrating resistance to high humidity levels.

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