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Ancient Technologies in Contexts of the Sustainable Development Goals

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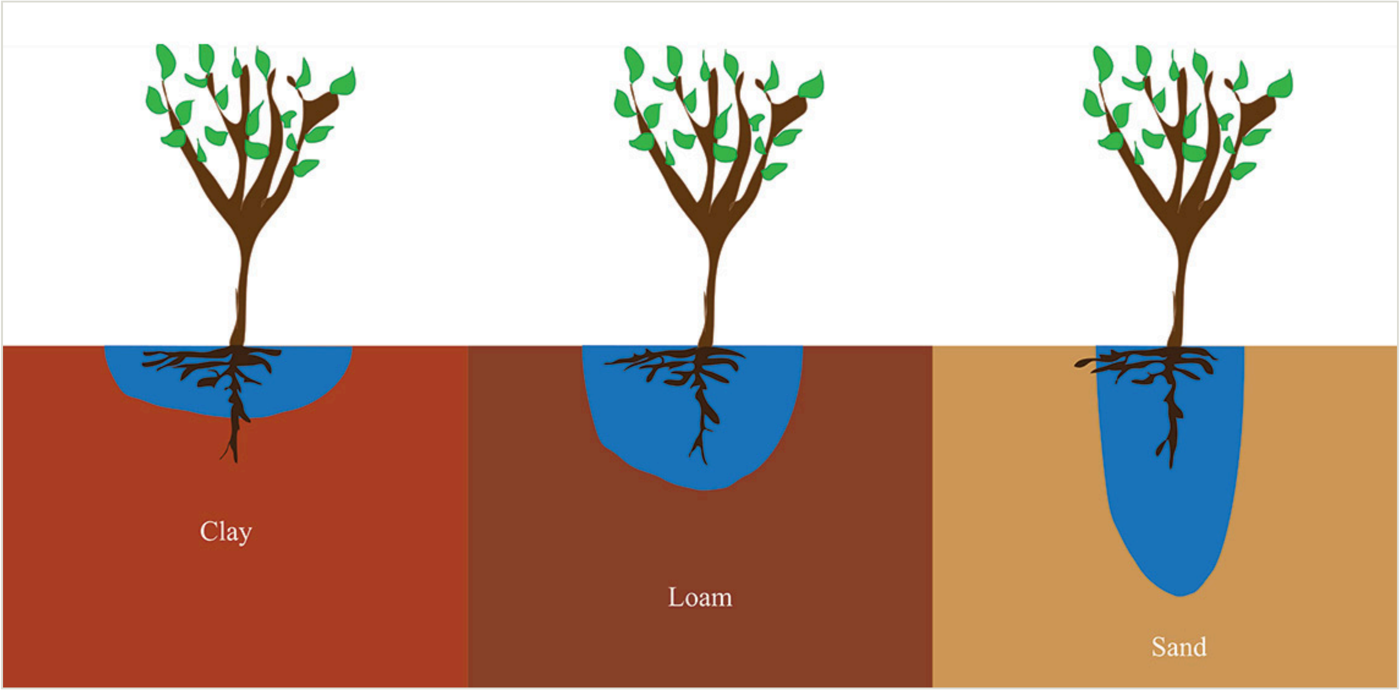

The demand for innovative solutions to pressing ecological and societal challenges is on a constant rise. Ancient technologies provide extensive yet underutilized opportunities to help solve such problems. This paper presents three of these technologies and their successful application in modern contexts based on five illustrating case studies: Clay pot irrigation, Dhajji dewari, and the shinbashira. Clay pot irrigation is an auto-regulative irrigation method especially useful in sustainable small-scale farming, horticulture, vegetable gardening, and

afforestation in arid and semi-arid regions. Dhajji dewari and the shinbashira are two earthquake-resistant construction technologies from Kashmir and Japan. Today, dhajji dewari is mainly used for private housing, while the shinbashira is applied in large buildings. Clay pot irrigation is simple, comparably cheap, and it is easy to get involved in experimental research and application as an individual. The two earthquake-resistant construction technologies, on the other hand, require more resources concerning time and funding, as well as a team. The objective of this paper is to raise awareness for the positive impact of ancient technologies on local, regional and national levels in contexts of climate change adaptation, disaster management, and in earthquake prone areas. It also aims to inspire more archaeologists to become involved in this area of research.

> “The ancient technologies presented in this paper were successfully applied in modern contexts of climate change adaptation, disaster management, and in earthquake-prone areas. Many more ancient and traditional technologies are being re-instated around the world, addressing the Sustainable Development Goals on local, regional, and national levels. Archaeology and experimental studies help better understand how these technologies worked and how to adapt them to modern needs.

Five Case Studies of Clay Pot Irrigation and Earthquake Resistant Construction Technologies

Clay Pot Irrigation

Overview

Clay pot irrigation, also referred to as pitcher irrigation, is an ancient sub-surface irrigation system based on locally manufactured clay pots buried in the ground. Seeds or seedlings are planted close to the pots, which distribute water directly to the plant roots saving between 40% and 90% of irrigation water. Different planting patterns are recommended depending on the characteristics of the plants intended for growing (See Figures 1-2).

The earliest preserved attestation of clay pot irrigation is documented in ancient Chinese manuscripts dated to the 6th century CE, quoting the even older agricultural book “Fan Shêng- Chih Shu” from the first century BCE. In chapter 7.5, the author, Fan Shêng-Chih, describes the cultivation of melons and melons intercropped with either scallions or lesser beans with clay pot irrigation:

> “*Make 24 pits in one mou [ca. 508 m2]; each pit 3 ch’ih [66 cm] across, 5 ts’un [110 cm] deep. To each pit put down 1 shih [21.336 kg] of manure. Mix the manure well with an equal amount of earth. Bury an earthern jar of capacity 3 tou [5,01 l] in the centre of the pit, let its mouth be level with the ground. Fill the jar with water. Plant 4 melon seeds around*

the jar.
Cover the jar with a tile. Always fill the jar to the brink if the water level falls. (...) Plant 10 scallions around the jar outside the melons. Towards the fifth month, the melons will begin to ripen, then pull out the scallions for sale, so as not to meddle with the melons. Or lesser beans, 4 to 5 shêng [668-835 ml] per mou, may be sown among the melons; the bean-leaves can be sold as greens. This plan fits well with level lands. When melons are harvested, one mou's gain will be 10,000 cash."
(Shêng-Han, 1982, pp.37-38, p.67).

There is no known archaeological evidence of clay pot irrigation. No abandoned field with buried clay pots and no storage place for clay pots has been discovered and identified as such. The latter is a key challenge, since knowledge about clay pot irrigation in archaeology is scarce.

For the successful planning and application of clay pot irrigation, it is important to know the key properties of the pots, the soil, the plants and the environment. The most relevant pot properties include height, shape, volume, maximum outside diameter, wall thickness, surface area, hydraulic- conductivity, base diameter, material composition, and firing temperature, of which the latter two determine porosity (See Figure 3). Relevant soil properties include its hydraulic conductivity and salinity (See Figure 4). Among the key properties of the plants are their root properties and water demand (See Figure 5). Concerning the environment, key factors include local climate and weather conditions as well as other plants nearby.

Case studies

Clay pot irrigation has been applied in multiple small and large development aid projects and is becoming increasingly common in community gardens around the world. The following three case studies were chosen to illustrate different contexts in which the technology has served as a sustainable solution to local and regional ecological challenges like water scarcity and desertification.

1. Millennium Village Project (MVP) in Tigray Regional State, Hawzen District, Ethiopia

The *Millennium Village Project* was conducted from 2005 to 2015 by the Earth Institute at Columbia University, the United Nations Development Program, and Millennium Promise.[1]

Between 2007 and 2009 it included a large-scale application of clay pot irrigation in the Hawzen District, Tigray Regional State, Ethiopia. One of the main problems the people of the villages in Tigray were facing concerned the lack of fruit production and therefore a lack of household food and nutrition security:

"*Homestead fruit production was almost impossible as the houses are located more than 1.5 km away from the closest water points.*"

(Woldu, 2015, p.161.)

Clay pot irrigation reduces the watering intervals significantly and the project promoted the production of high value fruit varieties in the surrounding area or on the homesteads of beneficiary farm households.

> "*During the dry season, it was observed that farmers often need to water their individual fruit trees without pitchers at least 4 times a month using the same capacity containers (20 liters capacity Jeri-cans), i.e. while it was procedurally only once a month under the pitcher system.*"

Almost 15 000 pitchers were distributed to communities and schools to grow sweet orange, mango, avocado, and apple. More than 1 400 households benefited from the technology. (Woldu, 2015, p.162, Table 2)

> "*The system was generally found to be as much as 10-fold efficient, saving 70-90% of water, compared to the conventional surface irrigation method in that there was almost no evaporation loss and infiltration loss was also negligible.*"
> (Woldu, 2015, p.164.)

> *"Fruits were also observed performing much better under the pitcher system, in all aspects including survival rate, growth and earliness to fruiting.*"
> (Woldu, 2015, p.162.)

2. "Application of Pitcher Irrigation in Agro Forestry to Combat Deforestation and Rural Poverty in Bauchi State", Nigeria

In Bauchi State, Nigeria, clay pot irrigation was applied "*to raise tree seedlings in woodlots to reduce deforestation and produce fruits in orchards*." (Olubamise, 2013, p.3.)

The project was conducted between 2010 and 2012 by the Environment and Development Foundation with funding provided by the GEF Small Grants Programme.[2]

> "*This simple and affordable technique has enabled the people of Udubo, Katagum, Zaki Local Government Areas in Bauchi State to reforest a whole Muslim Praying Ground, created several orchards and vegetable farms and created jobs for women who make the pots*."
> (Olubamise, 2013, p.3.)

3. "Backyard Gardening through Pitcher Irrigation System," Chotiari Wetlands, Pakistan

A project focusing on backyard gardening with clay pot irrigation in the Chotiari Wetlands, Pakistan, was conducted as part of the World Wildlife Fund-Pakistan "Indus for All Programme," which took place between 2007 and 2012.[3] 1 200 pitchers were distributed to herdsmen in the villages of Majeed Mangrio, Mangio Junejo, and Rano Junejo. The objective was:

> "*to establish, financially assist and strengthen a participatory community vegetable product management enterprise on 1 hectares, aimed at sustainably manage indigenous core livelihood source for poverty reduction, food self-sufficiency and better nutrition of the people of three villages*."
> (ul-Islam and Sumro, 2012, p.27.)

The application of clay pot irrigation resulted in a financially very successful harvest, leading to a recommendation of its further use even in large scale contexts:

> "*With the compiled crop harvest data from three villages, a total amount of 60,000 Pakistani rupee net profit is recorded, that highly advocates the introduction of Pitcher Irrigation System in arid & semi arid regions at large scale in such a scenario of severe water scarcity and desertification issues that our country is experiencing*."
> (ul-Islam and Sumro, 2012, p.27.)

Selected Quotes

"[Clay pot irrigation] *is especially useful in difficult conditions of high salinity, extreme aridity, limited water supply, and limited resources. It should be the focus of a major international effort to develop appropriate training materials in a number of languages and for people who are not literate.*" (Bainbridge, 2001, p.87.)

> "*PI technology* [Pitcher Irrigation], *besides providing economic returns with local value addition and environmental benefits, has led to women empowerment and has given nutritional support to children.*"
> (Singh et al., 2011, p.712.)

> "*I am a farmer and live with my large family in Hilkot. My main problem in growing crops is lack of water. For many years I have been trying to establish an apple orchard. In the past many of the tree seedlings died because of water shortages. Then I heard from PARDYP project about a simple and cheap way of establishing young fruit trees. By using pitcher irrigation I have established an orchard of 60 apple trees. All of the seedlings I planted have survived. The trees are now three years old and are very healthy. In a few years I will be able to harvest apples and sell them in the market. Once I set it up it hardly takes any work. The pots only need refilling about once a week. I am amazed how such a simple technique could produce such good results. In my area water is very scarce and vegetables and fruits are expensive and hard to grow.*"
> (Akhtar Khan, farmer in Hilkot, Pakistan, in: Providoli et al., 2006, p.12.)

Impact on today's lives

Clay pot irrigation addresses especially the Sustainable Development Goals[4] No. 1 "No Poverty," No. 2 "No Hunger," No. 5 "Achieve gender equality and empower all women and girls," No. 6 "Clean Water and Sanitation," and No. 13 "Climate Action."

Research and Research Gaps

The vast majority of scientific studies is experimental - either lab or field studies or a combination of both. Currently, there are only two concise overview studies available in English (Bainbridge, 2001; Adhikary and Pal, 2020). The most extensive publication of combined experimental lab and field studies is a German PhD by Thomas Stein (Stein, 1998). The majority of the experimental studies is concerned with analyses of the pot characteristics (e.g. Soomroa et al., 2018), especially seepage rates and wetting patterns (e.g. Abu-Zreig and Atoum, 2004; Siyal et al., 2016). Other studies focus on the performance of the pots and the yield outcome when using saline and waste water for irrigation (e.g. P. Vasudaven et al., 2011; Siyal, Soomro and Siyal, 2015). While lab studies are usually conducted with up to six pots, field studies can include a larger number.

Basically, all studies conclude that clay pot irrigation is an efficient technology in local small-scale applications in dry areas. Yet conclusions differ concerning the potential for large scale applications, especially in terms of labour. What is lacking are replicable experimental study designs and more research looking into the interactions of the various pot, soil, and plant properties and their influence on marketable crop yield to gain a better understanding of how to set up individual fields and gardens most efficiently.

Also lacking are quantitative studies analysing the long-term performance of pitcher irrigation in contexts of development projects, as well as qualitative studies evaluating the experiences of the people involved in a project, the problems that occurred and the recommended solutions ("Lessons learned"). A fundamental problem for research is the lack of compiled and accessible data, regardless of whether a project was conducted by government agencies or non-profit organizations. This data gap currently prevents project-based research and comparative studies on a broader scale that would provide insights into how to improve future projects.

Ancient earthquake resistant construction technologies Dhajji Dewari

Overview

Dhajji Dewari literally means "interconnected / patchwork quilt wall". It is a traditional timber-braced frame with random rubble masonry infill construction practiced in mountain regions of South Asia, especially in Kashmir and northern parts of Pakistan and India. The timber frames have vertical and cross elements with varying patterns dividing the masonry infill into small panels (See Figure 6). The walls are finally plastered with mud mortar. Dhajji dewari constructions are usually built on shallow foundations made from stone masonry. While the buildings are mostly single-story structures with wooden pitched roofs[5] , houses can have up to four stories and be built with flat timber and mud roofs. Dhajji buildings are used for housing, in rural areas to shelter livestock, and in urban areas for commercial buildings such as shops, workshops and bazaars.

Among the earliest preserved archaeological evidence of half-timber buildings with a stone-mortar infill are houses from Herculaneum (Italy) dating to the first century, of which the most famous one is the two-story "House of the Opus Craticium".[6]

> "*Opus craticium evolved from - but never fully supplanted - wattle and daub construction. Whereas simple wattle work was based upon the principle of creating walls by the construction of a light framework of timber sheathed by a grid of wattling panels, the more durable variant known as opus craticium employed squared structural timbers and thicker, tougher infill for the panels. The most popular filler was concrete and rubble."*
> (Ulrich, 2007, pp.97-98.)

In a recent overview study concerning opus craticium, the authors conclude:

> "*Due to specific historical and spatial constraints, namely the population growth and the 62-/63 AD post-earthquake reconstructions, the opus craticium was widely employed at Herculaneum*."
> (Stellaci and Rato, 2019, p.17.)[7]

During the middle ages, half-timber structures were widespread in Europe, known as, for example, "Fachwerk" in Germany, "Colombage" in France, "Bindingverk" in Scandinavia and "Half-timber" in the United Kingdom. During the Ottoman Empire in the middle east, the wooden frame structures diffused also in India, Kashmir, and Turkey (Perria, 2018, pp.80-114). At the beginning of the 19th century Dhajji dewari construction became one of the two main traditional construction systems in Kashmir.[8]

> "*The primary structural elements are generally thinner than those of their European cousins (colombage, Fachwerk). The secondary sub-divisions are made of board-sized short pieces nailed to the primary elements. The subdivision patterns can vary from stiff cross-bracings to ever more ductile zig-zag, chevron, fishtail or random assemblies*." [9]

Case study

4. Dhajji Dewari

During the October 2005 earthquake in Kashmir with a 7.6 magnitude, dhajji dewari buildings performed much better than other building types (see Bashir et al., 2018, pp.93-99). Their performance was so well that the "Earthquake Reconstruction and Rehabilitation Authority," the official body of the government of Pakistan responsible for reconstruction and rehabilitation in the earthquake-affected areas of Pakistan and Pakistan-administered Kashmir, encouraged the use of dhajji dewari for the construction of housing units (Ali et al., 2012, p.836). Following the earthquake, over 120 000 dhajji dewari houses were built (Schacher and Ali, 2009, p.iii).

> "*This extraordinary achievement was made possible by three factors: an owner driven reconstruction approach, accompanied by an extensive training programme directed at workers and house owners, and last but not least the need of the people to make use of local resources instead of spending their money on costly transport of modern building materials.*"
> (Schacher and Ali, 2009, iii).

Dhajji dewari buildings have recently also been recommended by the Government of India. (National Disaster Management Authority, India, 2020, p.17.)

Selected Quotes

> "*Dhajji dewari can safely resist earthquakes in high seismic regions of the world when built properly and maintained adequately. This makes dhajji dewari a valid form of construction in seismic areas. (...) If we are to create communities that are both sustainable and resilient, it is necessary to adopt construction technologies that make best use of available resources and are safe. Dhajji dewari offers hope to this cause by using durable renewable or recycled materials that are likely to be available locally. This research shows that it is a form of construction that can offer significant seismic resistance. If damaged dhajji dewari can be repaired relatively easily because the materials are readily available*."
> (Hicyilmaz et al., 2012, pp.9, 10.)

> "*The observed seismic behavior of considered Dhajji Dewari structure models on shake table under earthquake ground motions have shown an excellent global seismic performance, in avoiding structural collapse in extreme ground shaking*."
> (Ali et al., 2017, p.1058.)

Shinbashira

Overview

The "Shinbashira" is the central pillar in ancient multi-storey timber pagodas. While the details of its construction changed over time, the pillar rests in general on a base stone, is not interlocked with the wooden frame of each floor and does not support the vertical load of the structure (See Figure 7). The earliest archaeological evidence of a shinbashira is preserved in one of the oldest wooden buildings in the world: The 122-foot tall pagoda at the Hōryūji (Hōryū Temple) in Japan, which was built in the late 7th century AD.[10] It was added to the UNESCO World Heritage List in 1993.[11]

Case Study

5. The Tokyo Sky Tree

The Tokyo Sky Tree in Japan is the tallest tower and the second tallest structure in the world with a height of 634 meters. The ancient technology applied in its construction is the *shinbashira*. The tower is an excellent example of a hybrid solution: the combination of ancient and modern knowledge to get the best result (See Figure 8). On March 11, Tokyo Sky Tree nearing completion was shaken by the Great East Japan Earthquake. The tower withstood the quake without any damage.

> "*One of the reasons why Tokyo Sky Tree withstood the enormous quake was the vibration suppression system, used for the first time ever, known as Shinbashira-seishin (Center Column Vibration Control). The core section of the main structure of Tokyo Sky Tree is a void measuring 10 meters in diameter, which extends up to a height of about 475 meters. A cylindrical column made of reinforced concrete measuring 8 meters in diameter and 375 meters in height, called the shinbashira (...) has been installed through the void as if piercing Tokyo Sky Tree. Even though the shinbashira is structurally separated from the main tower structure, the two are joined by steel beams up to a height of 125 meters, and via devices called dampers that suppress vibrations by stretching and contracting in the sections above.*

The shinbashira is heavier than the main tower structure, which is made of steel, and barely vibrates. As such, the shinbashira and the main tower structure behave differently when shaken by an earthquake or storm. If the two move in opposite directions, the vibration is cancelled. It is said that the Shinbashira-seishin system reduces seismic vibration by up to about 50%."[12]

Selected Quotes

"In Japan no pagodas have ever suffered serious damage from earthquakes." (Nakahara et al., 2000, 1.)

> "*Central column contributes to an earthquake proof structure. But details are not clear yet. Theoretical research has just started, and further interdisciplinary studies including structural engineering, traditional wooden architecture, earthquake science and etc. will*

> *be required to clarify the facts*."
> (Harada, 2016, p.226)

Impact on today's lives

The two ancient earthquake resistant technologies address the Sustainable Development Goal No. 11 "Resilient Cities and Communities," the dhajji dewari especially "Safe and affordable housing".

Research & Research Gaps

Earthquake resistant construction constitutes a large area of research involving numerous disciplines. Interdisciplinary research in ancient and traditional building materials and building technologies has attracted a growing number of scholars during the recent decades. In the early 90s archaeoseismology began to evolve, the study of past earthquakes based on the analysis of archaeological evidence. Research focusing on the sustainable protection of ancient structures and buildings in earthquake prone areas is increasing. Yet only a small number of studies is concerned with the seismic properties of ancient structures and their experimental exploration. And even fewer studies look at the potential of these ancient technologies in modern applications. Currently, there are several research gaps that need to be addressed: More interdisciplinary research on the performance of ancient earthquake-resistant technologies and their potential applications in modern contexts is needed, including the development of hybrid solutions.

Systematic compilations and evaluations of existing studies and their results as well as overviews of the available methodologies and technologies for experimental research are additional desiderata.

Conclusions

The ancient technologies presented in this paper were successfully applied in modern contexts of climate change adaptation, disaster management, and in earthquake-prone areas. Many more ancient and traditional technologies are being re-instated around the world, addressing the Sustainable Development Goals on local, regional, and national levels. Archaeology and experimental studies help better understand how these technologies worked and how to adapt them to modern needs. These studies are instrumental in being able to unlock the potential of cultural heritage as a strategic resource in contexts of the Sustainable Development Goals. And for us to be successful in this endeavour, it is equally important to make sure our knowledge is shared:

> "*Using place-based case studies with locally contingent and motivated solutions is important, but it is accessing knowledge from the past that has been lost to the passage of time, presenting it in interesting ways, encouraging people to engage with it, and*

creating the necessary knowledge and social dynamics to focus on education that are vital. Because in the end, it is education and human capacity built on informed positions that provide the best hope of solutions to the impacts of global environmental change." (Cooper and Duncan, 2016, p.9)

1 https://www.un.org/esa/coordination/Alliance/Earth%20Institute%20-%20The%20Millennium%20Villages%20Project.htm

2 https://www.sgp.undp.org/spacial-itemid-projects-landing-page/spacial-itemid-project-search-results/...

3 https://www.foreverindus.org/ifap_about.php

4 https://sdgs.un.org/goals

5 A comprehensive overview concerning the construction and performance is provided in the "Housing Report Dhajji Dewari" in the World Housing Encyclopedia by Earthquake Engineering Research Institute (EERI) and International Association for Earthquake Engineering (IAEE): https://www.humanitarianlibrary.org/resource/housing-report-dhajji-dewari-0

6 Herculaneum, Insula III, 13-15.

7 The authors also provide an overview concerning the ambiguous modern use of the term opus craticium.

8 The other system is called Taq.

9 https://www.seismico.org/dhajji

10 http://www.horyuji.or.jp/en/garan/gojyunoto/

11 https://whc.unesco.org/en/list/660/

12 Cabinet Office, Government of Japan, https://www.gov-online.go.jp/eng/publicity/book/hlj/html/201112/201112_01.html

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Sources for images

Fig 8. Illustration of the shinbashira in the Tokyo Sky Tree, following the drawing provided at https://www.nippon.com/en/views/b01101/. Copyrights by Kirsten Dzwiza

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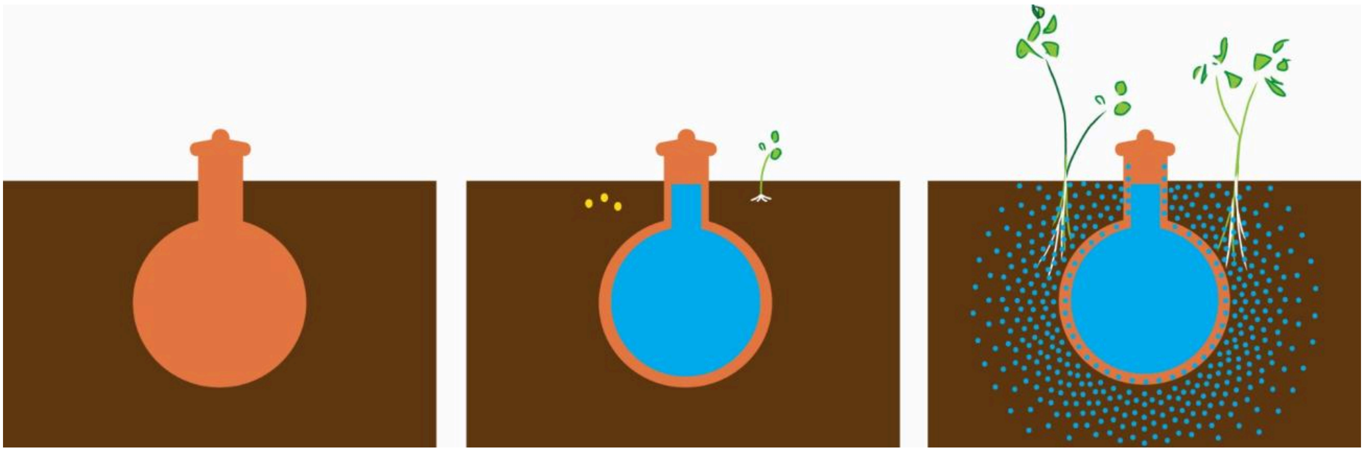

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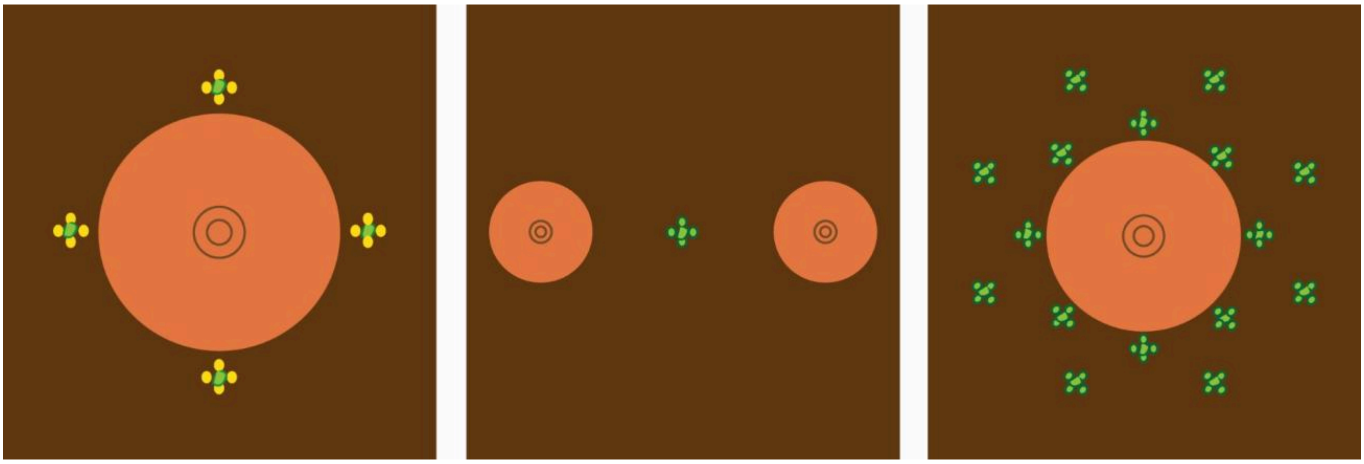

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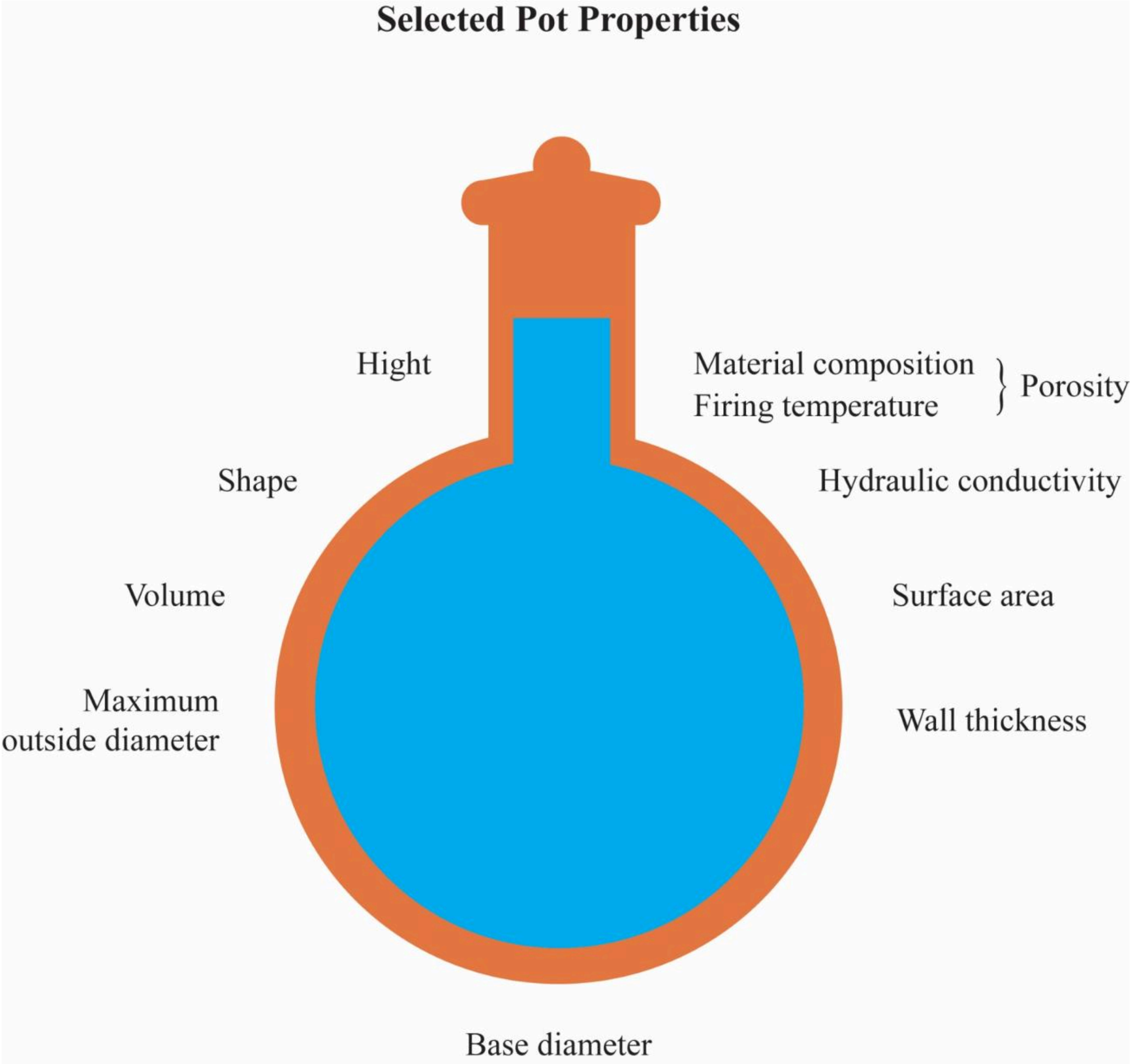

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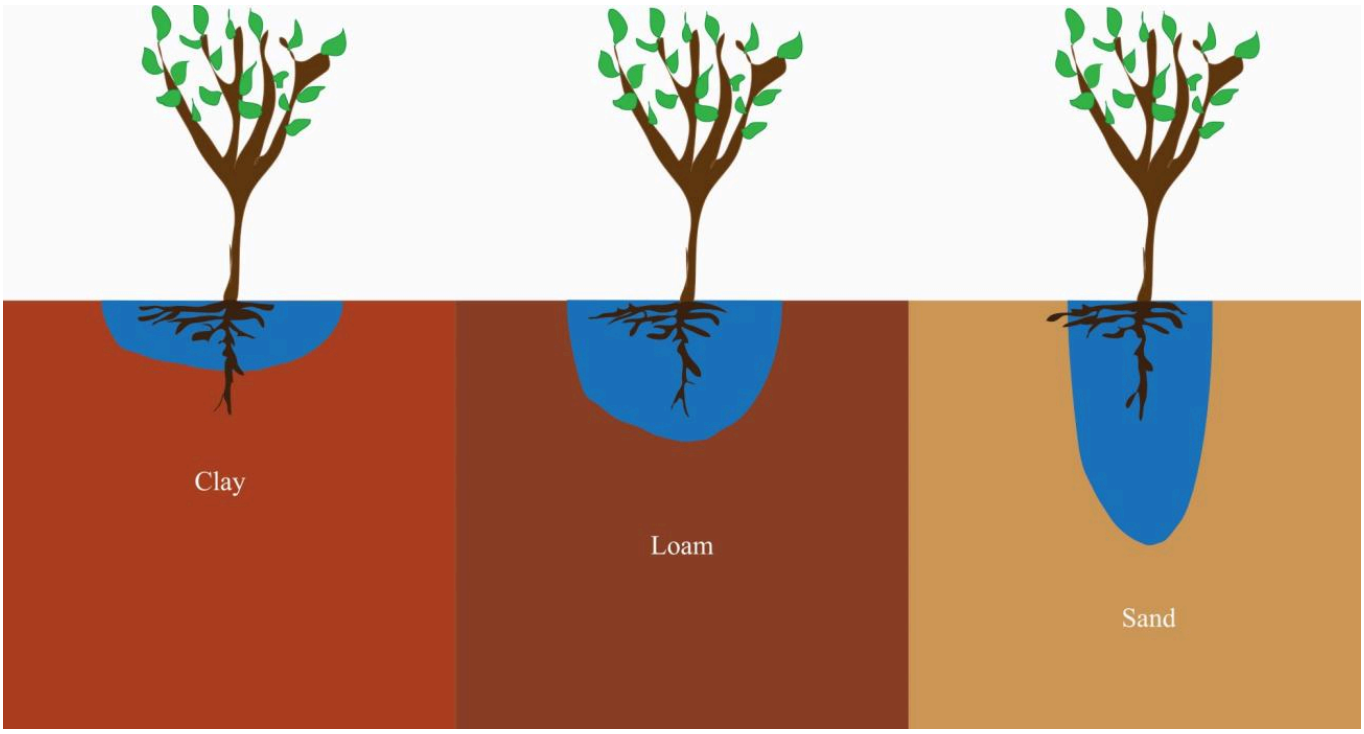

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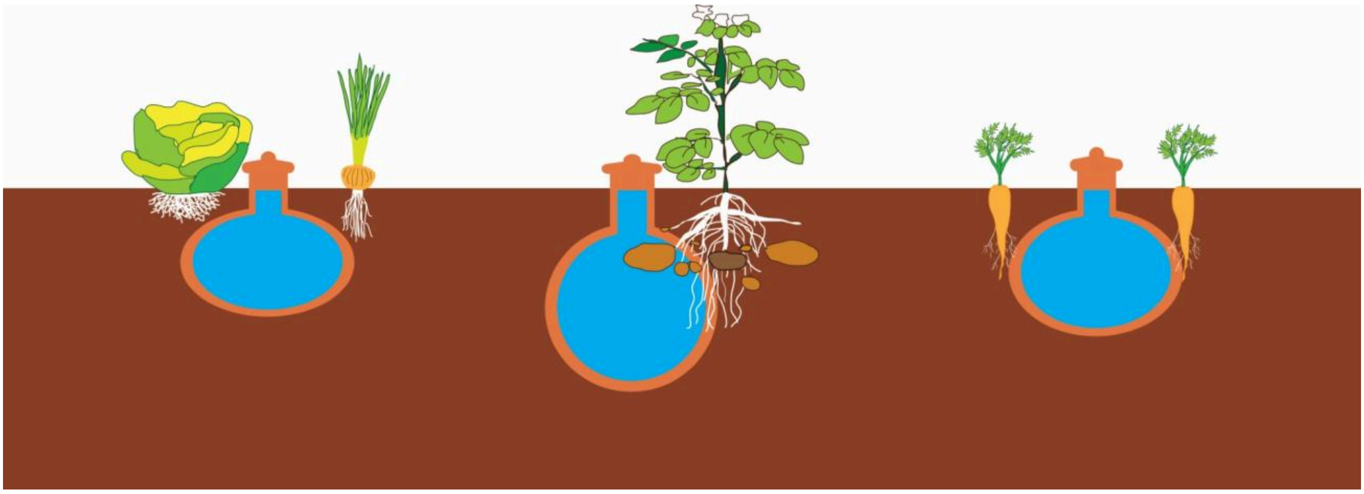

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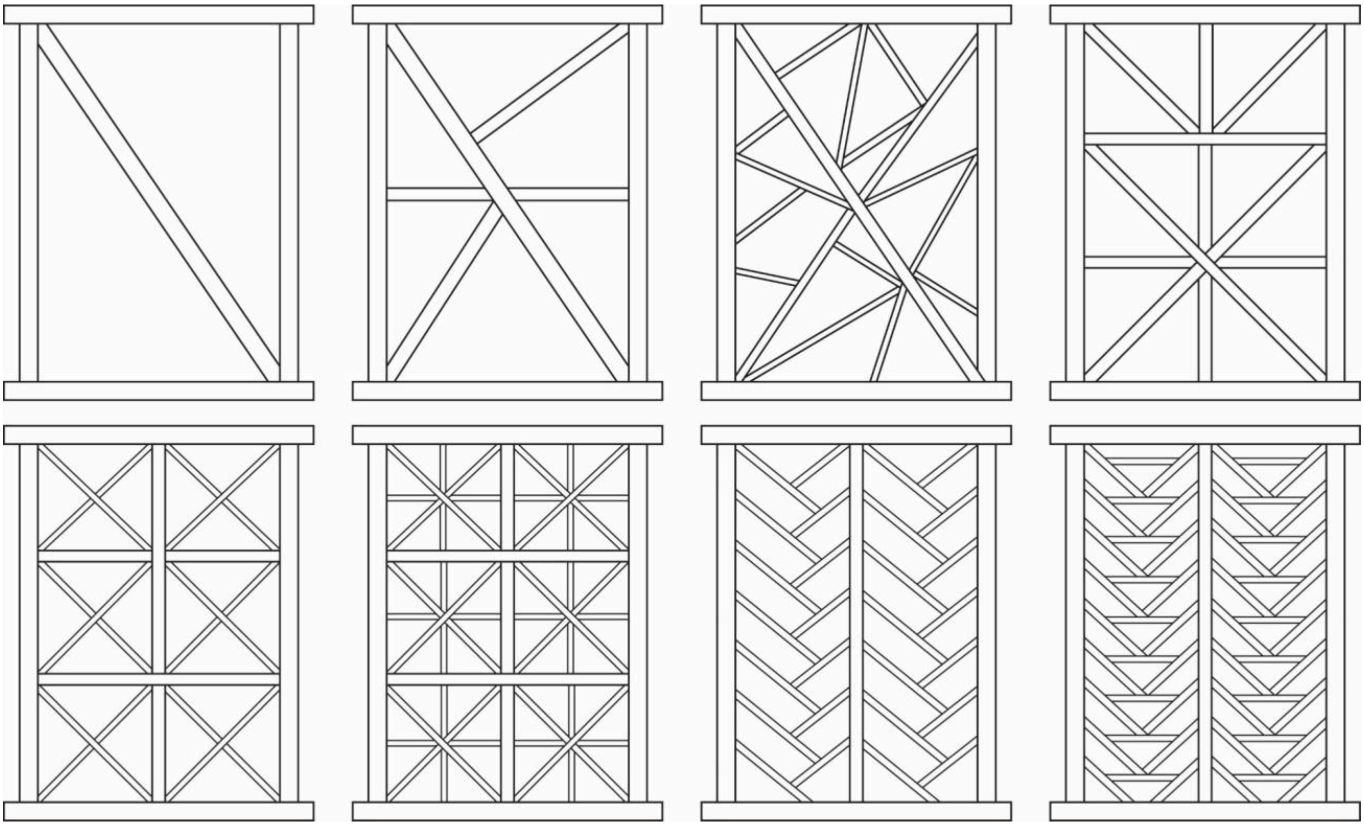

FIG 6. DHAJJI DEWARI - VARYING PANEL PATTERNS, BASED ON: WORLD HOUSING ENCYCLOPEDIA, HOUSING REPORT DHAJJI DEWARI, REPORT #146, 2011, PAGE 10, FIGURE 3 1. COPYRIGHTS BY KIRSTEN DZWIZA

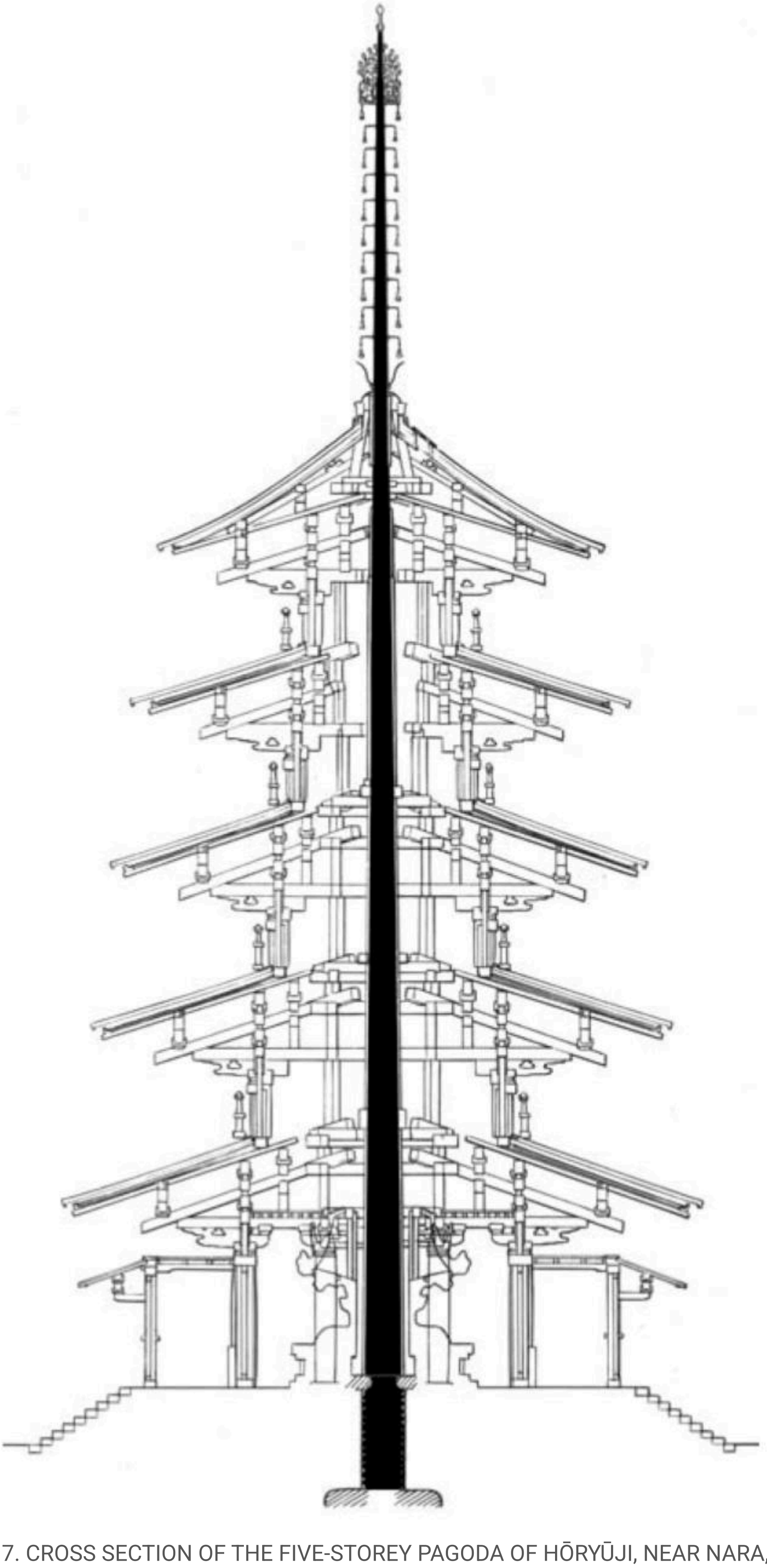

FIG 7. CROSS SECTION OF THE FIVE-STOREY PAGODA OF HŌRYŪJI, NEAR NARA, JAPAN, SHOWING THE SHINBASHIRA. ILLUSTRATION AFTER ZHANG SHIQING, FALONGSI JIANZHU DE DAMU JISHU, IN: ZHANG SHIQING, ZHONG RI GUDAI JIANZHU DAMU JISHU DE YUANLIU YU BIANQIAN (TIANJIN: TIANJIN DAXUE CHUBANSHE, 1992), 42.

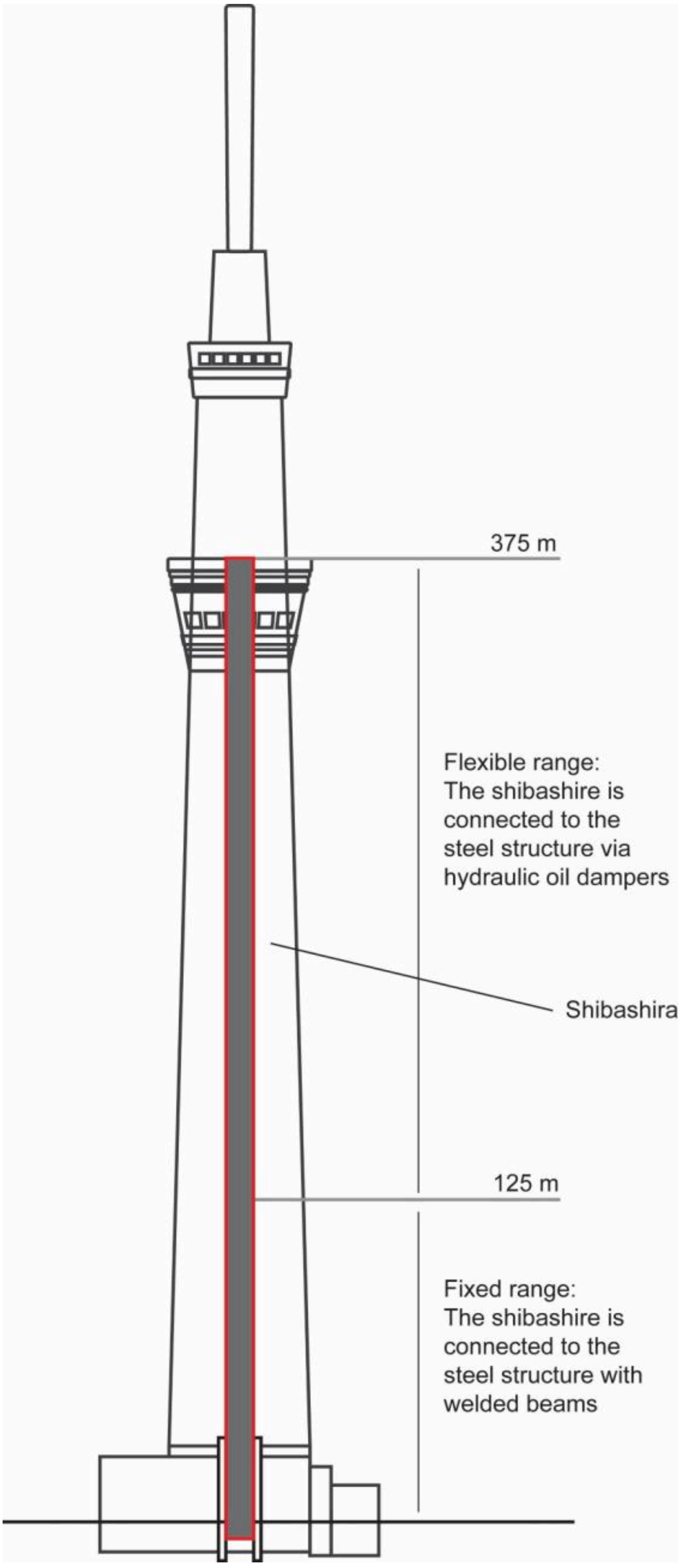

FIG 8. ILLUSTRATION OF THE SHINBASHIRA IN THE TOKYO SKY TREE, FOLLOWING THE DRAWING PROVIDED AT HTTPS://WWW.NIPPON.COM/... COPYRIGHTS BY KIRSTEN DZWIZA