THE ROLE OF STRUCTURAL SYSTEMS AND BUILDING MATERIALS IN SUSTAINABLE POST-EXPO USE OF WORLD EXPO PAVILIONS

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By

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ABSTRACT

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Advisor: Aysu Berk Haznedaroğlu

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World Expos are international mega-events, organized to display the industrial achievements of countries while providing social and cultural involvement. Since the 1970s, they have focused on minimizing ecological problems and promoting sustainability with innovations in science and technology. However, due to their mega-scale and ephemeral nature, issues like building boom, oversized infrastructure, and abandoned pavilions have been observed throughout the years, which conflict with their sustainability theme.

Since the concerns for the post-event period are generally caused by the lack of initial planning for the post-expo usage, this thesis claims that one of the solutions is a concise configuration of structural systems and materials by considering the further use of pavilions. Therefore, this study aims to reveal what the role of structural system and material configurations is on a sustainable post-expo use. With this aim, the selected pavilions from the World Expos with sustainability-related themes are categorized based on their permanency or temporariness and analyzed regarding four categories of sustainability (functional, environmental, socio-cultural and economic). For the analysis, 15 sustainable features are determined to observe the characteristics of structural system and material configurations related to the post-expo use. Based on the number of sustainable features of each pavilion, the role of structural system and material configurations in post-expo use are evaluated. The results show that for permanent pavilions, structural systems and materials have no or low role in the sustainable post-expo use. On the contrary, they have a significant impact on the efficient post-expo use of temporary pavilions. It is concluded that the well-conceived configuration of structural systems and building materials equipped with innovative sustainable features would allow for more efficient use of resources while minimizing harmful impacts on the environment and reducing energy consumption in construction, dismantling, reusing, and recycling processes. The findings suggest that; in order for World Expos to overcome the issues that arise in the post-expo period, as well as the real-life sustainability problems, all four sustainability categories should be integrated together with the use of innovative solutions by considering the post-expo process in the pavilions' structural system design and material selection.

Keywords: Ephemeral architecture, Post-expo use, Structural systems, Sustainability, World Expo pavilions

ÖZET

DÜNYA FUARI PAVYONLARININ FUAR SONRASI SÜRDÜRÜLEBİLİR KULLANIMINDA STRÜKTÜREL SİSTEM VE MALZEMENİN ROLÜ

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Dünya Fuarları, ülkelerin endüstriyel başarılarının tanıtılması amacıyla düzenlenen, sosyal ve kültürel etkileşimi arttıran uluslararası etkinliklerdir. 1970'lerden bu yana, fuarların odak noktası bilim ve teknolojideki yeniliklerle sürdürülebilirliği teşvik etmek ve ekolojik sorunları en aza indirmek gibi konulara doğru yönelmiştir. Ancak, Dünya Fuarlarının kentsel ölçekte büyük değişimlere ve yapılaşmalara neden olurken aynı zamanda geçici olmaları; inşaat patlaması, gereksiz ölçüde gelişmiş altyapı ve terk edilmiş pavyonlar gibi sürdürülebilirlik temasıyla çelişen çeşitli sorunlara yol açmıştır.

Yıllar içinde, etkinlik sonrası dönemde ortaya çıkan sorunların genellikle fuar sonrası kullanım için planlama eksikliğinden kaynaklandığı gözlenmiştir. Bu sebeple, bu tezde, yapısal sistem ve malzemelerin, seçim ve konfigürasyonunun fuar sonrası kullanım göz önüne alınarak yapılmasının en belirgin çözümlerden biri olduğu savunulmaktadır. Bunu gözlemlemek amacıyla, sürdürülebilirlik temalı Dünya Fuarlarından seçilen pavyonlar kalıcı ya da geçici olmalarına göre gruplandırılıp yapısal sistem ve malzemeleri dört sürdürülebilirlik kategorisine (fonksiyonel, çevresel, sosyo-kültürel, ekonomik) göre analiz edilmiştir. Strüktürel sistem ve malzeme konfigürasyonlarının fuar sonrası kullanımdaki rolünü analiz etmek için 15 sürdürülebilir kriter belirlenmiştir. Daha sonra seçilen pavyonların strüktürel sistem ve materyallerinin bu kriterleri taşıyıp taşımadığı analiz edilmiştir. Sonuçlar, yapısal sistemlerin ve malzemelerin, kalıcı pavyonların fuar sonrası sürdürülebilir kullanımında düşük bir role sahip olduğunu göstermektedir. Buna karşılık, geçici pavyonların verimli kullanımında önemli bir etkiye sahiptirler. Yapılan analizlerde, sürdürülebilirliğin dört farklı kategorisini de tasarımda yansıtarak yenilikçi çözümlerle entegre edebilen tasarımların, kaynakların daha verimli kullanılmasına, çevre üzerindeki zararlı etkilerin en aza indirgenmesine ve inşaat, söküm, yeniden kullanım ve geri dönüşüm süreçlerinde enerji tüketiminin azaltılmasına olanak sağladığı gözlenmiştir. Elde edilen bulgular göstermektedir ki; yenilikçi ve deneysel çözüm modelleri üretmek, pavyonların yapısal sistem tasarımı ve malzeme seçiminde temel ilke olmalıdır. Bu sayede, Dünya Fuarı pavyonlarının tasarımları, fuar sonrası dönemde ortaya çıkan sorunları en az indirgemenin yanı sıra gerçek hayattaki sürdürülebilirlik sorunlarına da çözüm üretebilir.

Anahtar Sözcükler: Geçici mimarlık, Fuar sonrası kullanım, Strüktürel sistemler, Sürdürülebilirlik, Dünya Fuarı pavyonları

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CHAPTER 1

INTRODUCTION

World Expos, so-called World Fairs, are international and ephemeral mega-events initiated with the 1851 Great Exhibition in London. They are enormous-scale events with huge costs that can attract large crowds in a limited time and create a global cultural exchange between different countries with their mediated content (Roche, 2000; Müller, 2016). Their extraordinary characteristics create positive and negative effects on the host cities and countries (Roche, 1994).

The dual nature of mega-events that "combine decisions about a short-term festival with long-term land use management" (Wilson, 2011, p. 1045) plays a transformative and developmental role at both national and international levels (Müller, 2016; Roche, 2000). World Fairs are differentiated from other mega-events like Olympic Games, Football World Cup, European Football Championship, or Asian Games (Müller, 2016) as being a platform for high cultural interaction with the display and share of achievements in science, industry, technology, art, and architecture of countries (Roche, 2000; Wilson, 2011). Besides the cultural exchange, they also provide opportunities for urban redevelopment, infrastructure upgrades, high-profile tourism, international investment, global media attention, city branding, and civic prestige (Hiller, 1998).

Since World Expos are creating a quick but massive urban renewal while also drawing global attention in different domains related to the industry, they encourage architects and engineers to provide innovative designs for the pavilions. The desire of countries

to show their technologic and industrial power through the design of pavilions put World Expo pavilions in the center of developments in architecture and structure with their wider span, new typologies, and innovative characteristics. Thus, throughout history, the design of Expo Pavilions has become a domain for structural development and innovation, as well as signature architecture, resulting in varied architectural and structural legacies after the Expo (López César, 2019).

Until the middle of the 20th century, the theme of World Expos mainly focused on industrial and agricultural developments, scientific and technological advances, and celebrating anniversaries of important events and discoveries in human history. The national characteristics and development in construction technology are mainly reflected through the architectural characteristics of pavilions, such as construction technologies, structural developments, and materials (Smits & Jansen, 2012). The Seattle World Expo 1962, for instance, lead the 'Expo-led urban renewal' concept, and this concept has become one of the main aims of the Shanghai 2010 and Milan 2015 World Expos (Deng & Poon, 2011). Since the 1970s, the role of innovations in science and technology on humankind, discovering ways of living in harmony with nature, and minimizing sustainability problems in architecture and construction have also gained importance (Schrenk & Jensen, 2014). As of the Hannover World Expo 2000, sustainability is raised as the main focus of the World Expos, which requires the themes to be developed around this issue and be supported by the related design principles for the Expo pavilions by the participant countries for each World Expo (McDonough, 1992). In this way, World Expos aim to become a stage for releasing the issues of humankind with humanitarian themes, rather than being an industrial show-off (De Groote 2005).

1.1. Problem Statement

World Expos have crucial impacts on the built environment of the host city: providing upgrades in infrastructure, transportation systems (Wilson, 2011), telecommunication networks, permanent housing, and new facilities for tourist attractions (Roche, 1992). They also become the platform for the arisen of signature structures that become a landmark or symbols of cities, as in the cases of the Ferris Wheel built for the 1893 World's Columbian Exposition that became an inspiration for the London Eye, the

Eiffel Tower built for the 1889 World's Fair, or the Atomium built for World Expo 1958 (Hiller, 2000b).

Despite the advantages of World Expos that promote urban development, evaluating these events only by considering their limited period might cause to ignore the long-term effects for the host countries (Hiller, 1998). The urban development provided by the mega-events brings potential risks that damage urban sustainability. Considering only the needs of the event that occurs in a short period with huge investment and urban implication requirements may convict the event to fail in the post-expo period (Wilson, 2011). Since the needs of the event and the post-event are not the same in size and capacity (Hiller, 2000a), the negative outcomes of the World Expos primarily are leading a building boom, abandoning unutilized structures, and creating oversized infrastructure (Müller, 2015).

Throughout history, various events that have been considered successful in the global media "have left legacies of unused facilities or public debt" (Wilson, 2011, p. 1052). The Knoxville 1982, Seville 1992, and Hannover 2000 World Expos are examples of vast lands left to deteriorate with the ruins of the abandoned pavilions (Schrenk & Jensen, 2014). Even designing temporary pavilions may not be the exact solution for the post-expo issues since disassembling processes requires concise planning to avoid excessive energy, time, and resource consumption. These examples of World Expos demonstrate the importance of well-designed structures with the consideration of their post-event usability. If not, some possible issues might be encountered, such as maintenance difficulties, over-costing for renovation and rehabilitation, functional obsolescence, and physical deficiencies that prevent adaptability, dismantling, and recycling (Deng, 2013). These issues of ephemeral architecture caused by the temporary nature of mega-events conflict with the sustainability and damage the image of World Expos while creating economic, environmental, functional, and socio-cultural issues at the building and urban scale.

1.2. Aim and Scope of the Thesis

The examples of the massive expo lands left with abandoned pavilions in history are mainly caused by design-related issues in addition to economic, social, or institutional factors. To avoid wasting resources, most national pavilions in World Expos have been

designed to be temporary at Expo sites since Aichi World Expo 2005, except for those whose post-expo usage is guaranteed. However, this also cause some potential issues including excessive resource consumption and green-house gas emissions due to disassembly, transportation, reassembly, and/or recycling processes (Schrenk & Jensen, 2014). In any case, the concerns of the post-event period are caused mainly by the lack of initial planning for the post-expo use of the pavilions. Therefore, the hypothesis of this study is: The configuration of structural systems and building materials have a crucial role in the post-expo usability of pavilions and if they are equipped with innovative and sustainable features by considering the pavilions' further use, they can provide solutions to prevent the sustainability issues occurred in the post-expo period. Regarding the hypothesis, this research investigates the role of the structural system and building material configurations in providing sustainable solutions for the post-expo usability issues by analyzing some pavilions of the selected World Expos. Besides, it also aims to observe the innovative approach of Expo pavilions in terms of structural solutions.

With this aim, the sample group is formed from four of the five World Expos with sustainability-related themes, which are Hannover (2000), Aichi (2005), Shanghai (2010), and Milan (2015) World Expos. The last World Expo centered on sustainability, Dubai (2020) World Expo, was held between October 2021 and March 2022 due to the global pandemic. Therefore, assessing the post-expo uses of Dubai World Expo pavilions is not feasible. Therefore, Dubai World Expo is not included in this study. From these Expos, five pavilions awarded or recognized by the Expo committees with their design approaches are selected in order to observe whether sustainable design principles are satisfied in the configurations of the structural and material features of prominent pavilions for efficient post-expo use. Besides, to obtain a homogenous sample group, the host-country pavilions of four World Expos (Germany, Japan, China, and Italy) are also selected to observe the attitudes of host countries in the design of the pavilions since the host-country pavilions are considered as the symbol of the Expo themes. As a result, six pavilions are chosen from each Expo, making twenty-four pavilions in total to be analyzed in this study.

The selected pavilions are categorized based on their long-term life expectancy (being designed either permanently or temporarily) and post-expo situations (in-use, no-use,

demolished, recycled/reused, relocated, or disassembled). Then their structural systems and building materials (structural and non-structural) are investigated. Based on the investigations, the configurations of structural systems and materials are analyzed regarding four categories of sustainability (environmental, functional, economic, and socio-cultural). By observing these features, the objective of this study is to analyze the role of structural systems and materials in the post-expo usability and sustainability of pavilions. Regarding the analysis, the following questions are answered:

1. What are the different approaches of World Expos for the design of the pavilions regarding post-expo use?

2. What is the relationship between the permanency/temporariness of pavilions and their post-expo use performances?

3. How does the selection of structural systems and materials differ based on the permanency or temporariness of the pavilions?

4. What are the specific features of the structural systems and materials in terms of four aspects of sustainability (functional, environmental, socio-cultural, economic)?

5. What is the role of these features on the usability of pavilions in the post-expo period?

Selecting the case studies from these four World Expos that cover twenty years with a considerable number of examples also allows for observing the evolution in structural systems and materials regarding sustainability. The details of the methodology and selection criteria for World Expos and their pavilions are articulated in Section 4.2 and Section 5.1, respectively. Still, it is also mentioned in this chapter briefly.

1.3. Structure of the Thesis

This thesis consists of six chapters which is arranged as follows:
The first chapter introduces brief information about the World Expos and their short-term and long-term effects on the urban environment. Then, the problem statement, aim and scope of the thesis, and the structure of the thesis are explained.

The second chapter is a literature review of the concept of sustainability. Firstly, the historical development of the 'sustainability' and 'sustainable development' terms is given. Then, one of the widely accepted concept models of sustainability, the three-dimensional model (environmental, economic, and social sustainability), is described. Lastly, the meaning and principles of sustainability in architecture and construction are detailed, together with the measurement tools and encountered challenges.

The third chapter is a literature review about the history of World Expos and their importance in the architectural domain. Firstly, the structural and architectural achievements in the history of World Expos are mentioned. Then, sustainability in World Expos, as being both theme and issue, is introduced.

In the fourth chapter, the methodology of the thesis is presented in detail. Four main components of the analysis table are explained through the literature review as follows:

- general information about pavilions and their post-expo situation
- structural systems (section-active, surface-active, form-active, and vector-active),
- structural and non-structural materials, and
- sustainable properties of the structural system and material configurations regarding four aspects of sustainability (functional, environmental, socio-cultural, and economic).

The fifth chapter is where the selection criteria for World Expos and their pavilions are explained. Then the analysis of the pavilions is conducted. Brief information about each World Expos with sustainability-related themes is given in each section. After that, the selected pavilions are explained in four parts: general information about pavilions, construction features (structural systems and primary building materials), sustainable features of the configuration of these two characteristics with their role in post-expo use, and analysis tables.

In the sixth chapter, the discussion of the findings is conducted regarding the five research questions.

Lastly, the conclusion and recommendations for further studies are presented in the seventh chapter. This chapter is followed by references and appendices.

CHAPTER 2

SUSTAINABILITY AND ITS PRINCIPLES

This chapter, first, presents how the sustainability term is emerged in history and became a concept that influences numerous fields related to human existence. Then, one of the most widely-accepted approaches, the three-dimensional model of sustainability, is defined. In the last section, how sustainability influences the fields of architecture and construction is explained together with its principles, measurement tools, and challenges.

Sustainability is a broad and multi-disciplinary term that has taken place in academic, professional, and public domains for the past half-century. It was raised to provide solutions against issues initiated with the Industrial Revolution to maintain life and resources on Earth with an appropriate level of development. Since it is a global issue, it requires addressing various aspects of the "physical planet, biological existence, and human society" (Diwekar & Cabezas, 2012, p. 5). Throughout history, numerous international organizations, groups, and researchers, including the United Nations, World Wide Fund for Nature (WWF), UNESCO, and NASA, have put efforts to define sustainability and establish a global framework to reach sustainable development. For providing effective solutions to global issues, the concept of sustainability has been in a transaction with varied disciplines by getting knowledge and different perspectives from them. Correspondingly, the sustainability principles are integrated into numerous disciplines and in a variety of contexts in the past few decades, including the fields of ecology, economy, social sciences, energy, architectural design and construction,

business and finance, politics, industry, agriculture, urbanism, transportation, higher education and research (Caradonna, 2014; Brown et al., 1987).

The relationship between humankind and the planet has been considered sustainable for a long time in human history since the world has the resources to power the existence of living beings (Bovill, 2014). However, it has been realized that there have been fundamental changes in the world with the Industrial Revolution, such as ecology, atmosphere, soil, natural resources, and the functional mechanism between them (Brundtland & Khalid, 1987). One of the crucial aspect of industrial revolution was the technological and scientific advancements that ran the profound industrial and social development. The improvements in science and technology provided nutrition, better health care, and consequently, longer and safer lives which caused a geometrical population growth (Caradonna, 2014; Bovill, 2014). As a result, the "exponential growth rates reached 2 percent per year during the mid-1960s" (Bovill, 2014, p. 5), and "the human population of the Earth increased from approximately 2.5 to 6.9 billion in the period between 1950 to 2011" (Diwekar & Cabezas, 2012, p. 4). The booming population was followed by increasing industrial mass production to meet the needs, which led to a consumer society by the mid-nineteen century. Although humans are less than 1% of the biomass, they could consume up to one-fifth of the World's primary production (Diwekar & Cabezas, 2012). It has been observed that the geometric growth in population, production, and consumption cannot be met at some point by limited natural resources, which will inevitably limit economic growth. More importantly, this rapid increase in consumption can surpass the sustainable yield capacity of renewable resources, which can only grow arithmetically, as in the example of forestry (Basiago, 1998). This rapid growth and uncontrolled consumption resulted in a considerable amount of chemical and industrial waste that the environment needs to absorb. At the same time, the use of cheap and abundant fossil fuels that run the industry has increased carbon dioxide concentration in the atmosphere, not seen in the past 800.000 years (Bovill, 2014). All these factors have been accumulated through the decades and created severe threats to the extinction of natural resources that human existence depends on. It also causes extreme stress on the ecosystem, resulting in environmental destabilization and climate change. Besides the ecological effects, the industrial revolution has created fundamental economic and societal changes, and the world entered a 'new plateau of civilization' which is more mobile and global. The economy

dominated by agriculture has evolved into a free economy that runs on new machines, modern factories, and an urban working class (Caradonna, 2014, p. 55). The new social order putting economic growth before everything has caused social inequalities and damaged private wealth.

Since the "population, industrial production and pollution would continue to grow exponentially in the future as they have in the past" (Basiago, 1998, p. 146), it will cause a collapse at some point in environmental, economic, and social dimensions that cannot be recovered anymore. As experienced with the industrial revolution, focusing on one issue and trying to solve it (economy) without considering the different domains caused to shift the problems from one field to another (society and environment) (Diwekar & Cabezas, 2012). Therefore, in the middle of the 20th century, the rising issues in different fields created a necessity for a new approach for solving the existing environmental, economic, and social problems to create a balanced environment.

2.1. Definition and Historical Development

For maintaining the resources and conditions required for the survival of humankind, sustainability was raised as a concept in the late 20th century in which new approaches needed to be composed, planned, and executed. Even though the term 'sustainable' first appeared in the Oxford English Dictionary in the late nineteens and was defined as "capable of being maintained or continued at a certain rate or level", the historical roots of the concept are going deep (Brown et al., 1987). The idea of sustainability was first initiated by political economist John Stuart Mill (Mill, 1871) due to the concern about "whether Earth's limited natural resources will continue to provide life support for humanity's burgeoning population" (Basiago, 1998, p. 146). Besides, numerous researches and reports were published regarding this issue to emphasize that humanity is on a dangerous path in terms of its maintenance (Du Pisani, 2006).

The 'self-defined sustainability movement' developed between the 1970s and the 1990s when new organizations were founded, international conferences were held, and reports and declarations were published (See Table 2.1) to create a framework for sustainable development (Caradonna, 2014, p. 136). One of the earliest mentions of the term in the global context was in the 'Limits to Growth' that emphasizes five factors that limit the survival of humankind such as booming population, pollution,

Table 2.1: Historical development of the ‘sustainability’ and ‘sustainable development’ terms

Date	Organization	Publication	Main Resource	Importance	Reference
1972	**The Club of Rome**	The Limits to Growth	Meadows et al., 1972	- one of the earliest uses of the term by arguing for a sustainable world system	(The Limits to Growth, 2021)
1972	**'The Ecologist'**	A Blueprint for Survival	Goldsmith et al., 1972	- present proposals for the creation of a ‘sustainable society’	(Basiago, 1998)
1972	**UN - The United Nations Conference on the Human Environment (UNCHS)**	Stockholm Declaration	United Nations Conference on the Human Environment - Stockholm Conference, n.d.	- first UN conference on environmental issues - leading the foundation of the UN Environment Program - the initiative for the integration of economic development with environmental measures	(Purvis et al. 2019)
1980	**International Union for the Conservation of Nature (IUCN)**	World Conservation Strategy: Living Resource Conservation for Sustainable Development	International Union for Conservation of Nature and Natural Resources (ed.), 1980	- first international document in which the term “sustainable development” appeared - emphasizes the importance of relationship between the environment and human well-being, rather than focusing only ecological conservationism	(Caradonna, 2014)
1987	**UN - World Commission on Environment and Development (WCED), Brundtland Commission**	Our Common Future	Brundtland & Khalid, 1987	- first and most widely accepted definition of sustainable development which is still valid - aim to creating a global framework -initiated the "three pillars of sustainability" (society, economy, environment)	(Diwekar & Cabezas, 2012; Caradonna, 2014)
1992	**UN - United Nations Conference on Environment and Development (UNCED), Earth Summit**	Rio Declaration	*United Nations Conference on Environment and Development (UNCED), Earth Summit,* n.d.	-the largest conference with world leaders in human history -proposes 27 principles for a sustainable development policy in local, national, regional and international levels	(Basiago, 1998)
		Agenda 21	*Agenda 21: Sustainable Development Knowledge Platform - UN*, n.d.	-prepare a detailed plan for the implementation the principles in Rio Declaration -articulated the model of "three conceptual pillars" (society, economy, environment)	*Agenda 21: Sustainable Development Knowledge Platform - UN*, n.d.
2002	**UN - World Summit on Sustainable Development (WSSD), Johannesburg Summit**	Johannesburg Declaration on Sustainable Development	*World Summit on Sustainable Development (WSSD) - Johannesburg Summit*, n.d.	- restatement of earlier declarations on sustainable development for the 10th anniversary of the Rio Summit	(*World Summit on Sustainable Development (WSSD) - Johannesburg Summit*, n.d.)
2012	**UN - United Nations Conference on Sustainable Development, Rio+20**	The Future We Want	*United Nations Conference on Sustainable Development, Rio+20*, n.d.	- strategies and policies for green economy, green energy, clean water and food, security, oceans and urban environment - led the establishment of Division of Sustainable Development within the UN	(*United Nations Conference on Sustainable Development, Rio+20*, n.d.; Caradonna, 2014)
2015	**UN - United Nations Sustainable Development Summit 2015**	Transforming our world: the 2030 Agenda for Sustainable Development	United Nations Department of Economic and Social Affairs (ed.), 2016	- planning the action for humans, earth, prosperity and world peace '-17 Sustainable Development Goals (SDGs) with the aim of “achieving sustainable development in its three dimensions – economic, social and environmental – in a balanced and integrated manner”	(Purvis et al. 2019)

agricultural production, utilization of nonrenewable resources, and industrial activities by Meadows et al. (1972). However, acknowledging the 'sustainability' term in the international and political context has been initiated with the United Nations Conferences (see Table 2.1). With the conferences, the term sustainability "became part of a political agenda and a clearly articulated ecological philosophy, and a plethora of frameworks, systems, and models were developed as a means of studying, measuring, and advancing its central tenets" (Caradonna, 2014, p. 137).

The first conference, The United Nations Conference on the Human Environment (UNCHS), was organized in 1972 in Stockholm and brought together delegates from varied nations, which became a milestone in the development of international environmental politics and initiative for further UN Conferences (*United Nations Conference on the Human Environment - Stockholm Conference*, n.d.). The conference led the way for establishing the UN Environment Program (UNEP) and published the Stockholm Declaration. The document aimed to solve international social and environmental issues by integrating them with economic development, which were considered non-compatible in those times (Caradonna, 2014). Following the Stockholm Declaration in 1972, "as awareness of pollution, population growth, and human-related destruction became more apparent, reactions to the negative effects of human action and inaction on the world's environments and the rapid use of limited resources began to shape the central agenda of these international fairs" (Schrenk & Jensen 2014, p. 555).

One of the milestones in the history of defining sustainability is the World Commission on Environment and Development (WCED), commissioned by the United Nations between 1983 and 1987, leading to the first critical decisions for a sustainable society with political implementations (Sverdrup & Stjernquist, 2013). The so-called Brundtland Commission, published the 'Our Common Future' report in 1987 to create a global framework of sustainable development with long-term proposals for achieving sustainable development by the beginning of the 21st century (Brundtland & Khalid, 1987). The commission embraces the notion that "environmental problems were related directly to social, economic, and development issues and that 'the environment' could no longer be approached in a vacuum" (Caradonna, 2014, p. 143). With this perspective, sustainability is interrelated with social, economic, and environmental

context, laying the foundations of the three E's model (equity, environment, and economy) of sustainable development (Diwekar & Cabezas, 2012). In the end, the commission presented the definition of sustainable development that is still valid today: "Sustainable development is to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland & Khalid, 1987, p. 24). The definition has been highly affirmed and created a basis for international policy discourse in which numerous scholars and organizations have adopted, credited, and referred through time (Sverdrup & Stjernquist, 2013).

Beginning with the 1990s, the consciousness achieved through conferences raised the need for agenda-setting to act and solve the problems with an international effort (*United Nations Conference on Environment and Development (UNCED) - Earth Summit,* n.d.). With this aim, a series of United Nations conferences were held between 1992 and 2015 (See Table 2.1). Within these conferences, Rio Earth Summit in 1992 was crucial in terms of being the largest conference that brought together world leaders and diplomats from 120 countries, which led to the rise of 'sustainable development' in public international law. The necessity of managing social and economic development in cooperation with environmental protection is also emphasized in the Rio Declaration, leading to the development of the 'three conceptual pillars' concept. Agenda 21 also provided measures for reforms in transportation, urban redevelopment, improvements in science and technology, and strengthening the role of major groups, which requires developed countries to provide aid for basic human needs, education, small businesses, etc. (*Agenda 21: Sustainable Development Knowledge Platform - UN*, n.d.). Besides the United Nations, there were numerous groups and organizations as well as publications in this period that put efforts to define the principles of global sustainable development and create a framework, including; the Worldwatch Institute, the Rocky Mountain Institute, the Global Tomorrow Coalition, the World Resources Institute, the Man and the Biosphere Program of UNESCO, the Earth Systems Science Program of the National Aeronautics and Space Administration (NASA), etc. (Brown et al., 1987; Caradonna, 2014; Purvis et al., 2019). The Bureau International des Expositions (BIE), being the body of organization of the International Fairs, has also been influenced by this movement which led to the organization of the first World Expo with a sustainability-related theme: Hannover World Expo 2000 with the theme

‘Man, Nature and Technology’. The Expo was influenced by the decisions taken in the Rio Earth Summit and used Agenda 21 as a base document for the formation of the design guide of the Expo, ‘The Hannover Principles’ (see Section 3.2).

In the last conference held in 2015, seventeen Sustainable Development Goals (SDGs) were proposed to be accomplished by 2030, with the aim of “achieving sustainable development in its three dimensions – economic, social and environmental – in a balanced and integrated manner”, which still is in progress (see Table 2.2) (United Nations Department of Economic and Social Affairs (ed.), 2016, p. 3).

Table 2.2: Sustainable Development Goals of the UN

Sustainable Development Goals of UN Sustainable Development Summit 2015	
Goal 1	End poverty in all its forms everywhere
Goal 2	End hunger, achieve food security and improved nutrition and promote sustainable agriculture
Goal 3	Ensure healthy lives and promote well-being for all at all ages
Goal 4	Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all
Goal 5	Achieve gender equality and empower all women and girls
Goal 6	Ensure availability and sustainable management of water and sanitation for all
Goal 7	Ensure access to affordable, reliable, sustainable and modern energy for all
Goal 8	Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all
Goal 9	Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation
Goal 10	Reduce inequality within and among countries
Goal 11	Make cities and human settlements inclusive, safe, resilient and sustainable
Goal 12	Ensure sustainable consumption and production patterns
Goal 13	Take urgent action to combat climate change and its impacts*
Goal 14	Conserve and sustainably use the oceans, seas and marine resources for sustainable development
Goal 15	Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss
Goal 16	Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels
Goal 17	Strengthen the means of implementation and revitalize the Global Partnership for Sustainable Development

2.2. ‘Three-Dimensional Model’ for Sustainability

The commonly-accepted definition of ‘sustainable development’ constructed by the Brundtland Commission emphasizes the importance of fulfilling human needs, which connects the term ‘sustainability’ to the varied aspects of human existence (Diwekar & Cabezas, 2012). One of the most commonly accepted and articulated models for sustainable development both in the UN Conferences and the literature is the ‘three-dimensional model’ that refers to social, economic, and environmental sustainability.

It is originated from the Brundtland Commission in 1987 and articulated in the following UN conferences between 1992 and 2015. Numerous proposals, requirements, and goals for global sustainable development were presented during this time. However, no clear theoretical framework for these three dimensions was developed. As Purvis et al. state (2019), since the 1990s, several researchers have been focused on this issue, including Basiago (1995), Khan (1995), Basiago (1998), Fricker (1998), Giddings et al. (2002), Gibson (2006), Barbier and Burgess (2017), and Mensah (2019) to define the three aspects of sustainability, in addition to their indicators, metrics and the relationship between them.

- **Environmental Sustainability:** Environmental sustainability aims to prevent the depletion of natural resources by protecting biodiversity, fundamental ecological processes, and the ecosystem's productivity (Brown et al., 1987). It refers to preserving the balanced ecosystem to maintain and utilize natural resources for a long time by keeping the production and consumption within the ecosystem's carrying capacity and allowing for the regeneration of resources (Basiago, 1998). Designing sustainable cities, ensuring balanced consumption and production, taking action against climate change, protecting below water and above land are the Sustainable Development Goals proposed in 2015 by the UN (United Nations Department of Economic and Social Affairs (ed.), 2016) for achieving environmental sustainability (Barbier & Burgress, 2017).

- **Economic Sustainability:** Traditional economy only considers profits and costs without considering the irreversible harm given to the limited natural resources through the process (Foy, 1990). Thus, the economic definition of sustainability has been considered elusive throughout history. Economic sustainability refers to the economic activities that “do not place a disproportionate burden on future generations” (Foy, 1990, p. 777) with the decisions that promote economic growth while considering the environmental and social aspects of sustainability (Mensah, 2019). From the Sustainable Development Goals of the United Nations Sustainable Development Summit 2015, ending poverty, ending hunger, ensuring good health and well-being, providing clean water and sanitation, ensuring accessibility for green energy, promoting economic growth, and promoting inclusive industry,

innovation, and infrastructure are the goals correlated with the sustainable economy (Barbier & Burgress, 2017).

- **Social Sustainability:** Social sustainability aims to decrease colonization, natural resource exploitation, world hunger, and poverty to reach a fair and stable social system with decent governance for human betterment without causing environmental devastation or economic instability (Barbier & Burgess, 2017; Mensah, 2019). The United Nations Sustainable Development Summit 2015 proposes high-quality education, gender equality, alleviated inequalities, promotes peace, justice, and strong institutions, and strengthens the Global Partnership to achieve a sustainable society.

Even though the definitions of environmental, social, and economic dimensions have been articulated similarly in the literature, the relationship between these three aspects of sustainability has been treated from different perspectives throughout history and remained ambiguous (Purvis et al., 2019). Earlier works have considered the three dimensions of sustainability as three explicit categories (Barbier, 1987; Basiago, 1998), namely "three conceptual pillars" (see Figure 2.1). Some researchers (Yunlong & Smit, 1994; Khan, 1995; Altieri, 1995), on the other hand, embrace the 'intersecting three cycles' model with sustainability in the center area (see Figure 2.1), which has been highly used in the academic literature and policy. Moreover, in some debates, environmental or economic sustainability has been put forward when sustainable development is defined by arguing that they do not have equal importance (Barbier & Burges, 2017). For instance, Macnaghten and Jacobs (1997), Mebratu (1998), and Giddings et al. (2002) have created similar models with concentric cycles (see Figure 2.1) in which the economy is encapsulated by society, and the environment embraces both of them. The approach considered economic sustainability as a crucial component for achieving a sustainable society in which both are restrained by the limits of the environment (Purvis et al., 2019).

The three-dimensional sustainability model has been widely accepted throughout the literature, and the definitions are adapted to different fields. However, it has always been criticized that this model has become a 'norm' or a 'common sense' with little or no theoretical framework. Some researchers have also proposed additional dimensions such as institutional (Valentin & Spangenberg, 2000; Turcu, 2013), cultural (Nassauer,

1997; Soini & Birkeland, 2014), technical or functional (Hill & Bowen, 1997; Rosen, 2012), while others refuse the division of sustainability into different dimensions and embrace a more holistic approach (Milbrath, 1989; Upham, 2000). Despite the varied perspectives in terms of the dimensions of sustainability and their interrelation, the need for embracing a holistic approach by considering the different aspects collaboratively has been considered a necessity in the literature to avoid shifting problems from one area to another (Diwekar & Cabezas, 2012).



Figure 2.1: Different approaches in the 'Three-Dimensional Model' for sustainability (Purvis et al., 2019)

2.3. Sustainability in Architecture and Construction

The principles of sustainability have been implemented in numerous professions throughout time, which led to the development of varied definitions of sustainability in academic, professional, and public domains such as sustainable agriculture (Reganold et al., 1990), sustainable forestry (Sverdrup & Stjernquist, 2013), sustainable fishery (Charles, 2008), sustainable business (Geissdoerfer et al., 2018), sustainable tourism (Liu, 2003), sustainable architecture (Sassi, 2006), sustainable construction (Hill & Bowen, 1997), sustainable education (Sterling, 2001), etc. Defining sustainability for different fields necessitates revealing principles, methodologies, approaches, and measurement tools based on the different needs and requirements of every profession.

One of the main fields where sustainability and its principles have become highly crucial and influential is the building industry containing both architecture and construction. With the industrial revolution, due to the evolving economic movement toward factories from agricultural lands, most of the population migrated to urban areas from rural districts, which caused excessive growth in the building industry. This

uncontrollable growth in the construction industry has caused significant environmental damage by consuming approximately 30% of natural resources, including freshwater, wood harvests, other raw materials, and 50% of all global energy (Martek et al., 2018). In addition, the Environmental Protection Department statistics state that 50% of greenhouse gas emissions and 38% of all waste produced worldwide, which is about 6408 tonnes per year, are caused by construction, heating, cooling, maintenance, and demolition activities (Tam, 2011). Besides the ecological aspects, "almost 50% of the total invested capital in developed countries is tied up in the housing sector alone, approximately 70% in existing buildings" which shows that architecture and construction sectors have a close relationship with social and economic development (Hegger et al., 2012, p. 26). In this scenario, implementing sustainable development principles in the building sector has become inevitable with the first energy crisis in the 1970s.

Although there is no agreed definition in the literature, sustainable architecture is considered as maintaining the continuously evolving needs of society by designing culturally functioning spaces while considering the economic solutions and their impact on the natural environment (Bennetts et al., 2003). Because the design and construction of a building is a complex domain, it requires integrating sustainability principles into varied aspects, including urban context, social and cultural values, architectural design, structural design, material choices, and interior-environment quality with the considerations of construction properties, building codes, acoustic performance, natural and artificial lighting, ventilation quality, and electrical and mechanical systems, etc. (Bovill, 2014).

2.3.1. Principles and Approaches

The sustainability problems in the building industry have occurred mainly in two phases: building construction and building operation. These phases cause excessive consumption of unrecoverable resources, environmental damage, and an increase in pollution levels if these phases are not conducted with appropriate design decisions and planning (Ding, 2008). Therefore, the environmental and economic dimensions of sustainable architecture and construction movement have utmost importance in the academic and professional discourses (Memmott & Keys, 2015). Consequently, there have been numerous economic and environmentally sustainable design principles in

the construction and operation phases. Some strategies are adapted for environmental sustainability, including:

- using renewable resources,
- ensuring resource efficiency,
- minimizing pollution and toxic emissions,
- utilizing eco-friendly materials,
- closing material cycles through recycling at the end of the building life
- integrating intelligent building technologies into the design (high-tech materials and responsive façades), and
- incorporating passive design techniques to reduce the energy consumption (providing solar shading, appropriate daylighting, passive solar heating, passive cooling, natural ventilation, or high insulation levels) (Caradonna, 2014; Dhir et al., 2019).

There are also some economic strategies to promote environmental strategies by focusing on the reduction of costs and environmental damage like:

- minimizing the use of materials through design,
- lowering the works on the site via prefabrication,
- reducing waste,
- ensuring the need for low-maintenance, and
- minimizing the transportation distances of materials (Bennetts et al. 2003; Hill & Bowen, 1997).

Besides, since “the built environment is a material environment”, the manufacturing and processing of materials cover a considerable part of the resource exploitation, energy consumption, and produced waste of the building industry (Hegger et al., 2012, p. 148). Therefore, utilizing sustainable materials plays a crucial role in reducing the environmental impact while ensuring the protection of resources. Sustainable materials, so-called green materials, have a variety of characteristics that promotes both environmental and economic sustainability, including “recycled, rapidly renewable, salvaged, locally manufactured, locally harvested, recyclable, minimally processed, low embodied energy, and non-toxic. durable and requiring low maintenance” with

low volatile organic compounds (VOC) emission, lightweight, and biodegradable etc. (Bovill, 2014, p. 156; Cordero 2001).

In addition to the environmental and economic sustainable design principles; there are different dimensions in sustainable building design, including social (Bay, 2010; Kefayati & Moztarzadeh, 2015), cultural (Memmott & Keys, 2015; Kim & Kwon, 2018), functional (Økland & Olsson, 2016; Kamara et al., 2020), or technical (Michael & Phocas, 2012; Zabihi & Habib, 2012). Since the main objects of the buildings are humans, the social dimension is a crucial aspect of architectural sustainability. The primary aim is to design "spaces that are compatible with the culture, behaviors, and methods of human life for the maximum time possible and is considered suitable for human life for prolonged times" (Kefayati & Moztarzadeh, 2015, p. 46). Social sustainability in architecture aims to create a living environment that promotes the occupants' sense of belonging, social interaction and participation, sense of security, and well-being by considering the habits and needs of the community in the design process of both buildings and the urban environment (Kefayati & Moztarzadeh, 2015; Bay, 2010). Since behaviors, beliefs, and culture are critical for social sustainability in architecture, socio-cultural approaches are also used interchangeably with social aspects in sustainable building design. It recognizes culturally specific spatial behaviors and supports cultural harmony by designing with the consideration of cultural differences (Memmott & Keys, 2015). Besides the social and cultural aspects, the properties related to the performance, quality, service life, the flexibility in the utilization of spaces, and adaptability of building systems for different conditions are also crucial for the sustainability of buildings that can be considered functional or technical dimensions (Hill & Bowen, 1997; Hegger et al., 2012).

2.3.2. Measurement Tools, Rating Systems and Challenges

Initially, sustainability was merely a concept or set of principles considered an unmeasurable discourse. When Agenda 21 was published in 1992, one of the initial aims was to compose better metrics, indicators, measurement tools, and methods for a semi-quantitative evaluation of human practices in terms of progress in sustainable development (Diwekar & Cabezas, 2012; Poveda & Lipsett, 2014). Since the 1990s, the generated models for evaluating sustainability have increased significantly, reaching up to hundreds of assessment tools. Sustainability assessment aims to measure

the current state, track for preventing possible damages by providing early warning, and improve sustainable performance by guiding decision-makers and policy-makers on the actions that should be taken to achieve a more sustainable society (Poveda, 2017). Various researchers have highlighted some principles for an instructive and effective assessment model. The characteristics required for the indicators are defined as being holistic, harmonious, habit-forming, helpful, humane (Brandon & Lombardi, 2010), innovative, integrated, interactive (Rotmans, 2006), fair, futuristic, and encouraging for public participation (Mitchell et al., 1995).

Due to multidisciplinary scope of sustainability, indicators and metrics should cover various issues on multiple scales with a well-based scientific approach. There are numerous approaches for developing indicators and assessment tools. Some concentrate on specific problems or fields, while others embrace an integrative approach (Rotmans, 2006). Issue or theme-based approaches focus on one of the three aspects of sustainability or directly on the sustainability of a product, including Life Cycle Assessment (LCA), Life Cycle Costing (LCC), process energy analysis, and product material flow analysis, etc. The mono-disciplinary frameworks have the advantage of working in a limited area in the determination of indicators and indices while also providing precise results for decision-makers (Poveda, 2017). However, the need for an integrative assessment approach that is "flexible, considers different scenarios and planning and design issues and includes easy-to-check and relevant criteria for the decision-makers" has been emphasized in the literature for a long time (Poveda, 2017, p. 16). There are numerous Integrated Sustainability Assessments (ISA) in the literature, while the new ones continually have been developed (Poveda, 2017, p. 18). However, due to the wide-scale principles for global sustainable development, generating integrated sustainability tools remains a challenge for policymakers and scientists since developing such a tool requires expertise from numerous areas. Therefore, there is still no standard method or sole document that comprises all the aspects of sustainability in the current portfolio of assessment models (Poveda & Lipsett, 2014; Rotmans, 2006).

As Francescato (1991) expresses, to generate a well-established assessment model, there is a need for a common-value system among the members of the community and experts that creates a basis for criteria. Due to the lack of an agreed-upon definition

and assessment tools, their selection for a specific subject and application in the decision-making process have also remained critical for stakeholders (Poveda, 2017, p. 30). The selection of the tools should be made by the stakeholders based on the characteristics of the issue and be applicable with its scale ranging from local to regional and global to fulfill the objectives of sustainability and the expectations of the stakeholders. Since every project or issue has different requirements, the indicators and metrics should be more flexible, prescient, ubiquitous, and adjustable for different needs, with participatory-focused methodologies as an integral part of the policies and decision-making processes (Diwekar & Cabezas, 2012; Caradonna, 2014). More importantly, to conveniently put sustainable development principles into practice, experts and authorities who are conscious of the process should be involved in the initial steps of any sustainable development attempt to execute the correct set of indicators and analysis tools (Brandon & Lombardi, 2010). As a result, "unification of criteria; common definitions for guidelines, processes, and methodologies; and adequate implementation of concepts to develop best practices" have been considered vital factors for improving the current assessment tools and models (Poveda, 2017, p. 4).

Since it is not feasible to implement all strategies into every design, there are many sustainability assessment systems to determine indicators and measure the implementations based on the needs of the different projects. They can be categorized as cumulative energy demand (CED) systems, life cycle analysis (LCA) systems, and total quality assessment (TQA) systems. While CED and LCA systems focus on a selected object, such as the total energy consumption of a building and environmental assessment of a produced material, TQAs are multi-criterion systems covering environmental, economic, and social aspects (Berardi, 2012). There are more than several hundred sustainability assessment rating systems in the literature and building industry. Every tool has varied categories: site selection, management, transportation, energy efficiency, water efficiency, material and resources, waste and pollution, indoor environmental quality, health and well-being, and waste and pollution. Most tools use a system in which each category has a number of criteria with determined points and summed in the end to reach the overall sustainability performance score (Berardi, 2012; Poveda & Lipsett, 2014). The most famous systems are BREEAM from the United Kingdom, LEED from the United States, CASBEE from Japan, Green Globes from

Canada, Green Star from Australia, and international tools like SBTool and GBTool (Poveda & Lipsett, 2014). Among the examples of rating systems, the two most widespread sustainability rating systems are LEED and BREEAM (Roderick et al., 2009). The LEED BD+C New Construction - v4.1 (USGBC, n.d.), for instance, has 112 credits under nine fundamental categories in addition to the plot credits category that refers to various aspects of design: integrative process, location and transportation, sustainable sites, water efficiency, energy and atmosphere, materials and resources, indoor environmental quality, innovation, and regional priority. The BREEAM International New Construction 2016 (BRE Global Ltd., 2016) tool has ten categories: management, health and well-being, energy, transport, water, materials, waste, land use and ecology, pollution, and innovation, with 56 credits in total. These tools give 'green certificates' to the buildings based on the number of points collected in different grades such as silver, gold, and platinum (LEED) or fair, good, very good, excellent, and outstanding (BREEAM). The rest of the tools are generally adaptations of these popular tools for different countries and regions due to the differences in climatic conditions, available techniques, and materials. Moreover, the rating tools also vary based on every project's different needs and requirements due to its function, size, scale, and user profile, such as LEED for Commercial Buildings, LEED for Residential Buildings, and LEED for Neighborhood (Poveda & Lipsett, 2014).

Despite the numerous principles, measurement models, and rating systems developed in the literature, the agreed definition, framework, and policy for implementing sustainable development principles are still lacking. Although the number of eco-friendly materials, intelligent building technologies, and buildings with green certificates has increased in the last decade, numerous projects have still been designed and constructed with conventional techniques with little or no sustainable considerations due to social, economic, and institutional factors (Poveda & Lipsett, 2014). This might be because the rating tools differ in what they measure, how they measure, and how their principles and weightings are designated (Martek et al., 2018). Having no standard set of principles in neither literature nor policy obstructs the implementation of sustainable principles in practice (Purvis et al., 2019). Due to the controversies about the sustainable development framework, sustainable principles could not become an obligation like building codes to get a building permit, which prevents their implementation for every project in practice (Martek et al., 2018).

Besides, since constructing a sustainable building is a more complex process than conventional construction, by requiring multidisciplinary and concise design and planning with the efficient use of current technology. Thus, it necessitates bringing additional consultants and experts to the design team. For a more effective method for the implication of sustainability principles, all members of the design team and other stakeholders (owner and contractor) should acknowledge and embrace the necessity and importance of the principles (Swarup et al., 2011). Moreover, as Hwang and Ng state (2013), the complex and multidisciplinary nature of sustainable building design and construction brings more challenges, including hiring additional consultants, "increased technical difficulty, lengthy approval processes, more complex contractual arrangements, higher project delivery risk, and longer duration to completion" (Martek et al., 2018, p. 12). As a result, all these uncertainties and challenges have led sustainability to become a domain in which environmental, social, and economic issues have continued to occur in the architecture and construction industry, despite its necessity has been acknowledged by professionals.

CHAPTER 3

WORLD EXPOS AND THEIR SIGNIFICANCE IN ARCHITECTURE

This chapter briefly mentions the history of World Expos and how they evolve throughout time. Then, their importance in the architectural and structural domain, together with the achievements in the history of World Expos, is mentioned. Then, sustainability in World Expos, as being both theme and issue, is introduced.

World Expos, so-called Registered Expositions or Universal Expositions, are international mega-events that catalyze the exchange of manufacturing goods, industrial power, cultural characteristics, ideological views that reflect national identity, and scientific and technological achievements of countries on a global scale (Roche, 2000). The events commenced with the 1851 Great Exhibition in London when the effects of the Industrial Revolution had been highly observed with the emergence of new industries and increasing production rates (De Groote, 2005). Within this context, the Great Exhibition created a significant impact with its size and 6 million visitors, which became a model for the following exhibitions in the later nineteenth century (Smits & Jansen, 2012). Since then, different types of international fairs have been organized, including World Expo, Specialized Expo, Horticultural Expo, and Triennale di Milano.

Since the Expos have witnessed a long history with crucial incidents, events, wars, and inventions, the focus of exhibitions has changed respectively throughout this time period. In the 19th century, agricultural and industrial advances, in addition to varied

inventions like glass and steel in construction (1851), the telephone (1876), electricity, and the electric light bulb (1893), movie (1900), the television (1937), "the tape recorder, air conditioning, and the washing machine" (1939), early version of computers (1962), and the laser (1967), etc. became the agendas of World Fairs (De Groote, 2005, p. 14). While turning into the new century, European fairs came to the stage with the focus of maintaining and promoting colonization, while industrialization still had importance. In 1928, the Bureau International des Expositions (BIE) was founded in Paris with 31 European countries to organize and control the events while maintaining "standards and the timing of world's fairs to preserve the value of the event by limiting the supply" (Wilson, 2011, p. 1046). Beginning with the 1930s, the expositions were centered around intercultural communication "to promote a better tomorrow through highlighting manufactured goods made possible by advances in science and technology" which was interrupted for 18 years due to World War II (Schrenk & Jensen, 2014, p. 554). After the war and the destruction caused by the atom bomb in 1945, the focus shifted towards new political and technological achievements like space-age technology with a more competitive approach while reflecting the devastating impacts of the technology. The Seattle World Expo 1962 initiated the 'Expo-led urban renewal' concept, which creates another mission for World Expos and turns them into essential events for the development of host cities. Together with the Stockholm Declaration in 1972 (see Section 2.1), sustainability had risen as a crucial concept in the World Expos, which has been maintained till today.

Witnessing all these time periods turns World Expos into the documentation of human history and civilization while creating global and local impacts. On a worldwide scale, they have been considered "a great sociological laboratory for testing the reception and spreading of new ideas and information" in science, technology, culture, art, and architecture (De Groote, 2005, p. 14). However, the Fairs have also been criticized throughout history for promoting consumerism and global consumer culture by boosting fast production, distribution, and consumption (De Groote, 2005). Besides, integrating urban redevelopment into the city-branding mission allows host countries to boost their economy, upgrade their infrastructure, and draw tourists in the local level. These create tremendous impacts on various fields throughout history, including tourism, social fabric, policy, economy, technology, media and marketing, agriculture,

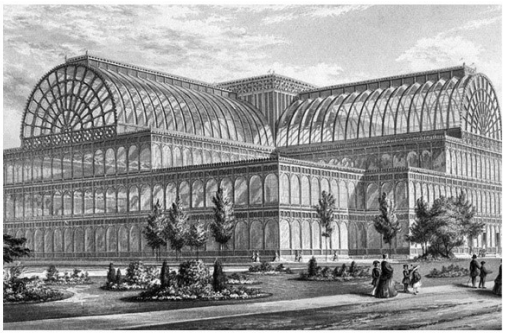
infrastructure and urbanization, architecture, and construction (Hiller, 1998; Chen, 2012).

3.1. Architectural and Structural Contributions of World Expos

Since the power and development level of countries in different areas has been represented in pavilions from the first World Expo till today, World Expo pavilions have had a crucial impact on the architectural and structural domains. In the first twenty-two years of the Expos, the exhibitions were held in a single pavilion, and later additional pavilions came to the stage. In 1878, national pavilions were started to be constructed, which became tools for expressing national identity and power (Smits & Jansen, 2012). When the beginning time and chronological interval of the World Expos are considered, "the Expos have witnessed significant developments in the field of structures: the development of iron engineering in the 19th century, the invention of reinforced concrete, the appearance of glued laminated timber, the development and far-reaching spread of space frames, the birth of cable networks and textile membranes, the development of pneumatic structures, as well as the revolution in the field of applied computer science" (López César, 2017, p. 23). Besides, the aim of nations to show off their power creates a competition between them and causes outdo in structural achievements in every Expo. It resulted in "advances in the spans reached, the appearance of new structural typologies, and experimentation with new materials or research into new shapes" and "greater creative freedom in the field of structures" (López César, 2017, p. 23). As a result, many pioneer and iconic structures have been designed during the Expos, which became the image of the Expos and symbol of the nations throughout history.

The 19th century World Expos was dominated by iron architecture in which varied structural, typological, and material representations were developed during this period. While cast iron was utilized as a structural material in the first half of the century, the collapse of some cast iron structures pushed designers to prefer wrought iron in the second half due to its better structural material properties (López César, 2017). The first pavilion in history, the Crystal Palace in Great Exhibition 1851 (Figure 3.1-a), is the only pavilion built at that Expo, which is the first prototype for the huge-scale (563 meters) iron and glass structures with modular components. It was constructed at a time when iron was new material in construction, while steel and reinforced concrete

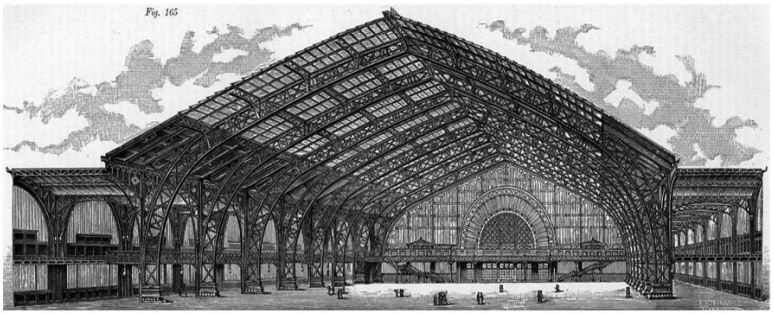
were not even invented. It also led to the production of industrial-scale glass, which promoted the use of the material in architecture and construction (Sandaker et al., 2019). The Galerie des Machines (Figure 3.1-c), built at 1889 Exposition Universelle in Paris as a host pavilion, broke the world record with its 110.6 meters span and marked the top point of iron architecture, which became a precedent for the use of metal arches, especially in large-scale railway stations. The Eiffel Tower (Figure 3.1-b), made of iron, was the tallest building ever built as the symbol of Exposition Universelle de 1889. It became an expression of technological development with its 300 meters height. Although it was built to be dismantled after the Expo, the iconic image of the structure allows it to be permanent (López César, 2019).



(a) Crystal Palace - 1851



(b) Eiffel Tower - 1889



(c) Galerie des Machines - 1889

Figure 3.1: Achievements of iron structures in World Expos

(a: https://blog.inoxstyle.com/en/crystal-palace/;

b: http://vrc-cbe-uw.blogspot.com/2008/06/galerie-des-machines-paris-1889-iron-or.html;

c: https://commons.wikimedia.org/wiki/File:Paris_Eiffel_Tower_On_Completion.jpg)

Despite the fact that steel was affirmed as a better choice for these two monumental structures by the specialized journals of that time, due to the limited knowledge about the structural behaviors of steel, “the technical manufacturing difficulties at the beginning, its high cost, and the greater development of iron production plants”, steel

had been avoided by the architects and engineers in those times (López César, 2017, p. 131). Nevertheless, as the structural benefits of steel over iron were acknowledged, technical and economic issues were overcome. As a result, the use of steel was expanded, and it became the primary material for especially bridges.

While the 19th century became the era of metal structures, glue-laminated timber and concrete were invented and developed at the beginning of the 20th century. Reinforced concrete was invented beforehand yet became more widespread in bridges, commercial buildings, industrial buildings, or tanks at the turn of the century. The use of reinforced concrete for "shell structures in the World Expos is scarce; while those that were built were a novelty within the field of the Expos, their contributions were not significant in the context of the history of structural typologies, given that they were late constructions" (López César, 2017, p. 242). Although small-scale timber structures were widespread in those times, large-scale structures made of timber were achieved using glue-laminated timber. World War I, which restricted the use of steel, led to an increase in timber structures. The invention of synthetic glues, with their long-lasting features and resistance to atmospheric agents and fire, promoted the application of glued laminated timber, especially in the second half of the 20th century.

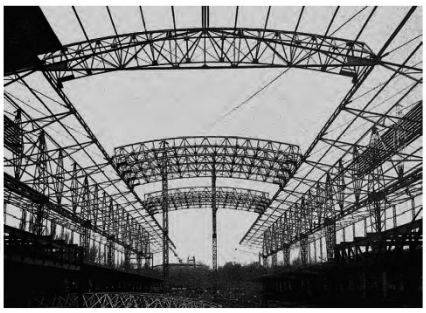
The invention and widespread utilization of reinforced concrete and glue-laminated timber in construction coincided with World War I and II. Since they were the incidents that interrupted the World Expos, the structural and architectural contributions of reinforced concrete and glulam timber pavilions of World Expos had also been delayed for a long time. With the Brussels World Expo 1958, a structural re-birth had occurred with innovative structural typologies in the Expos after the inter-war period. The structures that work in tension with cable-stayed decks or cable networks become significant examples of tensile structural typologies, including the French Pavilion, the Marie Thumas Restaurant Pavilion, the U.S. Pavilion, and the Soviet Pavilion (see Figure 3.2) (López César, 2017). Besides a considerable number of medium-sized glue-laminated timber structures, the reinforced concrete shell structures with a sculptural character (United Nations Pavilion and Philips Pavilion) also had a crucial role in that Expo.



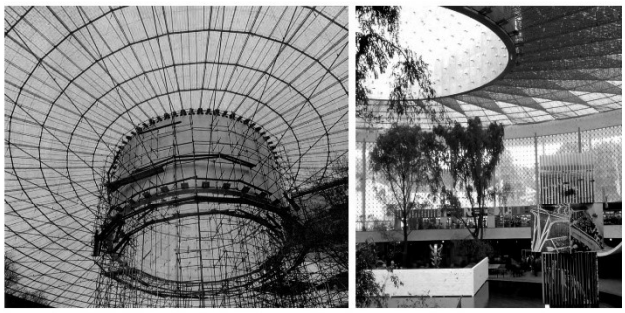
(a) French Pavilion - 1958



(b) Marie Thumas Restaurant Pavilion - 1958



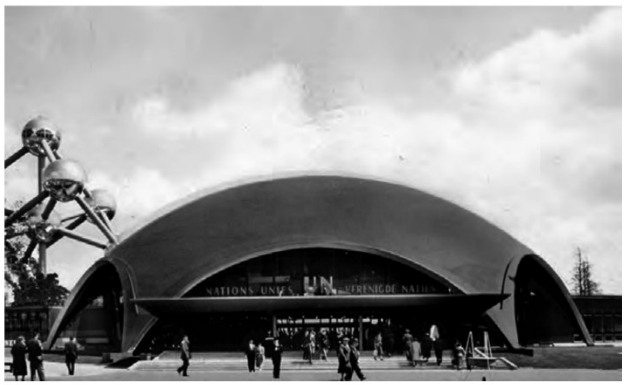
(c) Soviet Pavilion - 1958



(d) U.S. Pavilion - 1958



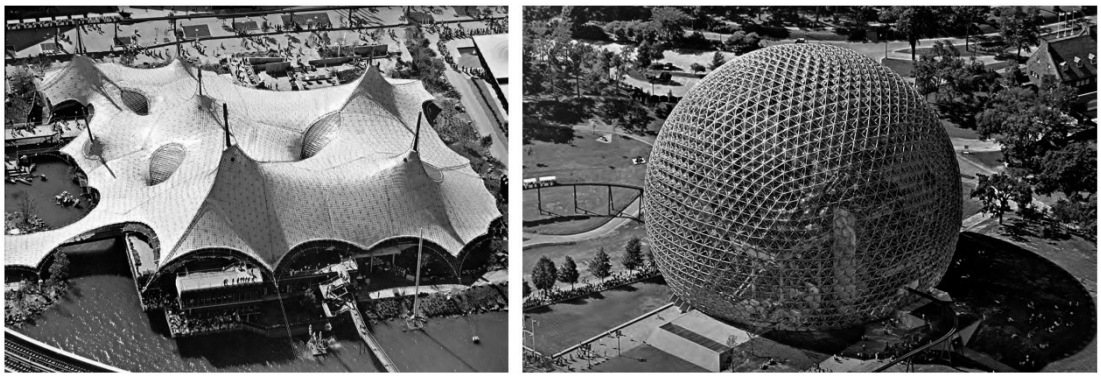
(e) Philips Pavilion - 1958



(f) United Nations Pavilion - 1958

Figure 3.2: Structural achievements in Brussels World Expo 1958 (López César, 2017)

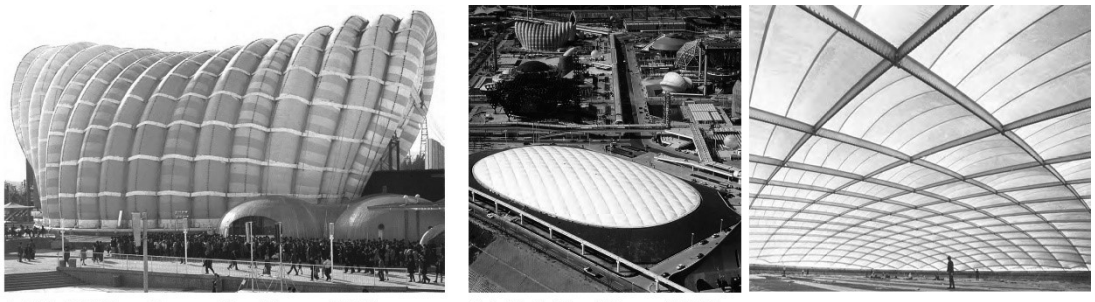
The Montreal World Expo 1967 was also crucial for witnessing the development of cable-net structural typologies, especially the German Pavilion (Figure 3.3-a), designed by Frei Otto. It "was a huge conceptual progress in the design of structures formed by cable networks, evolving from the use of geometrically known forms to free forms" that became precedent for later structures (López César, 2019, p. 10). Besides the tensile structures, space frames also played a crucial role in the Expo. United States Pavilion (Figure 3.3-b) is also considered one of the famous geodesic domes even today "as perhaps the most compelling built example of the tremendous spatial possibilities of this form of construction" (Sandaker et al., 2011, p. 487). At the same time, its lightweight acrylic panels also had innovative cladding solutions.



(a) German Pavilion - 1967 (b) U.S. Pavilion - 1967

Figure 3.3: Structural achievements in Montreal World Expo 1967 (López César, 2017)

The Osaka World Expo 1970 pavilions are mainly known for their innovative and distinctive sizes. The Expo was essential in the development of pneumatic structures, which was a crucial step in the history of inflated structures. At the same time, the cable nets, space frames, and pre-stressed membranes had still maintained their importance. The Fuji-Film Group Pavilion (Figure 3.4-a) was the largest pneumatic built until that time. It was constructed by a "series of horseshoe-shaped inflated membrane tubes tethered together stood out for its original form and structural system" (Sandaker et al., 2011, p. 432). Also, the United States Pavilion (Figure 3.4-b) was an innovative structural typology with its low-profile vault frame clad with air-supported membrane allowing for a significant span. The structure was the largest span ever built and the lightest for its span (López César, 2019).

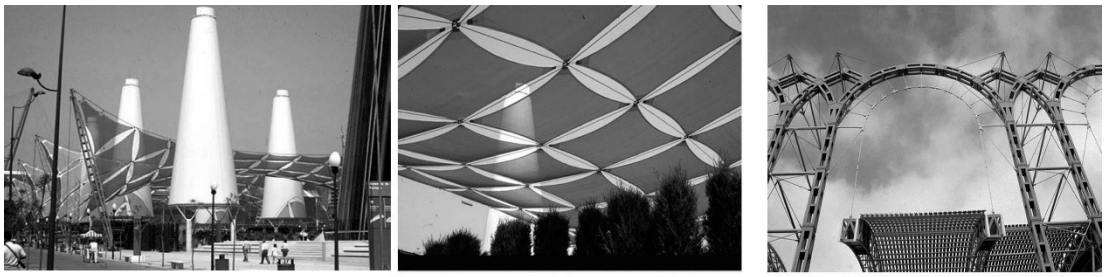


(a) Fuji-Film Group Pavilion - 1970 (b) U.S. Pavilion - 1970

Figure 3.4: Structural achievements in Osaka World Expo 1970 (López César, 2017)

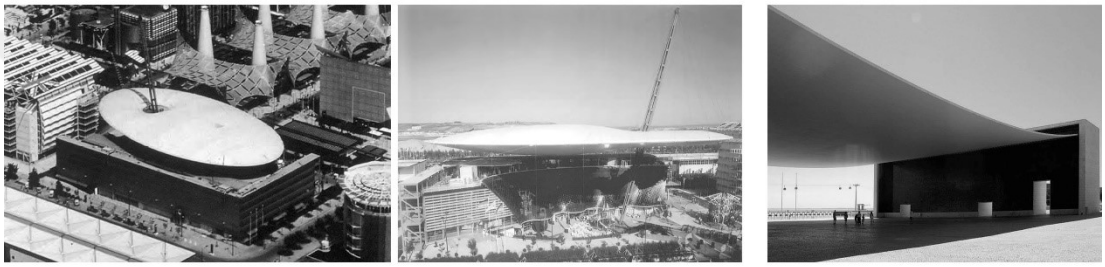
After the emergence of new typologies in the former Expos, the Seville World Expo 1992 and Lisbon World Expo 1998 were characterized by efforts to outdo structural achievements, especially in heights and spans. The east and west gates of the Expo 1992 (Figure 3.5-a), the Pavilion of the Future (Figure 3.5-b), and the German Pavilion

‘92 were crucial examples of prestressed membranes and prestressed cable nets. Alvaro Siza Vieira’s Portuguese National Pavilion in Lisbon Expo ‘98 was another example of the suspension cable with its unique shape and load-carrying capabilities that combine cable nets with reinforced concrete (Sandaker et al., 2019).



(a) East and West Gates of the Seville World Expo - 1992

(b) Pavilion of the Future - 1992



(c) German Pavilion - 1992

(d) Portuguese National Pavilion - 1998

Figure 3.5: Structural achievements in Seville (1992) and Lisbon (1998) World Expos (a-b-d:Sandaker et al., 2019; c:López César, 2017)

Overall, the World Expos have witnessed significant architectural and structural achievements in the invention of new structural typologies and materials and the improvement of the existing ones. Therefore, the World Expos have created a reputation for exhibiting innovative solutions for the issues they focused on, which is architectural structures in this case.

3.2. Sustainability in World Expos: Being a Theme and an Issue

While the World Expos’ aim of origin was to show off the countries’ industrial power and spread innovative ideas and developments in various fields, their themes have also been responsive to the current issues and events. The focus of the Expo themes in the 19th and 20th centuries was the Industrial Revolution and its outcomes, which directly focused on consumerism and globalization. As mentioned in Chapter 2, industrialization has various negative consequences on ecology and the environment. Besides, World Expos require a significant development in the urban environment including enhancing the infrastructure with newly built airports, highways, subway

lines, and/or railway stations; creating public spaces like pavilions, museums, parks, landmarks and cultural centers; and providing housing for Expo employees (Wilson, 2011). Conducting a considerable scale urban development for a short-term event lead the failures in the post-expo period like transportation networks with unnecessary capacity and scale, housing units that cannot be rented or sold, and abandoned legacies of Expos. Therefore, the World Expos have witnessed failed post-use of pavilions in a series of events throughout history which causes abandoned structures in the urban environment. New York ’64, Knoxville ‘82, Seville ’92, and Taejon '93 Expos are just a few of the examples.

Therefore, sustainability was raised as a new concept in the late 20th century. Following the Stockholm Declaration in 1972 (see Section 2.1), the World Expos have focused on more human-centered themes to demonstrate the ways of living in harmony with the natural environment and provide solutions for raising sustainability issues (Schrenk & Jensen 2014). From this time, some Specialized Expos with sustainability-related themes were organized, including *Celebrating Tomorrow's Fresh New Environment* (Expo ‘74), *The Sea We would like to See* (Expo ‘75), *The World of Rivers– Fresh Water as a source of life* (Expo ‘84), and *The Oceans: A Heritage for the Future* (Expo ‘98). However, the first sustainability-centered World Expo was Hannover World Expo 2000 with the theme *Man, Nature, and Technology,* which initiated the sustainability period in the World Expos. Four more World Expos have followed the Hannover Expo till today: Aichi (2005), Shanghai (2010), Milan (2015), and Dubai (2020) World Expos (*All World Expos*, n.d.).

Developing sustainability-centered themes have brought the responsibility for the design and construction of pavilions with sustainability principles since the pavilions are the main exhibition features of Expos. With this aim, sustainability guidelines have been prepared for Expos, initiated with the "The Hannover Principles" prepared by William McDonough Architects in 1992 for the Hannover World Expo 2000 by taking Agenda 21 into consideration, a document published in Rio Earth Summit (see Section 2.1). The Hannover Principles proposed general guidelines to “form the foundations of a new design philosophy underlying the future of proposed systems and construction for the City, its region, its global neighbors and partners in the world exposition” (McDonough, 1992, p. 2). It emphasizes the importance of designing pavilions as

flexible as possible with sustainable technologies to respond to the changing needs and purposes of Expos in during-event and post-event phases. Despite being crucial as an initiative for providing guidelines for designing sustainable pavilions, the principles become so general which does not provide a detailed guide about how to manage the post-expo process for the permanent or temporary pavilions. As a result, many pavilions have been abandoned to deteriorate on the Expo site, which demonstrates that the document could not perform its duty exactly. Therefore, to avoid this issue, all national pavilions in Aichi World Expo 2005 were designed temporarily with prefabricated and standardized modular units of 18 x 18 x 9 meters. Besides, the 3R's strategy (Reduce, Reuse, and Recycle) was also embraced, which was determined as a subtheme of the Expo under the guidance of a research committee established in the BCJ (Building Center of Japan) in 2002 (Tsunoda et al., 2007). These strategies enable the construction and deconstruction of the pavilions with minimum energy use and building waste which serves for sustainable event and post-event processes. However, the pavilions lost their architectural value and iconic images, which negatively impacted the global vision of the Expo, especially in terms of marketing and advertising.

Since the Expos have been recognized globally with their achievements in architectural and structural features of the pavilions, the modular strategy of the Aichi Expo has not been continued in the later Expos. Yet, the Shanghai (2010) and Milan (2020) Expos have kept the Aichi Expo's decision of building most of the national pavilions temporarily for the sake of the Expo land in the post-expo processes. The Shanghai World Expo (2010) is the biggest Expo till that time with its comprehensive expo-led urban renewal concept. While the main focus of the Aichi Expo was nature, Shanghai Expo greatly emphasized urban development with the use of "innovative, low-cost, and sustainable technologies to mitigate pressing urban problems" which were also requested from the national pavilions (Zhang, 2013, p. 79). However, since only five pavilions out of 54 were designed permanently, investing in these technologies for temporarily built pavilions has also created question marks about whether they were worth it (Schrenk & Jensen, 2014). At Milan World Expo (2015), there was more focus on the post-expo journeys of pavilions with different end-life scenarios:

- “the building reuse or relocation (considering the distance between the original site and the new one as well as the impact of the transport of materials);
- reuse or relocation of components in a new building;
- reuse of materials for manufacturing new components;
- recycling materials into new building materials” (Ministry of Ecological Transition, 2022, p. 13).

In any case, the construction, demolition, disassembly, relocation, reassembly, and/or recycling process of World Expo pavilions requires a huge amount of energy and resources. When combined with the energy needs for the operation of the buildings, carbon dioxide emissions caused by traveling, increasing resource (food, material, energy, etc.) consumption, and waste generated by all these actions, the Expos contribute to the current global ecological problems. The duality caused by the sustainability theme of the World Expos and the issues they caused has created controversies for a long time. Therefore, World Expos have been criticized because the innovative and sustainable solutions provided by Expos have been lacking, especially compared to their success in the field of structures. Thus, it has become crucial to develop innovative solutions for the design and construction of pavilions with a minimum environmental impact, which become prototypes for the real-life issues in the building sector that has a severe negative impact on the environment.

CHAPTER 4

METHODOLOGY

This chapter presents the methodology of this study, including how the data is gathered and how the analysis is conducted. First, the constitution of the analysis table for each pavilion as the primary analysis tool is explained. Then, the categories that constitute the analysis method are clarified by conducting a literature review: structural systems, building materials (structural and non-structural), and sustainable properties of their configuration.

The design of World Expo pavilions is crucial for solving the controversies between sustainability themes of Expos and environmental issues caused by them. To observe the attitudes and contributions of World Expos to the sustainability issue, the scope of the study is determined as World Expos with sustainability-related themes. With this aim, a set of cases awarded by the Expo committees is selected from determined World Expos and categorized based on their long-term life expectancy for the post-expo period (permanent or temporary) to observe whether the design of structural systems and selection of building materials are executed based on their post-expo state.

As mentioned in Section 2.3, sustainability in the architectural domain is mainly discussed in two parts: construction and building operation with a wide range of considerations from the urban environment to the interior environment. Since it covers a broad field, this study considers the features of pavilions related with the post-expo use process. Both construction and operation parts are crucial for a sustainable post-expo process which is also influenced by the design features of structural systems and

materials to some extent. Overall, since the design of structural systems and selection of building materials play a collaborative role in the design and construction of buildings, this study observes the selection of structural systems and building materials (structural and non-structural) of a selected group of pavilions, and analyze how they are configured to provide sustainable solutions for the post-expo use.

The structural system type plays a determinative role in the selection of materials since structures' load-carrying capacity, form, and efficiency are highly dependent on the properties of the utilized materials. Correspondingly, the sustainable properties and reusability of both structural and non-structural materials also depend on the structural system in which they are combined and how the overall system is designed. Therefore, the sustainable properties are determined by considering the configurations of structural systems and building materials to analyze the post-expo use performances. As a result, the selected cases are examined by creating an analysis table comprising four categories, including both data collection and analysis parts (see Figure 4.1):

1. general information, graphics, and post-expo situation of the pavilion,
2. structural systems,
3. building materials (structural and non-structural), and
4. sustainable properties of the configuration of structural systems and materials.

The first category contains mainly the information about pavilions gathered from the literature including the official web-sites of Expos, and the information provided by the designers of pavilions in online. Based on the observation of structural systems and building materials in the second and third parts, fifteen sustainable properties are revealed and evaluated in the fourth part. Each sustainable property is considered ‘one point’ gained by the configuration of structural systems and materials to provide a sustainable post-expo use. Based on the sum of sustainable property points of each pavilion, the role of structural systems and building materials in sustainable post-expo use of pavilions is evaluated and compared among pavilions accordingly:

- 1 to 3 sustainable properties: No/negative role (-)
- 4 to 6 sustainable properties: Low-level role (+)
- 7 to 10 sustainable properties: Mid-level role (++)
- 11 to 15 sustainable properties: High-level role (+++).

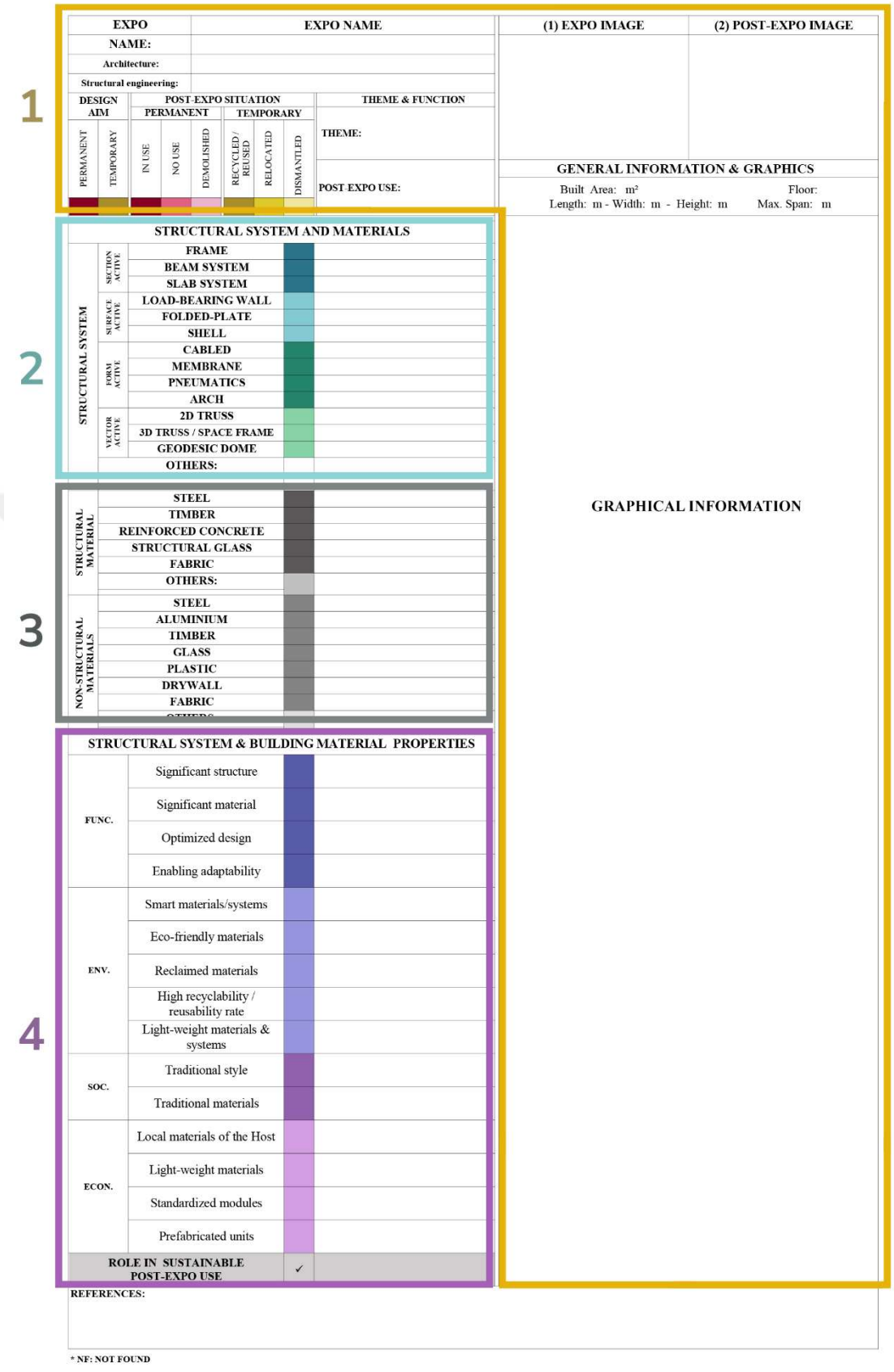


Figure 4.1: Analysis Table

Besides the analysis table constituted for each pavilion, there is also a comparison table that contains all pavilions. The 'sustainability scores' of structural systems and materials revealed, for each pavilion and presented in Table 7, allow us to compare the design approaches of pavilions regarding how much post-expo process is considered in the configuration of structural systems and materials (see Table 7 in Appendices).

4.1. General information about pavilions

The first part of the analysis table presents general information about the pavilion, including its name, year, nation, architect(s) and structural engineer(s), theme, expo, and post-expo images to give brief information about the pavilion. Also, the interior and exterior images, architectural and structural drawings, and diagrams that explain the details of architectural design, structural system, and material characteristics are presented. Besides, general building features like its size (length, width, and height), maximum span, and the number of floors is also given in that section. Lastly, the long-term life expectancy of pavilions (whether they are either designed temporarily or permanently) and their post-expo situation -are marked in this section. While categorizing the pavilions based on their long-term life expectancy and post-expo uses, it is considered that all pavilions in the Expo history have been designed with a pre-determined future use which ideally has three options:

- re-functioning the pavilion on the same site (permanent - in use),
- relocating the pavilions to be reused in a new location (temporary - relocated), and
- reusing or recycling the materials of the pavilions for manufacturing new building components (temporary - recycled) (Ministry of Ecological Transition, 2015).

However, the post-expo situations and uses of pavilions have not always been as they were designed. Therefore, although their post-expo function had already been defined before the Expo, there are examples of pavilions in history that had not been utilized as envisioned (Schrenk & Jensen, 2014). It resulted in:

- abandoned pavilions that are being left to deteriorate for years (permanent - no use),
- demolished pavilions without any further use (permanent - demolished), or
- relocated pavilions, even if they were designed as permanent, if their constructional properties allow (permanent - relocated).

Besides, there are also some temporary pavilions that decided to be dismantled, but their post-expo use is not clearly defined about whether their materials are recycled/reused or they are re-erected somewhere. These pavilions are coded in the table as ‘temporary - disassembled’.

Regarding this information, the pavilions are categorized in two main categories with three possible post-expo uses:

- permanent: in-use (refunctioned), no-use (abandoned), demolished
- temporary: recycled/reused, relocated, disassembled.

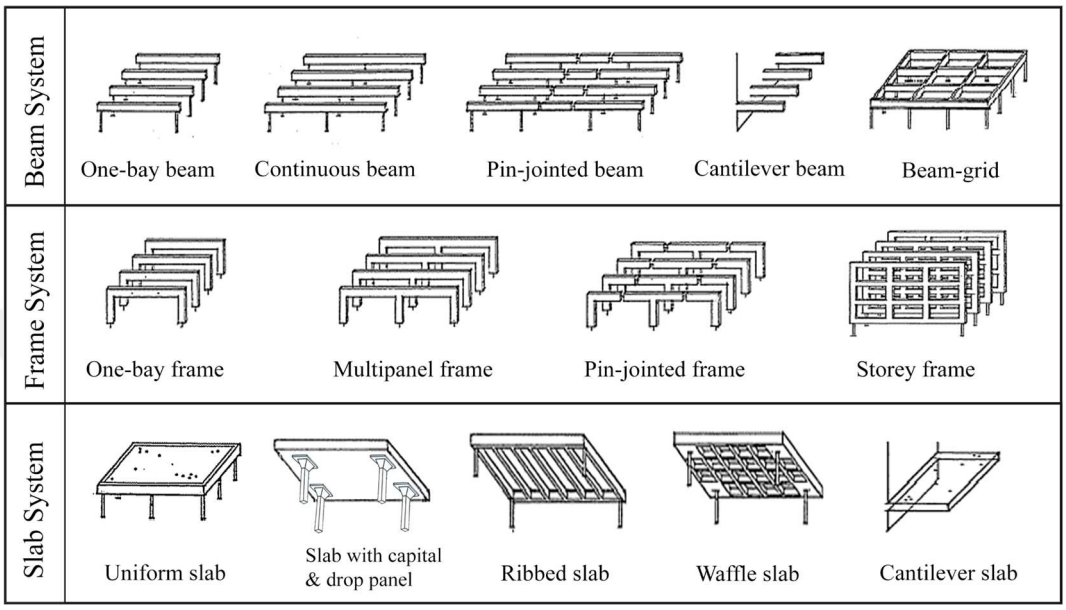
4.2. Structural systems

In literature, structural systems are categorized based on different aspects, such as their working principles (section-active, surface-active, form-active, vector-active) (Engel, 2013), active internal forces in the system (tension, compression, bending, tension + compression, hybrid) (Hurol, 2016), structural material types used (masonry, steel, timber, reinforced concrete) (Macdonald, 1997) and/or different combinations of these characteristics. In order to analyze the configurations of different materials and structural systems with similar working principles and their effects on post-expo use of pavilions, the work of Engel (2013) is taken as the base for the categorization of structural system types in this study. Therefore, thirteen fundamental structural system types are determined and categorized under four main categories: section-active, surface-active, form-active, and vector-active. Since some contemporary and innovative structural system types were developed after this categorization, there is also an ‘others’ section to note these cases in the table.

4.2.1. Section-Active Structures

Section-active structures are defined by Engel (2013) as simple rectangular-form systems with “rigid, solid, linear elements -including their compacted form as a slab- in which the redirection of forces is affected by mobilization of sectional (linear forces)” (p. 173). The most common system types encountered in the building industry are constructed by beams, columns, and slabs. They can resist axial tension and compression, bending, shear, and torsion (Silver et al., 2014). The efficiency of the systems is impacted by the cross-section of its components combined with the specific

material characteristics and continuity of the members. Systems like 'continuous beam, hinged frame, complete frame, multipanel frame, and multi-story frame' work with the principle of continuity to provide long-span and column-free area. Section-active structures can be divided into three systems: beam, frame, and slab. In Figure 4.2, these systems and some of their subsystems can be observed.



*Classifications and illustrations are adopted from Engel (2013).

Figure 4.2: Section-active systems and some subsystems (derived from Engel, 2013)

- **Beam System:** Beams are the main components of section-active systems. They are "bending-resistant structural elements that cannot only resist forces that act in the direction of their axis, but by means of sectional stresses can receive also forces perpendicular to their axis and transport them laterally along their axis to the ends" (Engel, 2013, p. 179). Since the depth of the cross-section of beams is crucial for the overall efficiency of the system, the use of pre-stressed members and composite materials allows efficient cross-sections (Engel, 2013). One-bay beams, continuous beams, pin-jointed beams, cantilever beams, and beam grids are different types of beam systems.

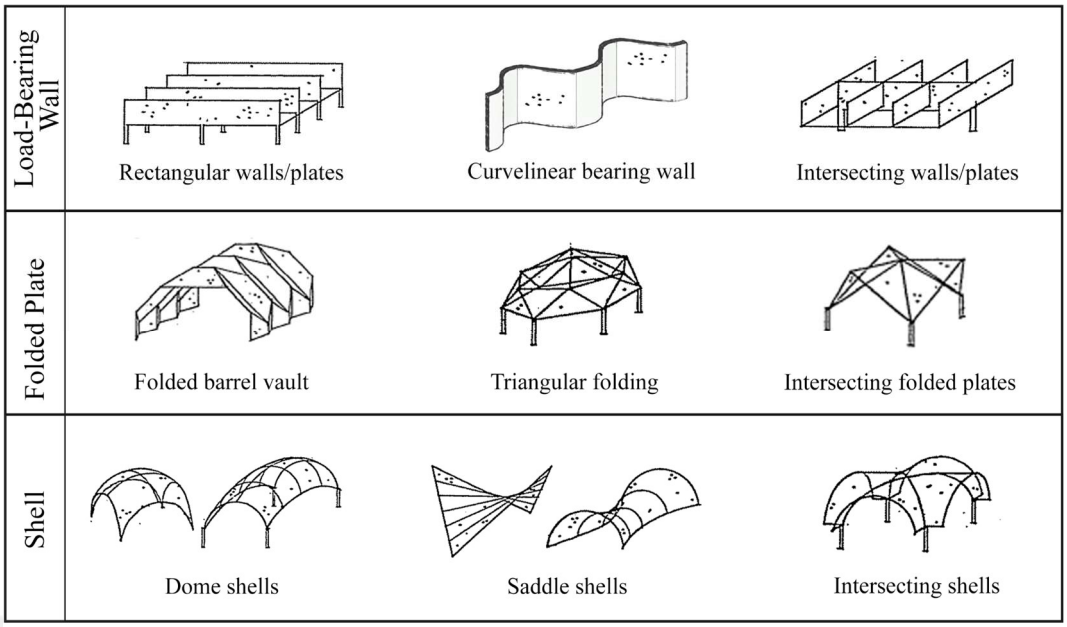
- **Frame System:** In frame systems, vertical and horizontal members are attached with rigid connections, which help to resist lateral loads (Hurol, 2016). The rigid connections allow joints to transfer bending stress between members to achieve inherent stability and redundancy. The connections are critical in the frame systems

since “the highest magnitude of stresses, and internal forces are concentrated at the joints” (Ambrose & Tripeny, 2011, p. 27).

- **Slab System:** There are different types of slabs: uniform slab, slab with column-capital and drop-panel, ribbed slab, waffle slab, and cantilever slabs (Engel, 2013; Hurol, 2016). Uniform slabs can be either supported by beams at their ends in both directions or carried by columns reinforced with capitals and/or drop panels. If the ratio of the longer span over the shorter span is equal to or greater than 2, one-way slabs are preferred in which beams are placed only on the longer span. In the design of the slabs, if the thickness needs to be higher than 20 cm and the dimension of the shorter span is higher than 7 meters, ribbed or waffle slabs are used to reduce dead-load (Hurol, 2016).

4.2.2. Surface-Active Structures

Surface-active systems are rigid surfaces that resist axial tension, axial compression, and shear. Their efficiency is determined by the form of the surface that the forces applied (Silver et al., 2014). The surfaces are formed to redirect forces, and they can perform best when the direction of acting forces is parallel to the surface, since they are weak in resisting point-loads that cause local bending stresses. Besides the importance of form, the continuity of surfaces is a prerequisite. When the proper form is achieved, the system can redirect and distribute the applied loads into small units equally through the surface. Since the surfaces are ‘geometric means of defining space’, the design of the structure determines the character of architectural space. The characteristics of the surface-active systems as the efficiency of the form, in addition to the ability to define the space, can provide material efficiency. Any deviation from the correct form causes wasting materials and creates economic problems. Besides, “all structure systems can be interpreted with surface-active elements and thus may become superstructures for surface-active structure systems” (Engel, 2013, p. 212). The surface-active structure types are load-bearing walls (or plates), folded-plate, and shell systems (see Fig 4.3).



*Classifications and illustrations are adopted from Engel (2013).

Figure 4.3: Section-active systems and some subsystems (derived from Engel, 2013)

- **Load-bearing Wall:** Load-bearing walls function like very-vide columns, and they either resist compression or behave like a shear wall. They act as surface-active structures, and generally are combined with section-active structures to resist lateral forces like wind, earthquake, or soil pressure (Hurol, 2016; Ambrose & Tripeny, 2011).

- **Folded Plate:** Folded plates with numerous folding types provide a wide range of form possibilities. Each slice of the folded plates acts as a beam, and they mainly resist bending stress. They can span up to 150 meters when appropriate depth is achieved through folding (Engel, 2013). To ensure safety, the span-over-depth ratio is considered 200, and edges can be reinforced with beams (Hurol, 2016).

- **Shell:** Shells are mainly constructed from reinforced concrete in which reinforcement bars are designed like a mesh all over the structure. They are categorized generally based on their curvature type (positively curved-work in compression, negatively curved-work in tension or their combination), thickness (thick or thin), and form. Thin shells are considered efficient since they can span up to 250 meters with a few centimeters thickness. Corrugating or folding the surface, and incorporating ribs can increase the strength of the system. Corrugating and

folding can be used to improve the strength of the structure. Adding ribs can also increase strength. - Economical for long-span shells (Hurol, 2016).

4.2.3. Form-Active Structures

Form-active systems are flexible, non-rigid structures that rest on the form of the system and achieve their best state under loading via the transmission of forces through their natural path. When designed perfectly, they work either in pure tension or compression, which makes them the most efficient and economical systems to span longer distances (Hurol, 2016). Any point load applied to the surface causes bending stress and deformations, which considerably decreases the structural efficiency (Silver et al., 2014). Suspended cable is the ancestor of form-active structures that works in tension and transfers the load to the hanging points. The upside-down version of the suspended cable is the form of a funicular arch, which works in compression. Since the natural laws govern their form, their architectural space characteristics highly depend on the bearing mechanism of the structure (Engel, 201). Cabled systems, membrane-tent structures, pneumatic systems, and arch are the systems of form-active structures (see Fig. 4.4).

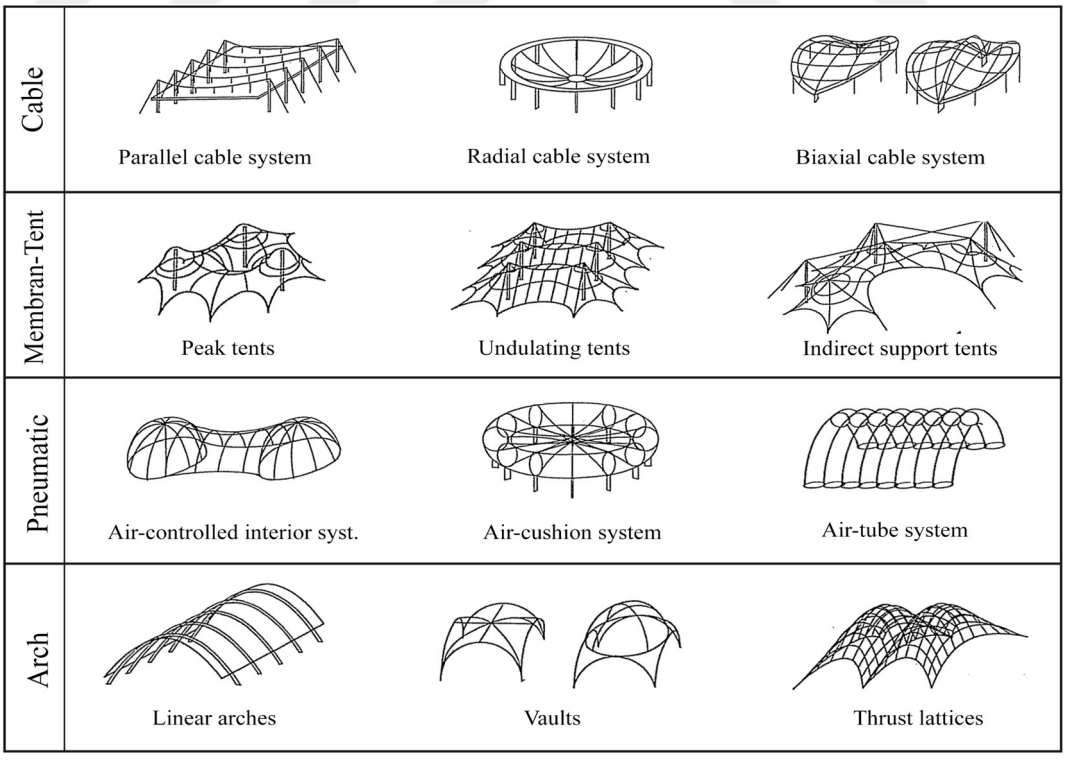


Figure 4.4: Form-active systems and some subsystems (derived from Engel, 2013)

- **Cable System:** Cables and suspension structures are considered the most lightweight and economical systems that only work in tension and span between 50 to 200m. There can be various forms like simply hung, crisscrossing networks, radiating, biaxial, or trussed, and combined with other structural members like beams, columns, arches, or truss systems. They are used in different functions requiring large column-free spaces like bridges, stadiums, and concert halls (Hurol, 2016). However, the critical issue in suspended structures is the lack of stiffness, causing reformation/deformation under changing loads, especially against wind loads. This issue can be solved by using pre-tensioned cables, cable nets, or tensegrity shells (Ambrose & Tripeny, 2011).

- **Membrane - Tent:** The membrane is a tensile structure that can span 80 meters, acting as both structure and cladding. Membrane structures are similar to cable structures in working principles, especially when designed to cover large spans. The primary membrane system is the tent, consisting of three structural elements: fabric in tension, struts in compression, and side-supports in either tension or compression. In large-scale membrane structures, cables and pre-tensioned cables are used to divide the membrane into smaller components to reinforce the system against stability problems caused by wind (Hurol, 2016). As they are both lightweight and economical while creating a wide column-free area by working as both structure and covering, it provides sustainable solutions, especially for temporary functions.

- **Pneumatics:** Pneumatic structures can be considered air-inflated membrane structures whose form is dependent on hydrostatic forces applied to their surface (Silver et al., 2014). There are two types of pneumatic systems: single-layer (continuously pumped air) or double-layer (two layers filled with air in between). There are various applications of pneumatic systems, such as being used as a roof, air-filled pneumatic dome, or series of linear pneumatic units. In order to span longer distances up to 200 meters and prevent instability issues caused by wind, steel or aluminum secondary structures are utilized. Besides, their structural characteristics highly resemble the membrane structures and share similar sustainable features (Hurol, 2016).

- **Arch:** Arch is the main component of the vaults and domes, which were intrinsically designed to span longer distances with the help of internal compression. The best

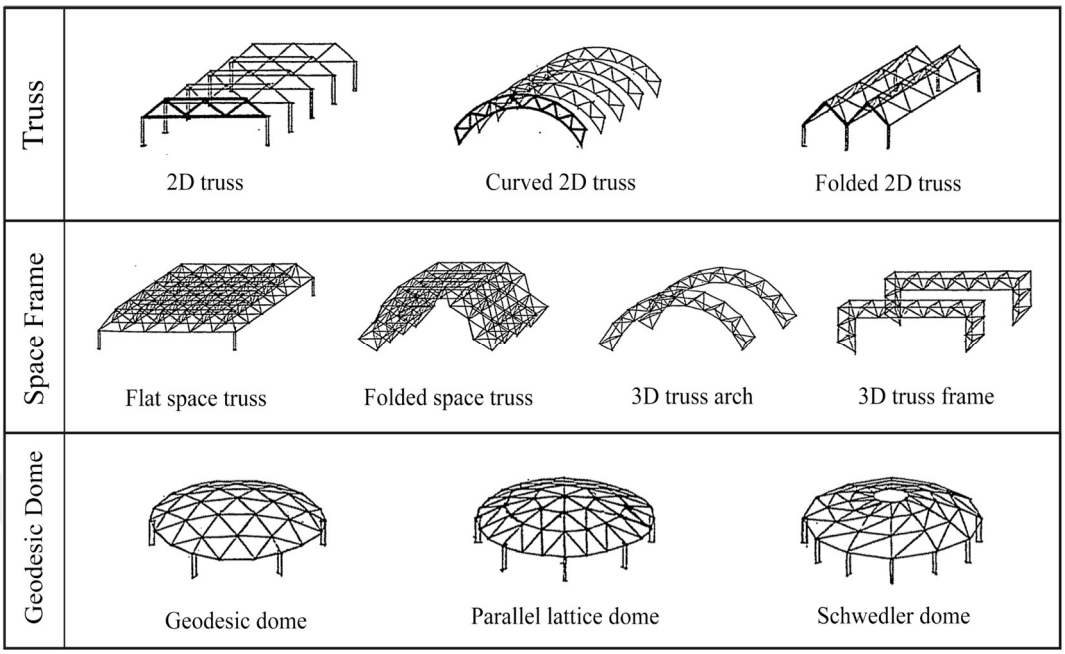
form of the funicular arch is a parabola which is the form of the moment diagram under the applied loading (Hurol, 2016). Historically, they were constructed with masonry materials. The high unit-weight of the masonries allows building arches to have a more circular profile with a low span-to-rise ratio. In contemporary times, thinner and lighter arches that span up to 100 meters with a high span-to-rise ratio can be built with steel, laminated wood, or reinforced concrete. The form of the pure arch can nearly be achieved, which provides economical solutions for longer spans. As the span-over-rise ratio increases, greater horizontal forces at the supports are produced, which should be resolved by additional structural elements (Ambrose & Tripeny, 2011).

4.2.4. Vector-Active Structures

Vector-active structures are multi-component systems consisting of linear, short, solid, compressive, and tensile members assembled in a triangular form to redirect forces by splitting them into single forces in different dimensions. The geometrical relationship between members rules the redirection of forces, while the suitable angle between members is from 45 to 60. Vector-active structures work as "systems in coactive compression and tension," which means that "the system members are subjected with one part to compression with the other part to tension" without any bending (Engel, 2013, p. 135). To avoid bending, trusses should be loaded at the nodes where the members connect (Silver et al., 2014). The members work in either tension or compression, which may change based on the loading conditions. Their efficiency is highly dependent on working only on axial tension and compression rather than in bending or shear, which allows them to span longer distances without requiring any intermediate vertical structure members (Silver et al., 2014; Hurol, 2016). Flat trusses (2D Truss), space frames (3D trusses), and geodesic domes are the types of vector-active structures (see Figure 4.5).

- **Flat (2D) Truss:** Trusses are the essential components of vector-active structures. They are beams configured with a triangular arrangement of small bars. "The self-stabilizing nature of the triangle" makes trusses an efficient system since triangles "cannot be changed in form without changing the length of a side" (Ambrose & Tripeny, 2011, p. 28). There is a wide possibility for the configurations of members, while famous efficient forms of trusses exist, such as K, W, Belgian, Pratt, or

Warren trusses. Timber 2D trusses can span 5-50m, while steel trusses can span up to 80m (Hurol, 2016).



*Classifications and illustrations are adopted from Engel (2013).

Figure 4.5: Form-active systems and some subsystems (derived from Engel, 2013)

- **3D Truss/Space Frame:** Spaces frames are three-dimensional (3D) truss systems with greater span capacity, which can reach up to 200 meters. Since they span in both x and y dimensions and cover all the space, there is no need for vertical supports inside the space. Being lightweight, prefabricated, and easily assembled on-site, they are one of the most economical and frequently used systems (Hurol, 2016).

- **Geodesic Dome:** This structural system is developed by Buckminster Fuller to transform hemispherical surfaces into triangulated hemispheres to design efficient, lightweight, and robust systems in circular/elliptical form and plan. They can span up to 200 meters and be constructed from various materials: plywood, plastic, cardboard, bamboo, and aluminum, in addition to timber, steel, and concrete (Ambrose & Tripeny, 2011). Overall, the final geometry should be organized to allow equal distribution of the loads through the system (Hurol, 2016).

4.3. Building materials (structural and non-structural)

The form and general arrangement of architectural structures are greatly influenced by the properties of the materials like strength, elasticity, unit-weight, as well as the

strength to weight and strength to elasticity ratios that determine the load-carrying capacity, form, and efficiency of the structural members and overall system. Within the widely used structural materials (steel, reinforced concrete, timber, and masonry), “each of the four has a unique combination of properties which makes it perform best in particular types of structural arrangement” (Macdonald, 1997, p. 13). Besides, the manufacturing and processing of materials cover a considerable part of the resource and energy consumption of the building industry (Hegger et al., 2012). Therefore, their specific properties play a crucial role in the environmental damage caused by the building industry, which makes utilizing sustainable materials with low environmental impact critical for the sustainable post-expo use of pavilions. For this reason, observing the building materials and the structural systems in which the materials are configured is crucial for determining sustainable properties.

In the composition of the table, the materials are divided into two parts: structural and non-structural. In addition to the most common structural materials (steel, timber, and concrete), fabric and structural glass are listed as structural materials, while steel, aluminum, timber, glass, plastic, concrete, and fabric are listed as widely used non-structural materials. Besides, there is a section as ‘other materials’ to note the high-tech, newly-developed and innovative materials. Each material has different chemical properties, structural characteristics, manufacturing processes, and sustainable features, which affect the post-expo use process of pavilions when they are configured with the structural systems.

- **Steel:** Steel is produced by alloying iron with less than 2 percent carbon which requires a lot of energy while releasing a significant amount of greenhouse gasses. It has the highest strength among the structural materials and is capable of resisting axial tension and compression as well as bending almost equally. Although it has a disadvantage due to its high unit weight, especially for the transportation and workload on the site, its strength/weight ratio reduces the number of materials needed and increases the efficiency of the system (Macdonald, 2001). Besides, its main drawback is being heat-conductive which causes it to work as a thermal bridge in buildings. As sustainable properties, it is durable, allowing for assembly with prefabricated components and not giving off volatile organic compounds (VOCs), which are organic chemicals that vaporize at room temperature. It is also “a material

once produced from raw materials being continually reused" with a significant recycling percentage (93%) while only 1% goes to the landfill, which lowers the required energy and carbon footprint of the manufacturing process significantly (Bovill, 2014, p. 197; La Tegola et al., 2019; Sandaker et al., 2019).

- **Concrete / Reinforced Concrete:** Concrete is manufactured from gravel, portland cement, and sand while mostly reinforced by steel bars to be able to resist tensile, compressive, and bending stresses. Mining sand and gravel and producing cement cause environmental problems, which increase when steel reinforcements come to the stage (Sandaker et al., 2019). It is a durable material and does not outgas VOCs (Bovill, 2014). It can be recycled only about 20%, and 75% of it is down-cycled. However, "there is no way to dismantle and reuse a concrete frame or a part of it; for this reason, this type of material is rarely used in the construction of temporary buildings" (La Tegola et al., 2019, p. 7). It can be used with 'precast' (beam, column, wall panel, slab, unreinforced concrete masonry block) or 'cast in place' types. While precast concrete components provide energy efficiency in terms of workload on the construction site and minimize waste, cast-in-place concrete allows inserting other materials into it to alter its properties and provide effective connections (Macdonald, 2001). Besides, moldable concrete allows continuity to create monolithic structures with complex forms, which provide high efficiency in form-active shells (Macdonald, 2001).

- **Timber:** Timber is a sustainably renewable material. It is suitable for elements that carry axial compression, axial tension, and bending-type loads. It has two types: 'sawn timber' with little processing except shaping, or 'manufactured products' like laminated timber and plywood. (Macdonald, 2001). It has a greater advantage compared to concrete and steel in terms of requiring very low energy for processing. However, "the use of glue to produce glue-laminated wood, plywood, and solid wood panels will, however, affect this very favorable energy and carbon footprint balance to a smaller or larger degree, as will the extensive use of steel detailing that often accompanies larger wood structures" (Sandaker et al., 2019, p. 145). Despite being a natural material, covering it with stains, sealers, and or paint for water resistance leads to the outgassing of VOCs. Besides, despite the fact that approximately %10 of the wood can be recycled and 60 % of it is moved to the

landfills, wood has other end-of-life options such as being used for firing, interior design, or roof insulation (La Tegola et al., 2019; Tam, 2011).

- **Glass:** Glass is usually used to provide daylighting since it is a brittle material with low tensile strength and less capacity to carry the loads. “Over the past few decades, however, the structural properties of glass have increasingly been explored and developed, and today it is a material that has its place among the viable palette of options for designing certain structural elements” (Sandaker et al., 2019, p. 147). It is made from sand (silica) with an intensive energy-consuming manufacturing process. However, it has advantages such as no outgassing and being easily recycled and turned into glass again (Bovill, 2014).

- **Fiber & Fabric:** Mineral and synthetic fibers are two widely used materials in tensile membrane fabrics and polymer composites due to their tensile strength in prestressed structures. The polyester-fibers, glass fibers, and carbon fibers are the most common material types. The glass fibers are more enduring against small cracks than sheet glasses, and carbon fibers have superior strength and stiffness to rigid composites. PVC and PTFE coatings are applied to increase the durability of the fabrics against moisture, UV radiation, dirtiness, and microbe attack. PTFE-coated glass-fiber fabrics are non-combustible, dirty-resistant, and more durable, making them a good fit for permanent membrane structures. They also are highly translucent. Besides, foils are also common materials for tensile membranes with equal strength and stiffness in all directions differing from other materials. Polymer ETFE foils have high recyclability, translucency, and permeability levels. However, due to their lower tensile strength, they are appropriate for smaller spans (Sandaker et al., 2019).

- **Aluminum:** Although the electrolytic process for extraction of aluminum requires a large amount of energy, aluminum can be recycled as aluminum with lower energy and budget since it has a lower melting point than steel which reduces the required energy. It comes after steel, among the widely used construction materials. However, it is a lightweight and malleable material with higher thermal expansion and corrosion resistance, and lower fire resistance which makes aluminum a suitable material for cladding rather than structure. Pure aluminum is generally not preferred as a structural material, since it is very soft. Thus, it is alloyed with copper,

manganese, zinc, silicon, and magnesium to increase its strength or casting based on the area in which it is used (Sandaker et al., 2019).

- **Plastic:** Chemical pollutants are released in the manufacturing process of plastics. There are different types of plastics, including fibers (polyester), coatings (PVC, PTFE), glass panels (acrylic glass, PC), and foils (ETFE) which are divided into two groups: thermosetting plastics and thermoplastics. Thermosetting plastics (epoxy and polyester) cannot be reshaped by heating, while thermoplastics (PVC, PTFE, ETFE, acrylic glass, and PC) are recyclable and can be shaped many times by applying heat and pressure. Polycarbonate (PC) is durable and weather-resistant while also stronger than acrylic glass and glass, but less transparent. Acrylic glass (plexiglass) has the best optical qualities, low unit weight, and high-tension strength compared to glass. Also, it can "experience both elastic and plastic deformation when subjected to stresses," which means it is not brittle (Sandaker et al., 2019, p. 153). Its only drawback is having a much lower elastic modulus which requires a thicker structural section.

The review of material characteristics demonstrates that every material has its own pros and cons in terms of sustainability with their different properties such as unit-weight, embodied energy, recyclability rate, strength, transportation requirements, carbon emission in the manufacturing and assembly processes, etc. While steel has disadvantages with its highest unit-weight value, embodied energy, and carbon emission in the manufacturing process, it also has significant strength requiring less material for the system to be robust, and it is 100% recycable, which are crucial properties to be considered as a sustainable material. Although the timber is less strong than steel and reinforced-concrete, requiring larger cross-sections within the system and more material, it requires low energy for manufacturing and can be sustainably harvested. Besides, all the sustainable properties of materials also depend on the structural system they are configured and how the overall system is designed. Therefore, in the analysis of post-expo use performances, the sustainable properties are determined by considering the configurations of structural systems and materials rather than keeping them apart.

4.4. Sustainable properties of the structural system and material configurations

As mentioned in Section 2.3.2, there is still no standard sustainability measurement tool in the literature for assessing the sustainability performance of a specific project. Besides, every project has its own needs and requirements based on its circumstances, requiring a few variations in the measurement tools and set of sustainability principles. Since World Expo pavilions are differentiated from other cultural or commercial buildings with their mega-scale, urban redevelopment context, and ephemeral nature, they might need a compilation of sustainability principles from different fields. Therefore, for every World Expo, a set of principles for guiding the participants in the design and construction of national pavilions are prepared to meet the specific theme and goals of Expos. Since this study focuses on the selection of structural systems and building materials and their configurations, a set of properties has been determined in order to analyze the post-expo use, which is an essential aspect of sustainable design. To determine the required properties of structural systems and building materials for a more sustainable post-expo use, the guiding principles of World Expos mentioned in Section 3.2, literature on sustainable materials and construction techniques, and the latest versions of the two most widespread sustainability rating systems (Roderick et al., 2009): LEED BD+C New Construction - v4.1 (USGBC, n.d.) and BREEAM International New Construction 2016 (BRE Global Ltd., 2016) mentioned in Section 2.3.2 are reviewed.

The categories of The LEED BD+C New Construction - v4.1: integrative process, innovation, materials and resources, sustainable sites, and plot credits have some credits that could be related to the post-expo use of pavilions. These credits are:

- "high-performance, cost-effective, equitable project outcomes through an early analysis of the interrelationships among systems",
- having innovative characteristics for the benefit of human and environment,
- appropriately storing the recyclables
- reducing the material amount that will be sent to the landfills via reduction, reuse, and recycling,
- promoting adaptive reuse,
- using of materials with environmentally, economically, and socially preferable life-cycle impacts,

- resourcing materials with eco-friendly procedures,
- using products without non-toxic ingredients,
- conducting construction/demolition waste management to minimize waste and protect resources,
- using circular products (zero waste, recyclable for several times, and/or can be turned into new materials),
- using low-carbon materials to minimize carbon emission (USGBC, n.d.).

Some of the categories and credits of BREEAM International New Construction 2016 could also be related to the scope of this study: energy (low carbon design, reducing energy use, and reducing carbon emissions), waste (construction waste management, recycled aggregates, operational waste, functional adaptability), land use and ecology (minimizing the impact on existing site ecology), materials (life cycle impacts, responsible sourcing of materials, material efficiency), and innovation. These credits have similar characteristics to the LEED rating system. Functional adaptability and material efficiency credits are differentiated from the LEED by emphasizing the importance of adaptability and efficiency of systems more explicitly, which are crucial properties for an efficient post-expo use focused in this study. Functional adaptability under the waste category refers to the "consideration and implementation of measures to accommodate future changes to the use of the building and its systems over its lifespan" (BRE Global Ltd., 2016, p. 290). Material efficiency under the materials category refers to identifying measures for optimizing the use of materials that could be ensured by the design of the structural system (BRE Global Ltd., 2016).

Considering these reviews, fifteen sustainable features of the structural system and material configurations for the post-expo sustainability are determined under four dimensions of sustainability which are functional, environmental, social, and economical. As stated in Section 2.2, sustainability is mainly examined in three dimensions, while other dimensions might also be added in some approaches. Referring to the functional properties of the structural system and material configurations of pavilions, such as their innovational properties, adaptability, and optimization, 'functional sustainability' is included in this study as a fourth dimension of sustainability.

4.3.1. Functional sustainability properties

Since the technical and functional properties of structural systems and building materials affect the post-expo use of pavilions, sustainability properties are classified into four groups to evaluate and analyze the pavilions with their specific characteristics on:

- significant/innovative structural system,
- significant/innovative building materials,
- optimized/efficient design, and
- flexibility/adaptability for future use.

These properties mainly concern the design of the pavilions and initial planning with the considerations of leading innovations in Expos and creating outstanding designs while considering the post-expo use of the pavilions.

- **Significant/innovative structural system & material:** Innovating new systems, design solutions, and materials in architectural design and construction has a place in most sustainability rating systems like LEED and BREEAM. Rather than a choice, it should be considered a necessary component since it can be a solution to the negative impacts of the building industry (Czarnecki & Gemert, 2017). Besides the innovation, significant, creative, and newly-developed solutions can contribute to adapting conventional construction processes into nature's zero waste management system and create an ideal artificial environment (Caradonna, 2014). Since World Expos are the stages for displaying innovative technologies, it is considered that significant sustainable solutions should be reflected in the design of the pavilions to promote a more efficient and less energy-consuming post-expo use.

- **Optimized / efficient design:** The efficient use of materials and minimization of the wastage can be provided by the good quality design and proper planning of construction methods. Since “the largest part of the embodied energy is usually that in the load-bearing structure,” designing efficient structural systems that require less material to be robust is crucial, as much as “the design of simple, functional details complying with building physics requirements results in lower operating costs” (Hegger et al., 2012, p. 162-171). It is considered that the most effective and economical way to design long-span structures is to form the structure only in

tension and/or compression (i.e., form-active and vector-active structures) (Hurol, 2016). Reducing the building components and overlapping material layers also contributes to minimizing the required energy for the construction, maintenance, deconstruction, and reassembly (Hegger et al., 2012).

- **Enabling future adaptability:** The adaptability of buildings reflects the buildings capability to respond to the changing circumstances and different demands of users throughout their lifetime (Kamara et al., 2020). Flexibility and/or adaptability are crucial properties for both temporary and permanent pavilions of World Expos, which could be achieved through the proper consideration of spatial, technical, structural, and constructional components in the initial stages of the design (Ministry of Ecological Transition, 2015). Soft skills like providing column-free interior space, varied layout opportunities, and movable or adjustable components are fundamental for pavilions to respond to changes that occurred in the post-expo period (Hegger et al., 2012). These skills require "early considerations for how spaces and different systems and components are designed, manufactured, and built to enable modifications to be made when required" (Kamara et al., 2020, p. 2).

4.3.2. Environmental sustainability properties

Environmental sustainability, as mentioned in Section 2.2, is explained as "a planning process that allows human society to live within the limitations of the biophysical environment" by Goodland (1995) (Basiago, 1998, p. 156). In the architecture and construction domain, environmental sustainability refers to the design and construction of buildings with the concern of reducing in both excessive energy consumption and environmental damage through numerous strategies mentioned in Section 2.3. These strategies are developed mainly for buildings with a 30-50 year lifetime with a predetermined function. However, since World Expo pavilions are designed temporarily to be either dismantled or refunctioned after the Expos, the focus of environmental sustainability principles for their post-expo use is differentiated with some inclusions and/or exclusions. Therefore, the environmental sustainability strategies regarding configuration of structural systems and building materials might be listed as:

- using smart materials and/or systems,
- using eco-friendly materials,

- using reclaimed/recycled materials,
- having higher recyclability/reusability rates, and
- reducing given harm to the site.

These properties mainly focus on easing the dismantling and recycling processes and reducing energy consumption rather than the long-term energy consumption of building operation systems.

- **Smart materials & systems:** Smart building-integrated technologies are engineered materials and components that can respond to the surrounding environmental changes to provide various ecological benefits in both permanent and temporary pavilions in their post-expo uses (Caradonna, 2014; Mohamed, 2017). They can significantly increase the efficiency and functionality of building materials and systems with varied characteristics, including being capable of observing, imitating, or responding to natural processes. Their properties may vary: enhanced strength, durability, and resistance to external factors, "life-cycle cost efficiencies", "ease of manufacture and application or installation", "improved response to extreme events such as natural disasters and fire", "environmental compatibility", and "ability for self-diagnosis, self-healing, and structural control" (Mohamed, 2017, p. 142).

- **Eco-friendly materials:** Utilizing materials that are durable, non-toxic, sustainably harvested, rapidly renewable, biodegradable, made of certified sustainable and renewable resources, locally manufactured, requiring minimum energy for manufacturing, and minimally processed (raw) is crucial to minimize the resource consumption and environmental damage (Bovill, 2014).

- **Reclaimed/recycled materials:** The energy and sources required for material production and the carbon emissions can be decreased by about 25% with the use of reclaimed or recycled contents (Cabeza et al., 2013). Aluminum and steel are high embodied energy materials that consume extreme energy in the production process. Yet, since they can be recycled as themselves, they could be produced with low expenses using salvaged content which provides advantages in the post-expo use processes (Sandaker et al., 2019).

- **Highly recyclable/reusable building components:** The chemical and physical properties of materials, as well as their way of assembly in the building, affect the recyclability and reusability of materials. “The appropriate use of building technologies and their successful integration into the design process eases a greater reuse of building components” (Ministry of Ecological Transition, 2015, p. 13). With a proper design, building components are not harmed and can be turned into new building materials without any degradation/decomposition processes, which reduces the energy consumed for reprocessing or regenerating the materials (Ministry of Ecological Transition, 2015). Besides, in the recycling process, a certain proportion of a material cannot be reused again and turned into waste or went into the downcycling process with a low quality, which is called downcycling which is directly related to the chemical properties of the material (Hegger et al., 2012, p. 35).

- **Reducing given harm to the site:** In order to reduce harmful traces left behind the pavilions after they are removed, the foundation works also have importance. Since the type of the foundation is determined based on the design of the structural system and selected materials, all three components of the building play a collaborative role in reducing the waste behind and consumed energy for the disassembly (Zavadskas et al., 2018).

4.3.3. Socio-cultural sustainability properties

Since World Expo pavilions are culturally specific exhibition buildings built by a nation as a representative image, socio-cultural sustainability is a critical issue for their post-expo uses. As Memmott and Keys (2015) also emphasized, the places with “highly symbolic and culturally specific, containing cosmological, spiritual and deep historical references that are identity markers for groups, societies, and nations” has potential to be highly visited and contribute to the development of cultural tourism while also culturally protected and/or developed by the society (p. 284). Socio-cultural sustainability refers mainly to the combination of physical and functional characteristics of the buildings. However, since the temporary pavilions' function has changed throughout their lifetime, their socio-cultural sustainability mainly depends on their physical and aesthetical properties. Therefore, in order to evaluate the socio-

cultural sustainability of the pavilions, the properties of the structural system and building materials are examined from two aspects as follows:

– traditional style of the Nation, and

– traditional materials of the Nation

- **Traditional style of the Nation:** Since architects and designers "from all cultures encode meanings into buildings and environmental configurations" in which "meanings take on widespread social currency and are regularly decoded by users" (Memmott and Keys, 2015, p. 284), the pavilions with culturally specific physical or aesthetic design characteristics might have a higher chance to take attention of the public during the Expo, and this could contribute to pavilions' further use by either preserving it or refunctioning it, even if it is not planned.

- **Traditional materials of the Nation:** The use of traditional materials can promote the pavilions' traditional and/or socio-cultural characteristics and contribute to post-expo use of the pavilions or their components with their specific material characteristics.

4.3.4. Economic sustainability properties

Economic sustainability principles in the architectural domain mainly refer to reducing costs by preventing excessive energy, resource, and time consumption because "worldwide, buildings consume about 50% of all resources in their construction and operation" (Hegger et al., 2012, p. 65). The measures include: lowering costs on the building site and in the building, minimizing the use of materials, lowering taxes and follow-up costs, and providing long-term cost security (Hegger et al., 2012). Some of the measures that ensure economic sustainability might also be related to the environmental principles since the efficient use of energy and resources is also considered among ecological strategies. Since most pavilions have been built temporarily, they have both construction and disassemble costs in a short period of time, which makes the consumed energy, time, and budget during construction, deconstruction, and transportation processes more critical than the operation phase of the building. Thus,

– using light-weight systems and materials,

- designing with standardized dimensions/modules,
- constructing with prefabricated units,
- having reversible connections for easier disassembly

are determined as economic sustainability properties for the configuration of structural systems and building materials regarding the post-expo use of pavilions.

- **Light-weight materials & systems:** Heavy-weight materials and structures require about 20% more energy in their production, manufacturing, and construction processes than lightweight structures, which creates a considerable burden on the environment. Also, heavy-weight forms of construction increase work-loads, consuming energy, natural and artificial resources, and time (Hegger et al., 2012). It should also be noted that the high weight of materials made transportation very expensive which is doubled when it is considered both in the pre-and post-event transportation processes (La Tegola et al., 2019). Since most of the weight percentage of the buildings comes from their structure, the unit-weight of structural materials is crucial, which could be listed: steel (7859 kg/m3), reinforced concrete (2500 kg/m3) and timber (650 kg/m3) (Sahu, 2021). Although steel has the highest density, it has more strength/weight ratio than reinforced concrete. Concrete structures are bulkier and require more material, increasing weight exponentially. On the other hand, wood has both low specific weight and "ensures a good performance with a small amount of volume" (La Tegola et al. 2019, p. 6).

- **Standardized dimensions/modularization:** Using building components with standardized dimensions and/or designing with modularity principles "allows for parallelization of tasks in construction projects, as groundwork and module construction can be executed at the same time", "potential cost savings due to specialization in tasks, application of manufacturing approaches in production and increased ability for learning", "reducing common sources of construction waste", reducing internal and external uncertainties which all contribute to saving resources, time and budget (Økland & Olsson, 2016, p. 5). All these advantages of modularization are crucial for the disassembly and reassembly processes.

- **Prefabricated units:** The degree of prefabrication increases the efficient use of resources in construction. "The production of building components in a factory

enables tighter tolerances and more slender dimensions, resulting in a better quality building with fewer deficiencies. The more careful planning and the better quality control lead to far fewer production errors and rejects" (Hegger et al., 2012, p. 168). It consequently minimizes the number of used materials, work-load on the construction site, resource waste, and costs both in the workplace and in the building (Tam, 2011).

- **Reversible connections:** Reversibility refers "to the capacity of building a system that can be unbuilt, retains several advantages compared to conventional demolition" (Ministry of Ecological Transition, 2015, p. 12). It is one of the most crucial characteristics of the pavilions for sustainable post-expo use. Keeping building layers separate and/or using connections as simple as possible allows for easy disassembly without harming materials, which facilitates the easy recycling and reusing process while preserving material embodied energy. Despite the fact that "dismantling a building typically requires more manpower and technical equipment than traditional demolition", the higher costs caused by the dismantling process "can be compensated by the lower expenditure on recycling and disposal of materials, provided the dismantling is well planned" (Ministry of Ecological Transition, 2015, p. 13).

CHAPTER 5

CASE STUDIES

This chapter, first, explains which World Expos and their pavilions are selected and what are the selection principles. Then, the information about the World Expos and the analysis of the selected group of pavilions from these Expos are presented. The pavilions are explained in four parts:

- general information about pavilions,
- construction features (structural systems and primary building materials),
- sustainable features of the configuration of these two characteristics with their role in post-expo use, and
- analysis tables.

5.1. Selection of World Expos and Pavilions

There have been five World Expos that centered on the theme of sustainability in history between 2000 and 2022, which are Hannover (2000), Aichi (2005), Shanghai (2010), Milan (2015), and Dubai (2020) World Expos (See Table 5.1). As mentioned in Section 1.3, four of the five World Expos with sustainability-related themes are decided to be examined since it is not feasible to analyze the post-expo use of the last World Expo pavilions, which ended on March 31, 2022 (Expo 2020 Dubai, n.d.). The selected four World Expos have been centered on sustainability with varied additional goals such as reflecting the role of technology in the relationship between humans and nature (Hannover World Expo - 2000), emphasizing the importance of nature for

human existence (Aichi World Expo - 2005), catalyzing urban redevelopment (Shanghai World Expo - 2010), and calling attention to global food and energy crises (Milan World Expo - 2015). Besides the differentiation in themes and goals, the strategies and rules of the World Expos have also been changing. Since every Expo has different attitudes, the selected four World Expos create a sample group with varied post-expo usages of national pavilions (abandoned, demolished, recycled, relocated, or reused).

Hannover World Expo 2000 is considered the first World Expo that focuses on sustainable development with its theme 'Man - Nature - Technology'. Both temporary and permanent national pavilions were built, while many were abandoned after the Expo. Aichi World Expo 2005 took lessons from the former Expo, and all national pavilions are built temporarily by standardized prefabricated units with the "Reduce, Reuse, and Recycle" principles. The Shanghai 2010 and Milan 2015 World Expos follow the Aichi Expo by designing temporary national pavilions. Only a few pavilions are kept on the site with defined post-expo uses (Schrenk & Jensen, 2014).

Table 5.1: World Expos with sustainability-related themes

World Expo	**Date**	**Theme**
Hannover World Expo 2000 Germany	1 June 2000 31 October 2000	"Humankind, Nature, Technology"
Aichi World Expo 2005 Japan	25 March 2005 25 September 2005	"Nature's Wisdom"
Shanghai World Expo 2010 China	1 May 2010 31 October 2010	"Better City, Better Life"
Milan World Expo 2015 Italy	1 May 2015 31 October 2015	"Feeding the Planet, Energy for Life"
Dubai World Expo 2020* UAE	1 October 2021 31 March 2022	"Connecting Minds, Creating the Future"
*Dubai World Expo 2020 was held at the end of the 2021 due to global pandemic; therefore, it is not included in this study.		

There have been varied types of pavilions in World Expos, including thematic pavilions, self-built national pavilions, joint national pavilions, NGO pavilions, and corporate pavilions. Among these different types, self-built national pavilions have the highest number in the World Expos, which create a crucial impact on the post-expo situation of Expo lands (Schrenk & Jensen, 2014). Therefore, this study has selected cases from the self-built national pavilions at World Expos. The selection of the pavilions for each Expo is based on two criteria: Either being the host-country pavilion

that reflects the theme of the Expo or being successful and/or awarded by the visitors and the Expo committee. The host-country pavilions of each Expo are selected because they are considered to be the symbols of the Expo themes. For the selection of the other pavilions, five pavilions that are considered attractive and/or successful from each World Expo are selected (See Table 5.2). In the determination of these well-perceived pavilions, the awards given related to the architectural design of pavilions by the BIE (Bureau International des Expositions) at the end of the Expos are taken as a reference for the Aichi (2005), Shanghai (2010), and Milan (2015) World Expos. The BIE-awards have a long history in Expos since the 1851 Great Exhibition. Yet, they had given at Brussels World Expo 1958 for the last time and were interrupted for nearly a half-century (Japan Association for the 2005 World Exposition, 2005). Then, they recommenced with the Aichi World Expo 2005 as an integral part of the Expos to give credit to the participant nations for their efforts and contributions with well-articulated pavilions. The awards are given in three levels: Gold, Silver, and Bronze, while evaluations have been conducted in different categories mainly based on the messages given, architectural design, and display content (BIE, 2015).

As the Expos have varied in terms of their themes, aims, and scales through history, the categories and criteria for the evaluation of pavilions have also evolved through time (BIE, 2015). At Aichi Expo 2005, the committee made two different evaluations: first, for the quality and functionality of the architecture, and second, for the theme development. Since the national pavilions are composed of standardized modules in Aichi Expo, each evaluation is made in four categories based on the number of modules that pavilions consist of, including category A (4 modules or more), category B (1.5 to 3 modules), category C (1 module or less), and category D (joint pavilions) (Japan Association for the 2005 World Exposition, 2005). At Shanghai Expo 2010, three types of awards were given (Theme Development, Creative Display, and Pavilion Design) in four categories based on the sizes of pavilions (category A: more than 4000 sqm, B: between 2000-4000 sqm, and C: less than 2000 sqm) (*Pavilion Design Prize disclosed in Shanghai World Expo*, 2010). Lastly, three types of awards were given at Milan Expo 2015 (Architecture & Landscape, Establishment, and Concept Development) in two categories: pavilions built under 2000 sqm. (A) and larger than 2000 sqm. (B) (Juc, 2015).

Table 5.2: Selected case studies and their characteristics

World Expo	Pavilion	Category
Hannover World Expo 2000	Germany	Host-country pavilion
	Poland	Most-visited
	Hungary	Most-visited
	Netherlands	Most-visited
	Japan*	Distinctive sustainable characteristics*
	Switzerland*	Distinctive sustainable characteristics*
Aichi World Expo 2005	Japan	Host-country pavilion
	Republic of Korea	Architectural Quality - Category A (1st Award)
	Turkey	Architectural Quality - Category B (1st Award)
	Philippines	Architectural Quality - Category C (1st Award)
	Spain	Architectural Quality - Category A (2nd Award)
	Mexico	Architectural Quality - Category B (2nd Award)
Shanghai World Expo 2010	China	Host-country pavilion
	United Kingdom	Pavilion Design - Category A (1st Award)
	Finland	Pavilion Design - Category B (1st Award)
	Portugal	Pavilion Design - Category C (1st Award)
	Republic of Korea	Pavilion Design - Category A (2nd Award)
	Norway	Pavilion Design - Category B (2nd Award)
Milan World Expo 2015	Italy	Host-country pavilion
	France	Architecture & Landscape - Category A (1st Award)
	United Kingdom	Architecture & Landscape - Category B (1st Award)
	Chile	Architecture & Landscape - Category A (2nd Award)
	Bahrain	Architecture & Landscape - Category B (2nd Award)
	China	Architecture & Landscape - Category A (3rd Award)
* The pavilions recognized by BIE with its sustainable architectural and construction characteristics in the Hannover World Expo (BIE, 2020).		

The pavilions are selected from the "Evaluation 1" (quality and functionality of the architecture) at Aichi Expo, the "Pavilion Design Award" at Shanghai Expo, and the "Architecture & Landscape Award" at Milan Expo. As a result, the top five pavilions are selected from each determined award category to be analyzed for this study (See Table 5.2). Besides, because no awards were given at Hannover World Expo 2000, five well-perceived pavilions are determined: three of the most visited pavilions with more than 2.5 million visitors (*Man, Nature, Technology,* n.d.), and two pavilions recognized by BIE with their innovative and distinctive sustainable characteristics (BIE, 2020).

5.2. Hannover World Expo Pavilions (2000)

Theme: Human, Nature, and Technology

Time Period: 01 June – 31 October 2000 (5 months)

Area: 160 ha.

Number of Participant Nations: 155

Total Visitors: 18.1 million

The Hannover World Expo 2000, hosted in Germany, had utilized the Deutsche Fair Grounds (100 ha.) in the old brownfield area to revitalize and modernize the existing Fair land for the future, which is located near the suburban settlement in the south-east part of the city (see Figure 5.1). The old fairground was integrated into a newly developed greenfield area on the eastern side (60 ha.). For the first time, the BIE agreed to reuse some existing structures in the Expo ground to avoid unnecessary construction works (Rizzi, 2010). The location of the land is appropriate to host an Expo since it has appropriate infrastructural functions thanks to the public urban train network linked to the city center and airport, which was further developed and upgraded thanks to the Expo. "The infrastructure, electricity and sewage system prepared for the expo later served new office space in the so-called EXPO PARK Hannover, making the area easy to be adapted as business industry area" (Chen et al., 2014, p. 4).

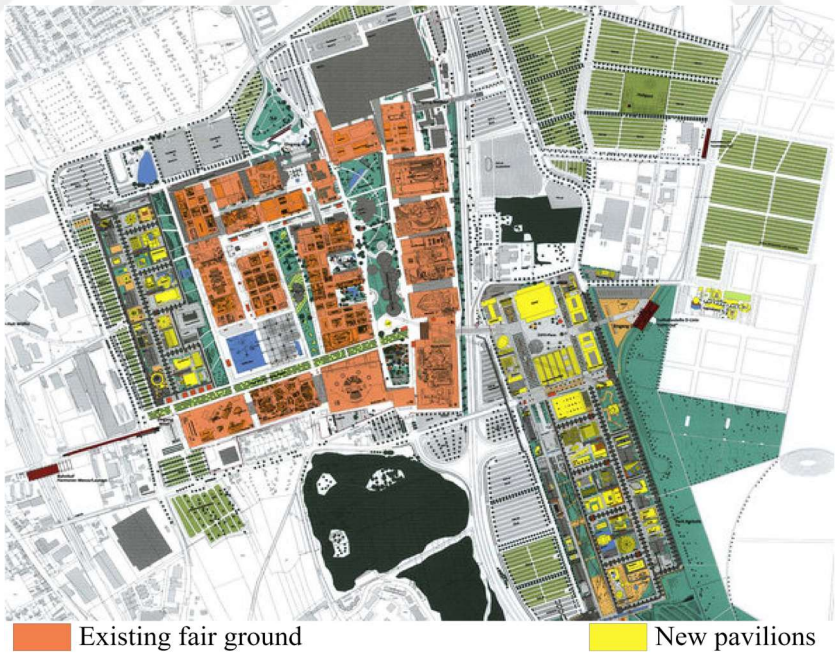


Figure 5.1: Hannover World Expo (2000) Site (https://www.as-p.com/projects/project/expo-2000-hannover-62/show/)

EXPO 2000 Hannover GmbH conducted the development of the Expo site. They "adopted the principles of Agenda 21 and made them a binding theme for all nations

partaking in the event" to provide sustainable solutions for the existing ecological problems and a detailed post-expo plan to avoid creating new problems (Schrenk & Jensen, 2014, p. 558). Despite the idea to turn the site into an Expo Park after the event with the clear post-expo use paths for each pavilion, it could not be achieved precisely. After the event, even though most of the pavilions were already sold to investors with pre-determined post-expo functions, among the 32 pavilions in the newly developed Eastern Pavilion area, "21 pavilions not in use, 11 were relocated elsewhere, 4 had been destroyed, and 6 are still being empty" (see Figure 5.2 for some of the cases) (Chen et al., 2014, p. 5). The north side of the site, on the other hand, has functioned more efficiently in which most of the area was sold and actually in use (Chen et al., 2014). There are 155 national pavilions, and the German pavilion was the host-country pavilion. The Netherlands, Hungary, and Poland pavilions were some of the most visited pavilions at the Expo, while Japan and Switzerland pavilions were the most recognized ones by the BIE and Expo Committee with their sustainable design features (see Section 4.1), which all are selected to be examined in this study.



Figure 5.2: Some abandoned pavilions after the Expo 2000

(a: https://earth.google.com/web/search/Hannover+expo+turkische+pavilion; b: https://divisare.com/projects/439465-mvrdv-piet-niemann-the-hanover-expo-2000-20-years-after-the-world-fair-took-place; c: https://www.archinform.net/projekte/9724.htm)

5.2.1. Germany Pavilion (2000)



Figure 5.3: Germany Pavilion (2000) (https://www.frener-reifer.com/references/german-pavilion-expo-2000/)

The Germany Pavilion (see Figure 5.3 and Table 5.3), designed by Josef Wund as the host country pavilion with a 6500 people capacity, was the most visited pavilion in the Expo 2000 with 5.400.000 visitors (Shen, 2012). The pavilion has importance to German authorities for creating an invitation for the Expo 2000 and drawing an impressive image. The exhibition reflects the innovative development process of the country under the theme of "Bridges to the Future" (*German pavilions over the years*, 2020). Three bridges in the interior are connected with stairs on different levels to provide different circulation options for visitors to explore the exhibition. To provide sustainable solutions, the pavilion is surrounded by small water channels utilized for cooling and ventilation, while the rainwater is also accumulated and re-used for sanitary (Vatansever, 2009). The pavilion is designed as a permanent structure. It has been used to house several IT companies' offices since the Expo ended (*Follow-up uses assured for many exhibition facilities,* 2000).

- **Construction Features: Structural System and Building Materials**

The structural design of the pavilion aims to respond to the theme of the Expo 2000, "The Human, Nature and Technology," with its construction technology and building materials like glass, steel, and timber (*The Building,* n.d.). The building was first designed as entirely transparent with its 7000 sqm inwardly curved, pre-tensioned filigree glass façade with no steel profiles. For the first time, the glass is planned to be used as the only structural material in the 14 columns that each could carry up to 300 tons (Çimen et al., 2000). However, the German authorities did not allow construction without steel reinforcement in the façade and the columns. As a result, steel profiles

Table 5.3: Germany Pavilion (2000)

EXPO	**EXPO 2000 HANNOVER - GERMANY**
NAME:	**GERMAN PAVILION (HOST)**
Architecture:	Wund Gruppe - Josef Wund
Engineering:	Arcadis Deutschland GmbH

DESIGN AIM		POST-EXPO SITUATION						THEME & FUNCTION
		PERMANENT			TEMPORARY			
PERMANENT	TEMPORARY	IN USE	NO USE	DEMOLISHED	RECYCLED / REUSED	RELOCATED	DISMANTLED	THEME: Bridges to the Future: Embracing the Future
■		■						POST-EXPO USE: Office Building used by different IT and media companies

(1) EXPO IMAGE



(2) POST-EXPO IMAGE

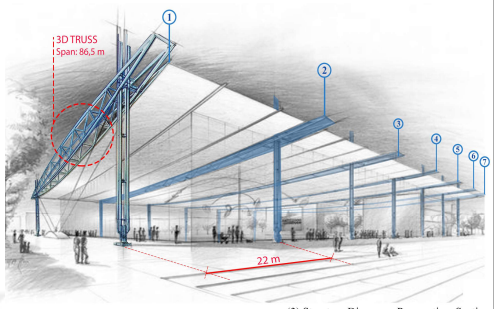


GENERAL INFORMATION & GRAPHICS

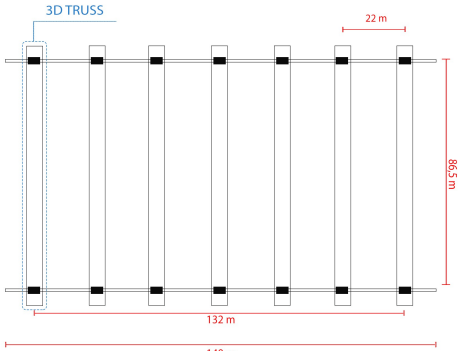
Built Area: 24.000 m² Floor: 2
Length: 140m - Width: 90m - Height: 15m Max.Span:86.5 m

STRUCTURAL SYSTEM AND MATERIALS

STRUCTURAL SYSTEM	SECTION ACTIVE	FRAME		
		BEAM SYSTEM		
		SLAB SYSTEM		
	SURFACE ACTIVE	LOAD-BEARING WALL		
		FOLDED-PLATE		
		SHELL		
	FORM ACTIVE	CABLED		
		MEMBRANE		
		PNEUMATICS		
		ARCH		
	VECTOR ACTIVE	2D TRUSS		
		3D TRUSS / SPACE FRAME		Steel Truss Beams
		GEODESIC DOME		
		OTHERS:		
STRUCTURAL MATERIALS		STEEL		Steel - glass composite column, steel truss beam, steel profiles in façade
		TIMBER		
		REINFORCED CONCRETE		
		STRUCTURAL GLASS		Steel - glass composite column Filigree, pre-tensioned, concave glass in façade
		FABRIC		
		OTHERS:		
NON-STRUCTURAL MATERIALS		STEEL		
		ALUMINIUM		
		TIMBER		6 roof pieces
		GLASS		
		PLASTIC		
		CONCRETE		
		FABRIC		
		OTHERS:		



(3) Structure Diagram - Perspective Section



(4) Structure Diagram - Top View

STRUCTURAL SYSTEM & BUILDING MATERIAL PROPERTIES

FUNC.	Significant structure		
	Significant material		High load-bearing capacity of glass which is configured as the structural material of the columns for the first time.
	Optimized design		
	Enabling adaptability		12.000 m² column-free area provides post-expo adaptability.
ENV.	Smart materials/systems		
	Eco-friendly materials		
	Reclaimed materials		
	High recyclability / reusability rate		
	Reducing impact on site		
SOC.	Traditional style		
	Traditional materials		
ECON.	Light-weight materials		
	Standardized modules		Standardized modules of roof pieces, columns and curtain wall systems.
	Prefabricated units		Most of the units are prefabricated.
	Reversible connections		Steel, glass and timber components have reversible connections.
ROLE IN SUSTAINABLE POST-EXPO USE PROCESS		+	12.000 m² column-free area provides flexibility in interior space and enables post-expo refunctioning.



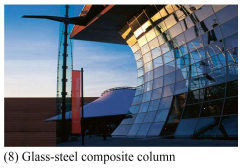
(5) Timber roof formed along 3D truss



(6) Aerial View - 6 pieces of roof



(7) Curtain wall detail view



(8) Glass-steel composite column

REFERENCES:
(1-7-8): https://www.frener-reifer.com/references/german-pavilion-expo-2000/; (3) www.gettyimages.com/detailnews-photoder-friedrichshafener-architekt-und-projekt-investor-josef-news-photo1213216010 - used for creating diagram; (6): https://www.expo2020germany.de/en/the-german-pavilion/german-pavilions-over-the-years/
(2-5): https://earth.google.com/web/search/hannover+expo/@ 52.3200765,9.8191113,84.62095642a,0d,60y, 302.31133435h,97.24657618t,0r/data=CigiJgokCcTtjTK OWT NAEcLtjTKOWTPAGaTkFLEIF0lAIaHkFLEIF0nAIhoKFnpKUzg1bFU1SzhzenJ4LW5jVmhYT0EQAg

are utilized in the façade, and the columns are re-designed as steel pipes surrounded by 25 mm glass profiles that strengthen the columns against wind forces (Çimen et al., 2000). In the final design, the six timber roof elements weigh 1.2 kilotons in total (*The Building,* n.d.), sit on seven truss beams that can span 87 meters long, and are carried by fourteen composite glass columns.

- **Sustainable Construction Features and Their Role in Post-Expo Use**

The building materials of the pavilion aim to reflect the theme "The Human, Nature, and Technology". While glass and steel symbolize human and technology, the timber resembles nature. Utilization of glass as a structural material reflects the development of the country in the field of construction technology (*The Building,* n.d.). Since the German Pavilion is a permanent structure, its post-expo use depends on varied external factors, in addition to structural systems and materials. The role of the structural design in the post-expo use can be considered as providing an 87 m x 140 m column-free interior. Since the steel truss beams span the entire building width, it allows for a 12.000 sqm clear space that can be manipulated based on the needs of the post-expo use. Also, the structure is made of only steel and glass materials with simple connections that could be dismantled and recycled up to a certain percentage if needed after the Expo.

5.2.2. Netherlands Pavilion (2000)



Figure 5.4: Netherlands Pavilion (2000) (https://arquitecturaviva.com/works/pabellon-de-los-paises-bajos-en-la-expo-2000-0)

Netherlands Pavilion (see Figure 5.4 and Table 5.4), designed by MVRDV, presents a new type of 'self-contained artificial ecosystem' to demonstrate that nature and technology can collaboratively create a 'survival kit' to deal with the increasing population (*Expo 2000*, n.d.). Following its theme 'Holland Creates Space', six Dutch landscapes with different concepts are stacked vertically to propose sustainable land-use design strategies for high-rise buildings by integrating renewable energy production and saving strategies (Rovers & Klickenberg, 2008). Organizing six landscapes in vertical direction rather than horizontal, which "not only saves space but also saves energy, time, water and infrastructure", aims to address the inadequate natural lighting and the lack of land issues in Holland (*Expo 2000*, n.d.). The pavilion has 8000 m² of exhibition space on six levels. The visitors first go up the top floor via elevators, then explore the exhibition by going to lower levels using the exterior stairs. From the top to the below, the exhibition areas are as follows: on the sixth level 6 (roof), there is a small dome-like structure used as a restaurant surrounded by a natural landscape in addition to various wind turbines that power the pavilion; on the fifth level there is main exhibition space surrounded by plastic rain curtains, on the fourth level there is a forest area resembles a real forest; on the third level there are several concrete 'pots' used as an exhibition feature for projecting animations; on the second level there is an agricultural space which functions as a greenhouse; on the first level there are concrete dunes covered with sands which houses additional services below them; and, finally, the basement level houses offices and utilities (*Historic precedent Dutch Pavilion Hannover 2000,* n.d.).

- **Construction Features: Structural System and Building Materials**

The pavilion has a different structural concept in which the structural system and materials are adapted to the exhibition concept on every floor. Concrete and steel are the primary materials that the systems are continuously changing. At the same time, timber is also utilized as a structural material on one floor (*Historic precedent Dutch Pavilion Hannover 2000,* n.d.). On the sixth level, the small dome-shaped structure has a steel frame. On the fifth level, triangulated steel columns surrounding the floor are used with reinforced concrete beams, creating a column-free space. Triangulated untreated tree-trunk columns that preserve their natural appearances are used together with steel I-beams to correspond to the small forest on the fourth level. In the third,

Table 5.4: Netherlands Pavilion (2000)

EXPO	**EXPO 2000 HANNOVER - GERMANY**
NAME:	**NETHERLANDS PAVILION**
Architecture:	MVRDV
Engineering:	ABT-Bouwkunde, Velp NL

DESIGN AIM		POST-EXPO SITUATION						THEME & FUNCTION
		PERMANENT			TEMPORARY			
PERMANENT	TEMPORARY	IN USE	NO USE	DEMOLISHED	RECYCLED / REUSED	RELOCATED	DISMANTLED	**THEME:** Holland creates Space
			2020					**POST-EXPO USE:** Renovation is started in 2020 to turned pavilion into a multifunctional office building

(1) EXPO IMAGE	(2) POST-EXPO IMAGE	(3) FUTURE IMAGE
		

GENERAL INFORMATION & GRAPHICS

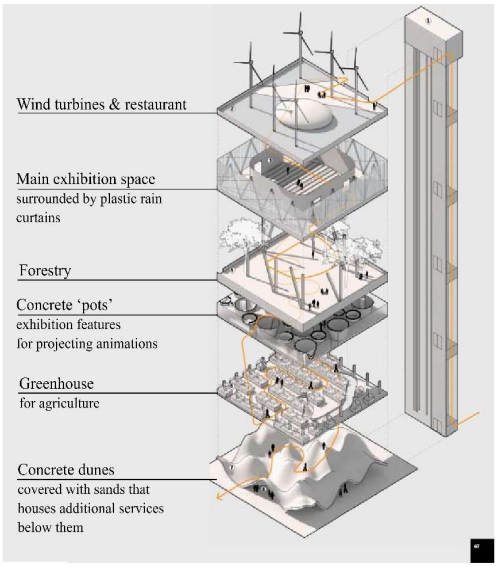
Built Area: 6000 m² Total Floor Area: 225 m² Floor: 1
Length: 15m - Width: 15m - Height: 20m Max. Span: 15m

STRUCTURAL SYSTEM AND MATERIALS

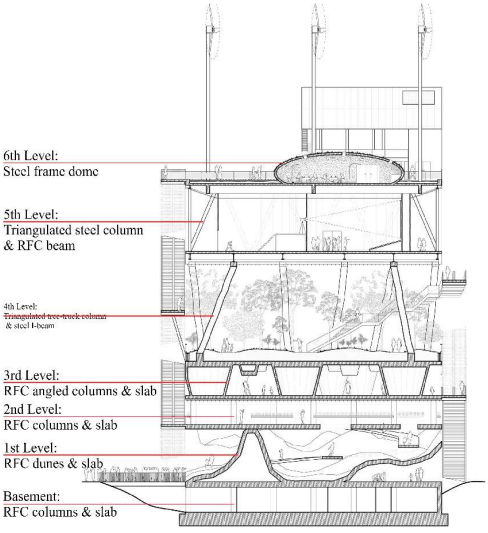
STRUCTURAL SYSTEM	SECTION ACTIVE	FRAME	**6th Level:** Steel frame
		BEAM SYSTEM	**5th Level:** Triangulated steel column & RFC beam **4th Level:** Triangulated tree-truck column & steel I-beam
		SLAB SYSTEM	**3rd Level:** RFC angled columns & slab **2nd Level:** RFC columns & slab **Basement:** RFC columns & slab
	SURFACE ACTIVE	LOAD-BEARING WALL	**1st Level:** RFC dunes & slab
		FOLDED-PLATE	
		SHELL	
	FORM ACTIVE	CABLED	
		MEMBRANE	
		PNEUMATICS	
		ARCH	
	VECTOR ACTIVE	2D TRUSS	
		3D TRUSS / SPACE FRAME	
		GEODESIC DOME	
		OTHERS:	
STRUCTURAL MATERIAL		STEEL	**Column:** Triangulated steel column **Beam:** I profile steel beam
		TIMBER	**Column:** Tree trunk columns
		REINFORCED CONCRETE	**Column:** Reinforced concrete column **Shear Wall:** Reinforced concrete dunes **Slab:** Reinforced concrete slab
		STRUCTURAL GLASS	
		FABRIC	
		OTHERS:	
NON-STRUCTURAL MATERIAL		STEEL	
		ALUMINIUM	
		TIMBER	
		GLASS	
		PLASTIC	**Façade:** Plastic curtain act as a rain wall
		CONCRETE	
		FABRIC	
		OTHERS: PHOTOVOLTAICS	**Façade:** Photovoltaic thin film sun curtain

STRUCTURAL SYSTEM & BUILDING MATERIAL PROPERTIES

FUNC.	Significant structure	The structure is adapted in every floor to create different experiences following the theme of the pavilion.
	Significant material	
	Optimized design	
	Enabling adaptability	
ENV.	Smart materials/systems	Photovoltaics in the façade, wind turbines on the roof: to provide energy for the entire life of the pavilion.
	Eco-friendly materials	
	Reclaimed materials	
	High recyclability / reusability rate	
	Reducing impact on site	
SOC.	Traditional style	
	Traditional materials	
ECON.	Light-weight materials	
	Standardized modules	
	Prefabricated units	
	Reversible connections	
ROLE IN SUSTAINABLE POST-EXPO USE PROCESS	-	Dispite its green energy production components, the unique design of the pavilion combined with unreversible connection obstructs pavilion to be refunctioned, relocated or recycled.



(4) Axonometric diagram of exhibition functions



(5) Section of the pavilion



(6) Post-expo rennovation & refunctioning

REFERENCES: (1) https://www.akt-uk.com/projects/uk-pavilion-expo-2010/; (2.1) https://www.dezeen.com/2010/03/31/uk-pavilion-at-shanghai-expo-2010-by-thomas-heatherwick-2/; (2.2) https://www.architecturalrecord.com/articles/6767-world-expo-2010-shanghai-united-kingdom-pavilion;(3) https://www.heatherwick.com/project/uk-pavilion/; (4-5) https://www.archdaily.com/58591/uk-pavilion-for-shanghai-world-expo-2010-heatherwick-studio

second, and basement levels, reinforced concrete columns and slabs are utilized, while the third floor's columns are angled to form the pots when they are cladded. Finally, reinforced concrete bearing walls in the form of dunes are used with reinforced concrete slabs on the first floor, which are also used as exhibition areas. Besides the distinctive structural design, the pavilion also has a distinctive façade approach in which no envelope is needed, and the structure is exposed completely (Comsa, 2015). Only in the fifth level, there is a plastic curtain utilized to give an impression of falling rain, in addition to a thin photovoltaic film integrated into a sun curtain in the south façade to generate power together with wind turbines (Scognamiglio & Privato, 2008).

- **Sustainable Construction Features and Their Role in Post-Expo Use**

Although the first plan was to dismantle the pavilion and relocate it to Amsterdam, it was observed that it would be "cheaper to rebuild the entire structure from scratch" since this huge building is mainly made of reinforced concrete (*Historic precedent Dutch Pavilion Hannover 2000,* n.d.). The distinct and specific spatial design features also make it challenging to readapt this permanent structure for a new use. As a result, despite the innovative sustainable features, the structural and material characteristics convict the pavilion to be left unused for 20 years.



Figure 5.5: Netherlands Pavilion 2.0 (https://www.mvrdv.nl/projects/432/expo-pavilion-20)

In 2020, iLive Expo Campus GmbH bought the pavilion to renovate and transform it into a co-working office (Figure 5.5) by adding two new stepped buildings for student housing, offices, and parking lots surrounding the pavilion *(Expo Pavilion 2.0,* n.d.*).* The original design characteristics of the pavilion are adapted into office features, such as the pots in the third level are glazed and converted into offices and meeting rooms

together with rectangular greenhouses on the second level, while concrete dunes on the first level are utilized as a socializing area with small cafés and exhibition areas. Since there were no façades in the former pavilion, high-transparent glass is used to protect the interior while maintaining the transparency of the pavilion (*Expo Pavilion 2.0*, n.d.). However, since the pavilion has stayed empty for twenty years, it costs excessive time, energy, and resources to renovate the pavilion, which contradicts the sustainability concept of the Expo. Therefore, the pavilion is considered to have 'no-use' in the post-expo period.

5.2.3. Hungary Pavilion (2000)



Figure 5.6: Hungary Pavilion (2000) (https://structurae.net/en/structures/hungarian-pavilion-expo-2000)

The pavilion (see Figure 5.6 and Table 5.5), designed by György Vadasz, consists of two 20 m high double-layered curvilinear walls forming the exhibition area surrounded by a low L-shaped service building containing shops, a café, and a restaurant (Çimen et al., 2000). The monumental wings that create the central part of the pavilion surround the open-air exhibition area and are connected by a tensile fabric covering the exhibition area from weather conditions (Hu, 2002). The double-layered wings are folded in and out, creating inner spaces called the 'Room of Spectacles' for exhibits and performances. The distance between walls is increasing towards the northwest direction to create an entrance to the pavilion (*Expo 2000: Hungarian pavilion*, n.d.). Big screens can pop up from the walls and fold back for multimedia presentations (Hu, 2002).

Table 5.5: Hungary Pavilion (2000)

EXPO NAME:	EXPO 2000 HANNOVER - GERMANY HUNGARY PAVILION
Architecture:	György Vadasz
Engineering:	Vadász & Partners Architectural Co.

DESIGN AIM		POST-EXPO SITUATION						THEME & FUNCTION
		PERMANENT			TEMPORARY			
PERMANENT	TEMPORARY	IN USE	NO USE	DEMOLISHED	RECYCLED / REUSED	RELOCATED	DISMANTLED	**THEME:** Stepping to the Ship of Time from the Gate of Love
■						2008		**POST-EXPO USE:** It was not used for 8 years and then relocated to be an entrance building of a commercial park in UAE.

(1) EXPO IMAGE	POST-EXPO IMAGE
	NOT FOUND

GENERAL INFORMATION & GRAPHICS

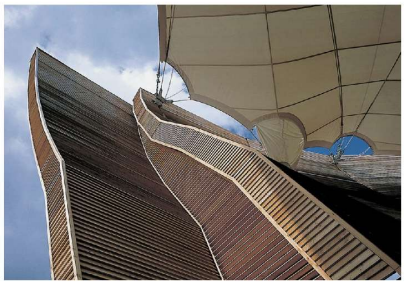
Built Area: 1788 m² — Floor: 1
Length: 41m - Width: 30m - Height: 20m — Max. Span: 22m

STRUCTURAL SYSTEM AND MATERIALS

STRUCTURAL SYSTEM	SECTION ACTIVE	FRAME		
		BEAM SYSTEM		
		SLAB SYSTEM		
	SURFACE ACTIVE	LOAD-BEARING WALL		**Steel rib frame shear walls:** Two seperate wings of the pavilion
		FOLDED-PLATE		
		SHELL		
	FORM ACTIVE	CABLED		
		MEMBRANE		**Tensile membrane:** Connects the wings from the top
		PNEUMATICS		
		ARCH		
	VECTOR ACTIVE	2D TRUSS		
		3D TRUSS / SPACE FRAME		
		GEODESIC DOME		
		OTHERS:		
STRUCTURAL MATERIALS		STEEL		**Steel rib frame shear walls:** Two seperate wings of the pavilion
		TIMBER		
		REINFORCED CONCRETE		
		STRUCTURAL GLASS		
		FABRIC		**Tarpaulin:** Tensile Membrane
		OTHERS:		
NON-STRUCTURAL MATERIALS		STEEL		
		ALUMINIUM		
		TIMBER		**Red fir sawn timber:** Exterior and interior cladding of wings
		GLASS		
		PLASTIC		
		CONCRETE		
		FABRIC		
		OTHERS:		




(2) Double layered shear walls & folded inner walls





(3) Detail of the membrane connections

STRUCTURAL SYSTEM & BUILDING MATERIAL PROPERTIES

FUNC.	Significant structure		
	Significant material		
	Optimized design		
	Enabling adaptability		Although the pavilion is designed as permanent, it has a simple structural system allows for easy deconstruction.
ENV.	Smart materials/systems		
	Eco-friendly materials		
	Reclaimed materials		
	High recyclability / reusability rate		
	Reducing impact on site		
SOC.	Traditional style		
	Traditional materials		Red fir sawn timber is a traditional Hungarian material.
ECON.	Light-weight materials		Timber and fabric is lightweight
	Standardized modules		
	Prefabricated units		All units are prefabricated and assembled in the site.
	Reversible connections		Steel, timber and fabric components have reversible connections.
ROLE IN SUSTAINABLE POST-EXPO USE PROCESS		+	Even the pavilion was designed as permanent it was not used for 8 years after the Expo. Yet, simple structural design allows for relocation.

REFERENCES:
(1-3) https://www.tensinet.com/index.php/projects-database/projects?view=project&id=4004; (2.1) https://www.flickr.com/photos/expomuseum/67831066; (2.2) https://structurae.net/en/media/2551-hungarian-pavillion-at-the-expo-2000

- **Construction Features: Structural System and Building Materials**

The 20 m high walls of the pavilion enclose a 41 m long and 30 m wide area. They consist of a steel-rib frame clad with red fir timber and are connected above with tensile tarpaulin and cables (Çimen et al., 2000). Between the double layers of walls, there are stairs and technical services. The service building, with a simple steel frame structure, has a green roof (*Expo 2000: Hungarian pavilion*, n.d.).

- **Sustainable Construction Features and Their Role in Post-Expo Use**

Although the pavilion is designed as a permanent structure, it was not used for eight years. However, since it has a simple structural system and lightweight materials, its constructional configuration allows it to be relocated. The pavilion was disassembled and moved to Abu Dhabi as an entrance building of a residential and commercial park in 2008 *(The EXPO 2000 - Reuse).* In this way, the pavilion demonstrates the importance of designing even the permanent pavilions with reversible connections for the cases that post-expo use plans are not executed as envisioned.

5.2.4. Poland Pavilion (2000)



Figure 5.7: Poland Pavilion (2000) (https://oldwww.mz.pl/en/realization/polish-exhibition-pavilion-expo-2000-world-exhibition-hannover-germany-general)

The pavilion designed by Wojciech Obtitowicz is an exterior envelope that houses smaller timber pavilions inside (see Figure 5.7 and Table 5.6). The pavilion's design embraces the principle of transparency with its mostly transparent façade elements, including the roof, which also reflects the "view of German technology and craftsmanship" (Świątek, 2012, p. 336). There are also transparent movable walls that provide flexibility and increase accessibility from both long sides. Some parts of the pavilion and its surroundings are filled with greenery that can be experienced thanks

Table 5.6: Poland Pavilion (2000)

EXPO				**EXPO 2000 HANNOVER - GERMANY**									
NAME:				**POLAND PAVILION**									
Architecture:				Wojciech Obtitowicz									
Engineering:				HJW+Partner Architects + Engineers									
DESIGN AIM		**POST-EXPO SITUATION**							**THEME & FUNCTION**				
		PERMANENT			**TEMPORARY**								
PERMANENT	TEMPORARY	IN USE	NO USE	DEMOLISHED	RECYCLED / REUSED	RELOCATED	DISMANTLED		**THEME:** Between fantasy and reality "the bridge of light"				
									POST-EXPO USE: Demolished in September 2015.				
STRUCTURAL SYSTEM AND MATERIALS													
STRUCTURAL SYSTEM													
	SECTION ACTIVE			**FRAME**					**Main:** Steel frame with concrete-poured columns **Small pavilions:** Timber frame				
				BEAM SYSTEM									
				SLAB SYSTEM									
	SURFACE ACTIVE			**LOAD-BEARING WALL**									
				FOLDED-PLATE									
				SHELL									
	FORM ACTIVE			**CABLED**									
				MEMBRANE									
				PNEUMATICS									
				ARCH									
	VECTOR ACTIVE			**2D TRUSS**									
				3D TRUSS / SPACE FRAME					**Truss beams:** Hanging perpendicular to the steel frame				
				GEODESIC DOME									
				OTHERS:									
STRUCTURAL MATERIALS				**STEEL**					**EXT.** Steel frame				
				TIMBER					**INN.** Small timber pavilions inside the main pavilion				
				REINFORCED CONCRETE					**EXT.** The foots of steel frame is poured concrete				
				STRUCTURAL GLASS					**EXT.** Both roof and floor are cladd with fiberglass				
				FABRIC									
				OTHERS:									
NON-STRUCTURAL MATERIALS				**STEEL**									
				ALUMINIUM									
				TIMBER									
				GLASS									
				PLASTIC									
				CONCRETE									
				FABRIC									
				OTHERS:									
STRUCTURAL SYSTEM & BUILDING MATERIAL PROPERTIES													
FUNC.				Significant structure									
				Significant material					The fiberglass which can be stronger than steel or concrete is used both on the floor and roof.				
				Optimized design									
				Enabling adaptability									
ENV.				Smart materials/systems									
				Eco-friendly materials									
				Reclaimed materials									
				High recyclability /									
				Reducing impact on site									
SOC.				Traditional style									
				Traditional materials									
ECON.				Light-weight materials									
				Standardized modules					Simple form & rectangular structure consists of standardized dimensions.				
				Prefabricated units									
				Reversible connections									
ROLE IN SUSTAINABLE POST-EXPO USE PROCESS									-	Although the column-free interior is suitable for new use, the pavilion was not used for 15 years, which may be caused due to excessive sunlight comes from roof and façades. Using concrete prevent deconstruction for further use.			

(1) EXPO IMAGE



(2) POST-EXPO IMAGE



GENERAL INFORMATION & GRAPHICS

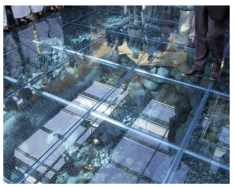
Built Area: 1455 m² Floor: 1-2
Length: 45m - Width: 28m - Height: 9/11.5m Max.Span: 28m





(3) Steel trusses hanging perpendicularly to steel frame





(4) Façade, roof and floor clad with fiberglass





(5) Small timber pavilions inside the pavilion

REFERENCES:
(1 - 3) https://oldwww.mz.pl/en/realization/polish-exhibition-pavilion-expo-2000-world-exhibition-hannover-germany-general
(4 - 5) https://hgp-h.com/buildings/polish-pavilion-3/

to the transparency of the pavilion, which creates a bright and relaxing natural space that corresponds to the Expo theme (Świątek, 2012).

- **Construction Features: Structural System and Building Materials**

The pavilion has a hybrid structural system in which steel trusses hang perpendicularly to the steel frame structure with concrete poured feet, creating over one thousand square-meter column-free area (Çimen et al., 2000). Three façades, in addition to the roof and floor of the pavilion, are entirely clad with fiber-glass, which turns the pavilion into a transparent box (Świątek 2012). The small pavilions inside have timber frame systems, which are "typical and densely occurring examples of the development of the Polish provinces" (Świątek, 2012, p.337).

- **Sustainable Construction Features and Their Role in Post-Expo Use**

The timber pavilions are dismantled and recycled after the end of the Expo since they are not suitable for post-expo use due to their small sizes. Despite the pavilion's 1230 sqm. the column-free area provided by the steel trusses, when the small pavilions are removed, using this transparent box with a new function is also challenging due to excessive sunlight. Since concrete was utilized as a structural material in columns, recycling or relocating the pavilion was not an ideal solution. As a result, the pavilion stayed empty for 15 years and then was destroyed, which is not compatible with the sustainability theme of the Expo (*The EXPO 2000 - Reuse*).

5.2.5. Japan Pavilion (2000)



Figure 5.8: Japan Pavilion (2000) (https://en.wikiarquitectura.com/building/japan-pavillion-expo-2000-hannover/)

The Japanese pavilion (see Figure 5.8 and Table 5.7) is designed by the Japanese architect Shigeru Ban in the counseling of Frei Otto. The pavilion is considered one of the most significant structures in the Expo, with its grid shell structure made of paper cardboard tubes, the largest structure ever built by paper (López-César, 2019). The pavilion is designed as a temporary building in which the paper cardboards are recycled and turned into newspapers and notebooks (Çimen et al., 2000). Shigeru Ban aims to respond to the sustainability theme of Expo 2000 by designing a cost-efficient structure as low-tech as possible (Shigeru Ban Architects, n.d.). The pavilion aims to show that humans and nature can be in harmony with these design principles, which creates a base for the theme of Aichi World Expo 2005 (Çimen et al., 2000). Although the original design consisted of only a grid shell structure made of paper tubes, the German authorities required to increase the rigidity by timber ladder arches and providing the planar strength with steel cables (Chilton & Tang, 2016).

The pavilion maintains the legacy of Expos as catalyzing structural innovations. It creates a fundamental base for the use of paper both in the field of wide-scale structures and fire resistance (Shigeru Ban Architects, n.d.) thanks to the several performed test such as form-finding exercises, bending trials, effects of temperature and humidity on mechanical properties, different connections types between cardboard, wood, and metal as well as the fire resistance tests (López-César, 2019; Correa, 2004). The use of PERI scaffolding towers is first experienced in constructing the pavilion. This innovative and efficient technique allows to lay down the structure on a lower level and push up some parts to achieve the final form (Correa, 2004). The pavilion becomes a precedent with its structural qualities and construction techniques for the projects such as Abby Aldrich Rockefeller Sculpture Garden for The MoMA, Weald, and Downland grid shells (Chilton & Tang, 2016).

- **Construction Features: Structural System and Building Materials**

The pavilion has a paper cardboard grid-shell structure strengthened by arched timber ladders and stiffened with steel cables. The paper cardboard tubes are made of Hanoverian recycled paper (BauNetz, 1998), which can reach up to 68 m with the help of socket joints (Chilton & Tang, 2016). The cardboards are tied with polyester tapes at the intersection points, which is an easy, economical, and environmentally-friendly solution (Chilton & Tang, 2016). Although the structural analyses indicate that it is

Table 5.7: Japan Pavilion (2000)

EXPO	EXPO 2000 HANNOVER - GERMANY
NAME:	JAPAN PAVILION
Architecture:	Shigeru Ban (Frei Otto: Consultant)
Engineering:	Buro Happold Consulting Engineers

DESIGN AIM		POST-EXPO SITUATION						THEME & FUNCTION
		PERMANENT			TEMPORARY			
PERMANENT	TEMPORARY	IN USE	NO USE	DEMOLISHED	RECYCLED / REUSED	RELOCATED	DISMANTLED	**THEME:** Harmony between human & nature
	■				■			**POST-EXPO USE:** Recycled and turned into newspaper & notebook

(1) EXPO IMAGE	POST-EXPO IMAGE
	-

GENERAL INFORMATION & GRAPHICS

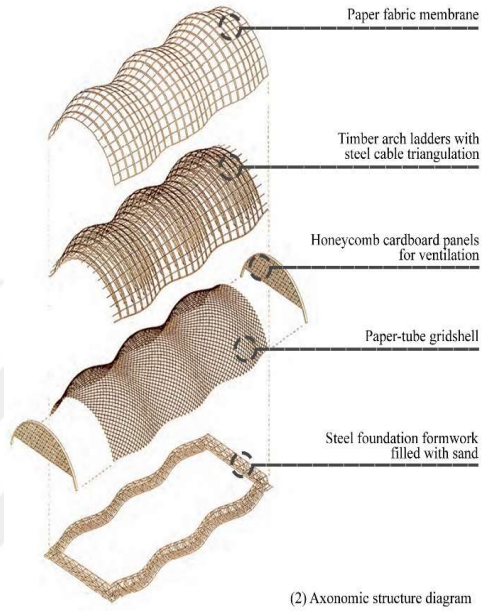
Built Area: 3.500 m² Floor: 2
Length:75m - Width:25m - Height:16m Max.Span: 25-75 m

STRUCTURAL SYSTEM AND MATERIALS

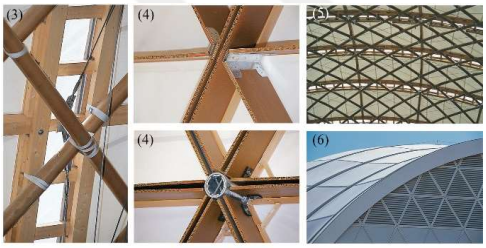
STRUCTURAL SYSTEM	SECTION ACTIVE	FRAME		
		BEAM SYSTEM		
		SLAB SYSTEM		
	SURFACE ACTIVE	LOAD-BEARING WALL		
		FOLDED-PLATE		
		SHELL		
	FORM ACTIVE	CABLED	3RD	**Tertiary Structure:** Cables in a 60-degree from the foundation
		MEMBRANE		
		PNEUMATICS		
		ARCH	2ND	**Secondary Structure:** Timber ladder arches
	VECTOR ACTIVE	2D TRUSS		
		3D TRUSS / SPACE FRAME		
		GEODESIC DOME		
	OTHERS: GRIDSHELL		1ST	**Main Structure:** Paper-tube grid-shell
STRUCTURAL MATERIAL	STEEL		3RD	**Tertiary:** Steel cables
	TIMBER		2ND	**Secondary:** Laminated timber - thickness: 60 mm
	REINFORCED CONCRETE			
	STRUCTURAL GLASS			
	FABRIC			
	OTHERS: PAPER		1ST	**Main:** Recycled paper cardboard tubes - length: 40 m, diameter: 120 mm
NON-STRUCTURAL MATERIAL	STEEL			
	ALUMINIUM			
	TIMBER			
	GLASS			
	PLASTIC			
	CONCRETE			
	FABRIC			
	OTHERS: PAPER			**Membrane:** Semi transparent impregnated paper-made textile

STRUCTURAL SYSTEM & BUILDING MATERIAL PROPERTIES

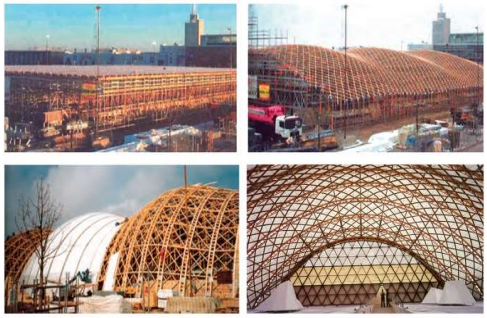
FUNC.	Significant structure	■	It is the largest cardboard gridshell structure, and an experimental model.
	Significant material	■	Paper as the main structural material for the first time.
	Optimized design	■	Efficient form-active structure allows for using less material and joints.
	Enabling adaptability	■	Enables recycling to make newspaper, and notebook.
ENV.	Smart materials/systems		
	Eco-friendly materials	■	Paper & paper-fabric membrane developed for fire-resistance without any PVC ingredient.
	Reclaimed materials	■	Hanoverian recycled paper is used in the pavilion.
	High recyclability / reusability rate	■	All materials are recycable including foundation.
	Reducing impact on site	■	Steel foundation boxes filled with sand allow pavilion to touch ground gently.
SOC.	Traditional style		
	Traditional materials	■	Paper and timber are traditional materials
ECON.	Light-weight materials	■	Paper cardboards, paper fabric and laminated timber
	Standardized modules		
	Prefabricated units	■	All units are prefabricated and assembled in the site.
	Reversible connections	■	Simple joints (poliester and metal tapes / ribbons) and bracings (steel cable)
ROLE IN SUSTAINABLE POST-EXPO USE PROCESS		++ +	Easily demountable structural system and 100% recycable materials including the foundation. The materials are transformed something useful (newspaper, notebook).



(2) Axonomic structure diagram



(3) Fabric strips: in between cardboard tubes & in between cardboard-timber arch
(4) Triangular mesh of honeycomb sidewalls - metal ribbons
(5) Overlap layyers: Papertube gridshell - timber ladder arch - steel cable
(6) Ventilation panels in sidewalls



(6) Construction process with PERI scaffolding towers - Final view (Right bottom)

REFERENCES: (1) https://en.wikiarquitectura.com/building/japan-pavillion-expo-2000-hannover/; (3 - 4 - 5) https://inspiration.detail.de/japanese-pavilion-at-the-expo-in-hanover-106867.htmlhttps://inspiration.detail.de/japanese-pavilion-at-the-expo-in-hanover-106867.html ; (2 - 6) López-César, I. (2019). World Expos and architectonic structures. An intimate relationship. - used for creating diagram(2)

not needed, the steel struts are also utilized in the grid shell structure to be approved by the German regulations (Correa, 2004). Also, German authorities required to stiffen the structure with the arched ladders made of glulam timber and diagonal steel cables to increase the planar strength (Chilton & Tang, 2016). The timber ladder arches also serve as a spot for attaching the membrane and maintenance issues (Shigeru Ban Architects, n.d.). The sidewalls of the pavilion are made of honeycomb cardboard panels attached to the timber arch ladders and strengthened by cables. The equilateral triangles of the honeycomb also become another spot for the ventilation and attachment of the membrane (López-César, 2019). The translucent membrane consists of five layers of waterproof and fireproof paper (López-César, 2019), which the architects discover a waterproof and fireproof fabric without containing PVC (Shigeru Ban Architects, n.d.). The translucent quality of the membrane also reflects the traditional Japanese architecture, inspired by the Shoji Roof, for efficient use of natural light and energy (Bulut & Gürani, 2018).

- **Sustainable Construction Features and Their Role in Post-Expo Use**

The Japan Pavilion is designed to be easy to construct, cost-effective, and sustainable in all terms, considering the characteristics of Japanese architecture. The assembly of the pavilion last for three weeks (*Japan Pavilion Expo 2000 Hannover - Data, Photos & Plans*, 2020), with the help of the lightweight and easily mountable/demountable characteristics of the building materials, while all materials used are also low-cost, local, and recyclable. The structure is designed to "touch the ground gently" (Chilton & Tang, 2016, p. 47) in order to be completely recycled, leave no trace behind after the removal, and cause minimum industrial waste. For this purpose, the foundation is solved by a sustainable solution which is using steel boxes filled with sand by avoiding using concrete (López-César, 2019). Besides, the innovative water-proof membrane produced without any PVC ingredient is also a crucial strategy for recycling since PVC decreases the recycling rate and causes dioxin emissions when it is burned. Besides, the innovative grid shell structures can resist their own weight with sufficient curvature (Hurol, 2016). They have the advantage over shell structures by becoming robust through their form rather than the amount of material. Thus, the structural system helps reduce the number of used materials (Chilton & Tang 2016). This consequently reduces the energy needed to dismount and recycle the materials after the Expo.

The use of recycled paper rather than timber for the tubes has environmental, structural, and economic advantages. Firstly, utilizing waste paper rather than cutting trees is an eco-friendly solution. Also, paper eliminates the size limitations caused by the length of trees and allows for longer tubes in any diameter and thickness without joints (Harris et al., 2003). Since the axial forces are transmitted efficiently with longer members to the points where they can be resisted in grid shell structures (Harris et al., 2003), eliminating the number of joints makes the system structurally and economically more efficient. Reducing the number of joints while keeping them simpler eases construction and disassembly. By integrating innovative and sustainable solutions to all building components, including the selection of structural and non-structural materials, the design of the structural system, and the foundation type, the pavilion become a pioneer in the field of post-expo use. In this way, it eases the disassembly, enables recycling up to 100%, reduces the energy consumption and pollution in the recycling process while minimizing the impacts on the urban environment.

5.2.6. Switzerland Pavilion (2000)

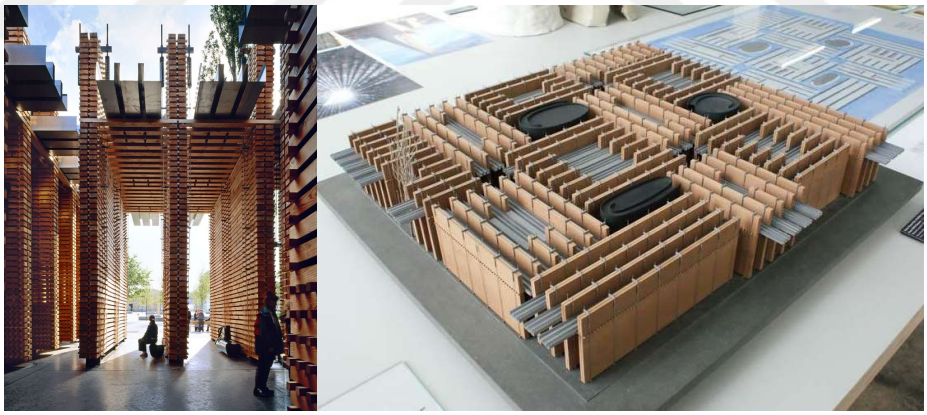


Figure 5.9: Switzerland Pavilion (2000) (https://en.wikiarquitectura.com/building/swiss-sound-pavilion/)

The Swiss Pavilion, so-called the Sound Box (see Figure 5.9 and Table 5.8), is designed by architect Peter Zumthor in collaboration with composer Daniel Ott to demonstrate how “the relationship between sound and space extends to music and architecture” (Alvin, 2017, p. 52). The structural and architectural design is inspired by the “musical instruments that are used to fill its spaces with sound” like the violin or dulcimer, with the use of tuned materials (Lutz, 2005, p. 73). It is a fine-tuned spatial

structure like an instrument consisting of a series of wooden walls arranged like a labyrinth which “amplify and direct the tone and timbre of the commissioned musical compositions” (Kanekar, 2014, p. 103). The pavilion consists of twelve modules of stacked timber walls “which repeat, rotate and at times vary ever so slightly” and create a ‘warp-werp’ pattern (Kanekar, 2014, p. 88). The series of parallel walls, covered on top with metal beams, are very close to each other, creating interconnected corridors that lead the visitors to open-air courtyards with elliptical service cores, gathering areas, and rooms (*Swiss Sound Pavilion - Data, Photos & Plans*, 2020). The pavilion is accessible from any side, providing 50 different routes for different experiences. Together with a labyrinth-like design, the openness of the pavilion to the weather conditions plays a crucial role in the experience of the pavilion. As a result, the pavilion is also considered a performative architecture of the senses which creates a sensory and continuously changing experience involving sounds, music, human voices, smell, lighting, and weather conditions thanks to its permeable design (*Swiss Sound Pavilion - Data, Photos & Plans*, 2020).

- **Construction Features: Structural System and Building Materials**

The pavilion consists of twelve modular groups called *stacks*, which are structurally independent 99 walls (Kanekar, 2014). The walls are constructed by 45.000 wooden beams of 144 km of bio-mass, “totaling 2800 cubic meters of larch and Douglas pine from Swiss forests” (Pietrogrande, 2016, p. 601). The two parallel lines of Douglas pine beams are crossly stacked with larch ribs to build semi-permeable walls (Jeska, 2014). The beams are compressed by the vertical steel rods every 3 m to provide flexural strength, which also fastens the walls to the ground (Jeska, 2014; Kanekar, 2014). At the top of every tension rod, there are steel springs that provide flexibility for the changes in the height of timber, which can reach up to 60 mm due to shrinkage or expansion that occurs in different weather conditions (*Swiss Sound Pavilion - Data, Photos & Plans*, 2020; Jeska, 2014). The structure only works by compression while the wooden beams are held together by the rods and springs, as well as the friction between the beams which requires no “nails, bolts glue or any other fasteners” (Lutz, 2005, p.74). Timber decks link the walls at the height of 6.25 m that cover the interior and carry metal gutters to strengthen the structure with its weight (Zsolt, 2001). The slab on which the structure lies and foundation are made of unreinforced concrete.

Table 5.8: Switzerland Pavilion (2000)

EXPO	EXPO 2000 HANNOVER - GERMANY
NAME:	SWITZERLAND PAVILION - SOUND BOX
Architecture:	Peter Zumthor
Engineering:	Karoline Gruber, Daniel Ott

DESIGN AIM		POST-EXPO SITUATION						THEME & FUNCTION
		PERMANENT			TEMPORARY			
PERMANENT	TEMPORARY	IN USE	NO USE	DEMOLISHED	RECYCLED / REUSED	RELOCATED	DISMANTLED	**THEME:** Swiss Sound Box - The Resonance of Switzerland
	■				■			**POST-EXPO USE:** Reused as construction and interior design materials

(1) EXPO IMAGE	POST-EXPO IMAGE
	-

GENERAL INFORMATION & GRAPHICS

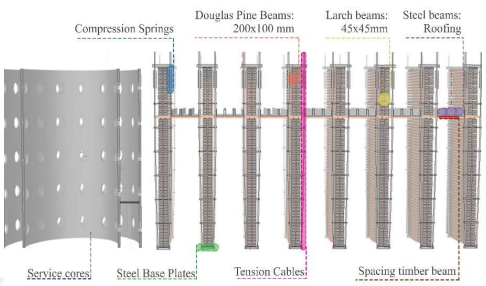
Built Area: 2750 m² Floor: 1
Length: 50m - Width: 55m - Height: 8.7m Max. Span: 11.25 m

STRUCTURAL SYSTEM AND MATERIALS

STRUCTURAL SYSTEM	SECTION ACTIVE	FRAME		
		BEAM SYSTEM		
		SLAB SYSTEM		
	SURFACE ACTIVE	LOAD-BEARING WALL		
		FOLDED-PLATE		
		SHELL		
	FORM ACTIVE	CABLED		
		MEMBRANE		
		PNEUMATICS		
		ARCH		
	VECTOR ACTIVE	2D TRUSS		
		3D TRUSS / SPACE FRAME		
		GEODESIC DOME		
	OTHERS: STACKED BEAMS			Crossly stacked lumber beams by cables and springs
STRUCTURAL MATERIAL	STEEL			
	TIMBER			Two types of crossly-stacked beams Douglas Pine:20x10cm - Larch:45x45mm
	REINFORCED CONCRETE			
	STRUCTURAL GLASS			
	FABRIC			
	OTHERS:			
NON-STRUCTURAL MATERIAL	STEEL			U-beams, cables, tension rods and springs
	ALUMINIUM			
	TIMBER			
	GLASS			
	PLASTIC			
	CONCRETE			Slab and foundation
	FABRIC			
	OTHERS:			

STRUCTURAL SYSTEM & BUILDING MATERIAL PROPERTIES

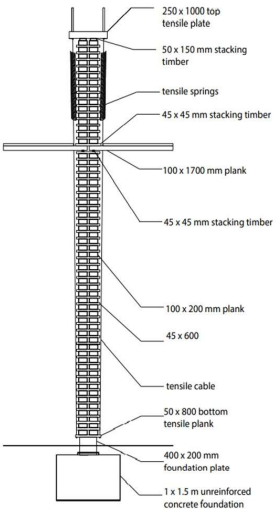
FUNC.	Significant structure		The beams are stacked by rods and springs, without requiring any nails or glue that damages the materials.
	Significant material		The timber beams are completely untreated.
	Optimized design		The structure only works by the compression provided by cables, and friction between the beams.
	Enabling adaptability		Simple structure and ready-to-reuse materials after the disassembly provides high level adaptability.
ENV.	Smart materials/systems		
	Eco-friendly materials		The timber beams have no chemical treatment.
	Reclaimed materials		Wooden beams made of biological mass.
	High recyclability / reusability rate		Untreated timber beams and steel members have a high recyclability rate.
	Reducing impact on site		
SOC.	Traditional style		
	Traditional materials		The larch and pine from Swiss forests.
ECON.	Light-weight materials		Timber beams, steel cables & tensioners
	Standardized modules		The pavilion consists of modular rectangular prism timber beams, which provide easier transportation.
	Prefabricated units		All components come to the site as ready-to-assembly.
	Reversible connections		Pavilion is designed to ease the dissambly process.
ROLE IN SUSTAINABLE POST-EXPO USE PROCESS		++ +	The structure allows for efficient disassembly, transportation, and reuse. The beams were sold as construction materials without requiring any treatment.



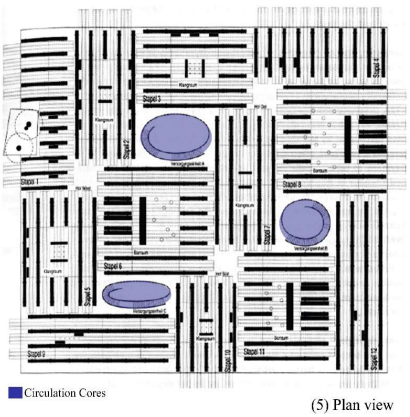
(2) Perspective Section Diagram



(3) Structure system views



(4) System detail section



(5) Plan view

NOTE: The concrete slab and foundation damage the sustainable design of the pavilion since they complicate the dismantling process and increase the harm given to the site.

REFERENCES: (1) https://www.swissinfo.ch/eng/swiss-pavilion-at-expo-2000-offers-respite-from-assault-on-senses/1507598; (2-3-5) http://mfbranksdisplaypractices.blogspot.com/2015/03/sound-box-swiss-pavillion-at-hannover.html, https://en.wikiarquitectura.com/building/swiss-sound-pavilion/
(4) Nurözler, Ö., & Ma, M. (2015, November 26). Swiss Sound Box - Swiss Pavilion Expo 2000 Peter Zumthor 1996-2000. Retrieved April 9, 2022, from https://arch303fall2015.wordpress.com/exercises/

- **Sustainable Construction Features and Their Role in Post-Expo Use**

The temporary pavilion's structural design and material choice provide an efficient post-expo use with easy disassemble and reuse processes. Since the whole structure works in compression supported by tension cables and springs requiring no adhesives or nails to brace the structure, the lumber beams get no damage during the construction or disassembly (Lutz, 2005). Besides, "wood materials were built totally untreated, without any chemical treatment" (Zsolt, 2001, p.3). Thus, they were sold as construction materials after the disassembly without requiring any treatment and became a good instance of reusing post-consumer wood (Werner et al., 2002). After six months end of the Expo, the Swiss Wood Industrial Association sold the lumbers to England, The Netherlands, Germany, Austria, and Switzerland to be utilized as the structural material of prefabricated wooden houses, interior material for parquet floors, tables, garden furniture (Zsolt, 2001), and in the construction of exhibition and information center at the CERN (Blume, 2000). The pavilion is a remarkable example of using an innovative structural system that preserves the material value for a more efficient reuse process. However, the concrete slab and foundation damage the sustainable design of the pavilion since they complicate the dismantling process and increase the harm given to the site.

5.3. Aichi World Expo Pavilions (2005)

Theme: Nature's Wisdom

Time Period: 25 March - 25 September 2005 (6 Months)

Area: 173 ha.

Number of Participant Nations: 120

Total Visitors: 22.049.544

The Aichi World Expo 2005, organized in Japan, is held in a natural setting used by endangered hawks as a nesting area (see Figure 5.10). The selection of the natural site has shaped the theme of the Expo as Nature's Wisdom which also led to the decision to protect much of the natural features on the site, including the vast forestry (Tsunoda et al., 2007). As other expos, innovative environmental technologies including "biodegradable-plastic eating utensils used everywhere on the site at food concessions;

a world-class greening wall (biolung) for suppressing the heat-island effect seen in urban areas;" and green transportation technologies like "the fuel cell hybrid bus that linked the perimeter of the site" (*Aichi 2005: The first Eco-Expo,* n.d.). In addition to preserving the natural environment, one of the main aims of the Expo is to minimize building waste. With this aim, pavilions and raised walkways all around the site are designed to minimize the negative impact on the land and to easily transform the site into a nature park after the Expo (Schrenk & Jensen, 2014). The pavilions are designed and constructed by standardized prefabricated units consisting of cladding panels attached to steel framing to ease the disassembly and reuse processes while reducing transportation costs. This is also supported by 3R's system (reduce, reuse and recycle) as the main theme in all parts of the exposition (Tsunoda et al., 2007). All these characteristics have led to the consideration of the Expo as the "greenest of the modern expositions" and the most successful one in terms of accomplishing the post-expo sustainability goals (Schrenk & Jensen, 2014, p. 559). Nine pavilions in three categories are evaluated with their quality of the interior and exterior design and functionality which are awarded by the BIE with Gold, Silver, and Bronze awards Japan Association for the 2005 World Exposition, 2005). The first five awarded pavilions and the host-country pavilion, are selected to be examined in this study (see Section 4.1).



Figure 5.10: Aichi World Expo (2005) Site (http://www.expo2005.or.jp/en/venue/index.html)

5.3.1. Japan Pavilion (2005)



Figure 5.11: Japan Pavilion Nagatuke (2005)
(https://commons.wikimedia.org/wiki/File:Japan_Pavilion_Nagakute.jpg)

The Japan Pavilion Nagatuke (see Figure 5.11 and Table 5.9) is the biggest national pavilion in this Expo, with its 6300 m² footprint and 8029 m² construction area. The pavilion aims to address the environmental issues and demonstrate possible solutions using advanced future technologies and new lifestyles that strengthen the bonds between humans and nature (*Japan Pavilion Nagakute,* 2004). The pavilion consists of a rectangular timber building inside, and a free-form bamboo cage outside that filters the direct sunlight. It is an active experimental pavilion where innovative environmental technologies and materials can be experienced. For instance, there is a glass-free 3D vision simulator called 'Geo-Space' in the pavilion in addition to an 'Earth Room' with "the world's first 360-degree spherical imaging system, which displays the Earth's vitality and current state in 1:1 million-scale images in a 12.8m diameter theater" (*The Japan Pavilions -The Host Country Welcomes Visitors with its National Pavilions,* n.d., p. 1). Besides, the pavilion proposes a self-sufficient energy system in which all of the electricity utilized in the building is generated by using a new kind of renewable energy source. The cooling of the spaces is also conducted by an innovative system composed of a roof made of photocatalytic steel plates and water sprinklers. The wastewater is also recycled in the pavilion by an ozone treatment system (*Japan Pavilion Nagakute,* 2004).

Table 5.9: Japan Pavilion (2005)

EXPO	**EXPO 2005 AICHI - JAPAN**
NAME:	**JAPAN PAVILION - NAGATUKE**
Architecture:	*Not Found*
Engineering:	*Not Found*

DESIGN AIM		POST-EXPO SITUATION						THEME & FUNCTION
		PERMANENT			TEMPORARY			
PERMANENT	TEMPORARY	IN USE	NO USE	DEMOLISHED	RECYCLED / REUSED	RELOCATED	DISMANTLED	THEME: Redefining wealth from 20th to 21th centuries; rekindling the relationship between mankind and nature POST-EXPO USE: Sold in online auction for re-use
	■				■			

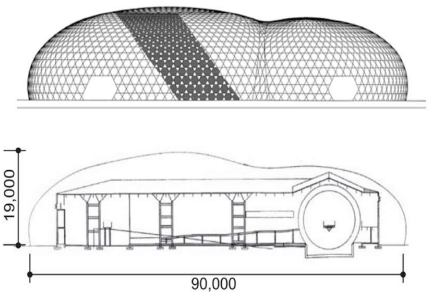
(1) EXPO IMAGE	POST-EXPO IMAGE
	-

GENERAL INFORMATION & GRAPHICS

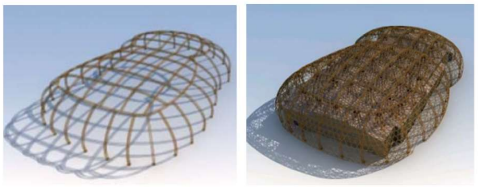
Foot-print Area: 6300 m² — Floor: 1
Length: 90 m - Width: 70 m - Height: 19 m — Max. Span: 90 m

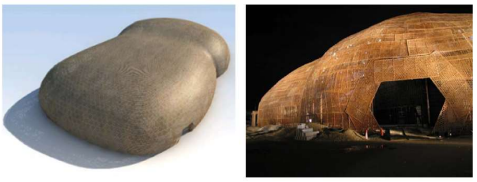
STRUCTURAL SYSTEM AND MATERIALS				
STRUCTURAL SYSTEM	SECTION ACTIVE	FRAME		
		BEAM SYSTEM		**Interior Pavilion:** Box-beams of reinforced plywood & bundled laminated pillars
		SLAB SYSTEM		
	SURFACE ACTIVE	LOAD-BEARING WALL		
		FOLDED-PLATE		
		SHELL		
	FORM ACTIVE	CABLED		
		MEMBRANE		
		PNEUMATICS		
		ARCH		**Exterior Cage:** Bamboo arched trusses
	VECTOR ACTIVE	2D TRUSS		
		3D TRUSS / SPACE FRAME		**Exterior Cage**: Bamboo arched trusses
		GEODESIC DOME		
	OTHERS:			
STRUCTURAL MATERIALS	STEEL			
	TIMBER			**Interior Pavilion:** Box-beams of reinforced plywood & bundled laminated pillars
	REINFORCED CONCRETE			
	STRUCTURAL GLASS			
	FABRIC			
	OTHERS: BAMBOO			**Exterior Structure-Cage:** Bamboo arched trusses **Interior Pavilion:** Bamboo connectors
NON-STRUCTURAL MATERIALS	STEEL			
	ALUMINIUM			
	TIMBER			
	GLASS			
	PLASTIC			**Interior Pavilion:** Biodegredable insulation
	CONCRETE			
	FABRIC			
	OTHERS: BAMBOO & BRICK			**Bamboo-grass:** Green wall; **Bamboo-fiber:** Roof insulation, cage, screen-wall, flooring; **Brick:** Biodegredable wall

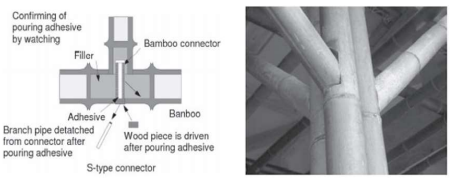
STRUCTURAL SYSTEM & BUILDING MATERIAL PROPERTIES			
FUNC.	Significant structure		Innovative bamboo connectors which allows for easy recycling process.
	Significant material		New eco-friendly materials and bamboo technologies.
	Optimized design		
	Enabling adaptability		Easing disassembly and recycling to allow adaptability.
ENV.	Smart materials/systems		Biodegradable plastic and brick, photo-catalytic steel plate, bamboo-fiber insulation
	Eco-friendly materials		Materials provide higher insulation level, less energy consumption in production, less carbon emissions.
	Reclaimed materials		Biomass timber structural materials are produced from the wastes of forest thinning.
	High recyclability / reusability rate		Bamboo and biomass materials have higher recycling rate.
	Reducing impact on site		The structural system is designed to minimize the effects on the natural setting.
SOC.	Traditional style		
	Traditional materials		Bamboo and timber are Japanese materials.
ECON.	Light-weight materials		Bamboo and timber structures, as well as steel plates are lightweight that eases assembly and disassembly.
	Standardized modules		Units are standardized, except the knitted bamboo mesh on the exterior of the pavilion.
	Prefabricated units		
	Reversible connections		The connections are reversible to ease the dissambly.
ROLE IN SUSTAINABLE POST-EXPO USE PROCESS		++ +	Biodegredable and natural materials allow for high recycling rate with low energy consumption.



(2) Elevation and section


(3)Bamboo truss system - Bamboo cage in a hexagonal pattern


(4)Bamboo mesh knitted on the cage



(5) Bamboo connectors detail

REFERENCES: (1) https://commons.wikimedia.org/wiki/File:Japan_Pavilion_Nagakute.jpg; (2-3-4-5) Hikosaka, Y. (2005). Eco-friendly technologies in the Japanese Pavilion at EXPO 2005 in Aichi, Japan. Internationales Holzbau-Forum 2005. Retrşeved from: https://www.forum-holzbau.com/pdf/Hikosaka_Yutaka_2005.pdf

- **Construction Features: Structural System and Building Materials**

The pavilion combines traditional Japanese craftsmanship with innovative technologies and materials, making the construction techniques and materials a crucial part of the exhibition (*The Japan Pavilions -The Host Country Welcomes Visitors with its National Pavilions,* n.d.). The bamboo cage surrounding the pavilion is driven from the traditional Japanese blinds produced by traditional technology of Japanese bamboo craft with 40.000 domestic bamboos (Inoue et al., 2008; Hikosaka, 2005). The hexagonal patterned cage knitted with bamboo mesh has a bamboo truss structure made of smoked bamboo produced by the "Eco-Dry-System, to make them stronger and protect against cracking and corruption" (Hikosaka, 2005, p.7). The cage with a hexagonal pattern, fixes and reinforces the trusses, while the bamboo trusses carry the cage and connect it to the main building.

The pavilion inside the cage consists of a long-span reinforced plywood boxed beam and bundled columns made of small-diameter log timber from forest thinning considered biomass. The connecting system between columns and beams is an innovative system developed by Inoue et al. (2008) and adopted for this pavilion. It is called 'bamboo connector' which is a system that utilizes connectors made of laminated bamboo lumber rather than metal. The connectors are embedded at joints via adhesives which increases the load capacity and bonding effect between parts (Inoue et al., 2008).

Biomass and natural materials are the primary sources of the building and structural materials. Bamboo is utilized in screen-walls, flooring, and blinds, while the roof is made of bamboo tiles. Biodegradable plastics and bamboo fibers are used as insulation materials in walls. Brick that returns to the soil is another biodegradable material used for walls. The pavilion also allows for observing wall-greening with bamboo grass green walls (Hikosaka, 2005; Inoue et al., 2008).

- **Sustainable Construction Features and Their Role in Post-Expo Use**

The pavilion becomes a laboratory for timber engineering technologies and eco-friendly materials (Inoue et al., 2008). The bamboo cage works as a sunscreen and has effects such as reducing solar energy gain and thermal load with the bamboo grass green wall (Hikosaka, 2005). Utilizing bamboo roof tiles, bamboo fiber, and

biodegradable plastic walls as insulation members also increases the thermal insulation efficiency “by air pockets trapped between the materials” (Hikosaka, 2005, p. 5). The photo-catalytic steel tiles and water sprinklers in the roof cool down the spaces (*The Japan Pavilions -The Host Country Welcomes Visitors with its National Pavilions,* n.d.). All these materials and implementations reduce the energy consumption and greenhouse gas emissions of the pavilion.

The pavilion is also considered “an experimental model for the concept of reuse and recycle of architecture” in terms of utilizing biodegradable and recyclable materials and making disassembly and recycling processes easier while preserving the material value of the construction elements (Tsunoda et al., 2007, p. 188). Utilizing bamboo connectors developed by Inoue et al. (2008) rather than metal connectors allow to recycle the dismantled timber beams and columns without requiring to separate connectors from dismantled parts, which saves both energy and time. When the pavilion was dismantled after the Expo, timber materials were sold in an Internet auction for reuse (Tsunoda et al., 2007).

5.3.2. Republic of Korea Pavilion (2005)



Figure 5.12: Republic of Korea Pavilion (2005) (http://www.expo2005.or.jp/en/nations/1j.html)

The Korean pavilion (see Figure 5.12 and Table 5.10) with the theme “Light in Life” received Architectural Quality Golden Award in category A. The pavilion has five 18x18 m modules. The Korean culture, world-view, and industrial successes are blended into five colors and represented through video clips and short films. Through the exhibition, blue symbolizes water and vitality in life, red signifies Korean fashion and the sun, yellow reflects soil and the wellspring of life, black is for natural coal, and white represents light. These colors are also represented in the façade of the pavilion as a symbol of the Korean view of life and nature (*Republic of Korea,* 2004).

Table 5.10: Republic of Korea Pavilion (2005)

EXPO	EXPO 2005 AICHI - JAPAN
NAME:	REPUBLIC OF KOREA PAVILION
Architecture:	*Not Found*
Engineering:	*Not Found*

DESIGN AIM		POST-EXPO SITUATION						THEME & FUNCTION
		PERMANENT			TEMPORARY			
PERMANENT	TEMPORARY	IN USE	NO USE	DEMOLISHED	RECYCLED / REUSED	RELOCATED	DISMANTLED	THEME: Light in Life
	■							POST-EXPO USE: Dismantled

(1) EXPO IMAGE	(2) POST-EXPO IMAGE
	-

GENERAL INFORMATION & GRAPHICS

Foot-print Area: 1620 m² Floor: 2
Length:54m - Width:36m - Height: Not Found Max.Span:18m

STRUCTURAL SYSTEM AND MATERIALS

STRUCTURAL SYSTEM	SECTION ACTIVE	FRAME	■	**Main Pavilion:** Steel frame
		BEAM SYSTEM		
		SLAB SYSTEM		
	SURFACE ACTIVE	LOAD-BEARING WALL		
		FOLDED-PLATE		
		SHELL		
	FORM ACTIVE	CABLED		
		MEMBRANE		
		PNEUMATICS		
		ARCH		
	VECTOR ACTIVE	2D TRUSS		
		3D TRUSS / SPACE FRAME		
		GEODESIC DOME		
		OTHERS:		
STRUCTURAL MATERIALS		STEEL	■	**Main Pavilion:** Steel frame
		TIMBER		
		REINFORCED CONCRETE		
		STRUCTURAL GLASS		
		FABRIC		
		OTHERS:		
NON-STRUCTURAL MATERIALS		STEEL		
		ALUMINIUM	■	**Main Pavilion:** Aluminum exterior cladding
		TIMBER		
		GLASS		
		PLASTIC		
		CONCRETE		
		FABRIC		
		OTHERS: KOREAN PAPER	■	**Smaller pavilion inside:** 6x6x7 m Korean paper cube

STRUCTURAL SYSTEM & BUILDING MATERIAL PROPERTIES

FUNC.	Significant structure		
	Significant material	■	Korean paper used for the interior small pavilion
	Optimized design		
	Enabling adaptability	■	The standardized and simple design of the pavilion enables both refunctioning and/or easy disassembly.
ENV.	Smart materials/systems		
	Eco-friendly materials		
	Reclaimed materials		
	High recyclability / reusability rate		
	Reducing impact on site	■	The structural system is designed to minimize the effects on the natural setting.
SOC.	Traditional style		
	Traditional materials	■	Korean paper and ceramics are used inside the pavilion for exhibition areas and to built smaller pavilion.
ECON.	Light-weight materials	■	Aluminum, dry-wall, and Korean paper
	Standardized modules	■	Standardized modules is the key principle of the design of the pavilion.
	Prefabricated units	■	Prefabricated panels and structural components are utilized in the construction of the pavilion.
	Reversible connections	■	The connections are reversible to ease the dissambly.
ROLE IN SUSTAINABLE POST-EXPO USE PROCESS		++	Simple structural system for easy disassambly in the post-expo period.

NO IMAGES FOUND

REFERENCES:
(1) http://www.expo2005.or.jp/en/nations/1j.html

- **Construction Features: Structural System and Building Materials**

The pavilion consists of five modules of steel frame structures, cladded with aluminum panels. Yellow Korean ceramics crafted by Korean masters are utilized as interior wall cladding in the exhibition areas. The Korean paper is also used to create a small structure inside the pavilion, which is "a huge box (6x6 m) of Korean paper laced with traditional Korean mountain bridgework floats up to 7 meters high", in addition to a tiger sculpture made of traditional Korean paper (*Republic of Korea Pavilion,* 2004).

- **Sustainable Construction Features and Their Role in Post-Expo Use**

The post-expo use of the pavilion is not clearly defined, except that the pavilion is dismantled after the event. The structural system characteristics are standardized for easy construction and disassembly while reducing the impact of the site as in most national pavilions. With this aim, lightweight and prefabricated components with standardized dimensions and reversible connections are utilized.

5.3.3. Turkey Pavilion (2005)



Figure 5.13: Turkey Pavilion (2005) (http://www.expo2005.or.jp/en/nations/3m.html)

The Turkey Pavilion (see Figure 5.13 and Table 5.11), designed by Hassa Architecture, received Architectural Quality Golden Award in category B. The pavilion consists of three modules arranged in an L-shaped layout. The theme "The Geometry of Nature" is reflected through timber structures featuring fractal geometrical motifs built inside the pavilion. The motifs respond to the traditional Turkish-Islamic architecture while also reflecting the geometries repeated in nature, such as Nautilus or snow crystals. They aim to illustrate the beauty hidden in the particular order of nature (*"Nature's Wisdom Award" Expo 2005 Aichi, Turkey Pavillion*, 2005).

Table 5.11: Turkey Pavilion (2005)

EXPO NAME:	EXPO 2005 AICHI - JAPAN TURKEY PAVILION
Architecture:	Hassa Architecture
Engineering:	*Not Found*

DESIGN AIM		POST-EXPO SITUATION						THEME & FUNCTION
		PERMANENT			TEMPORARY			
PERMANENT	TEMPORARY	IN USE	NO USE	DEMOLISHED	RECYCLED / REUSED	RELOCATED	DISMANTLED	THEME: The Geometry of Nature POST-EXPO USE: Materials are used in the History Museum - İstanbul
	■				■			

(1) EXPO IMAGE	(2) POST-EXPO IMAGE
	-

GENERAL INFORMATION & GRAPHICS

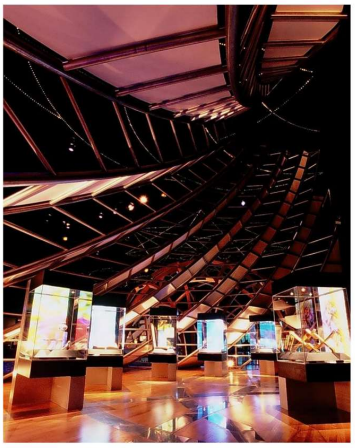
Foot-print Area: 972 m² — Floor: 2
Length: 36 m - Width: 36 m - Height: Not Found — Max. Span: 18 m

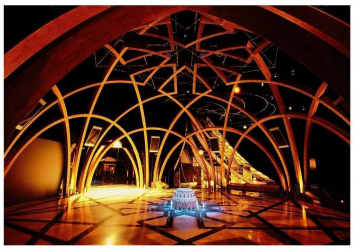
STRUCTURAL SYSTEM AND MATERIALS

STRUCTURAL SYSTEM	SECTION ACTIVE	FRAME	**Pavilion:** Steel frame
		BEAM SYSTEM	
		SLAB SYSTEM	
	SURFACE ACTIVE	LOAD-BEARING WALL	
		FOLDED-PLATE	
		SHELL	
	FORM ACTIVE	CABLED	
		MEMBRANE	
		PNEUMATICS	
		ARCH	
	VECTOR ACTIVE	2D TRUSS	
		3D TRUSS / SPACE FRAME	
		GEODESIC DOME	
		OTHERS:	
STRUCTURAL MATERIALS		STEEL	**Pavilion:** Steel frame
		TIMBER	
		REINFORCED CONCRETE	
		STRUCTURAL GLASS	
		FABRIC	
		OTHERS:	
NON-STRUCTURAL MATERIALS		STEEL	
		ALUMINIUM	
		TIMBER	**Spatial timber structures:** with fractal geometries inside the pavilion
		GLASS	
		PLASTIC	
		CONCRETE	
		FABRIC	
		OTHERS: DRYWALL	Exterior cladding and interior finishing

STRUCTURAL SYSTEM & BUILDING MATERIAL PROPERTIES

FUNC.	Significant structure		
	Significant material		
	Optimized design		
	Enabling adaptability		The standardized and simple design of the pavilion enables both refunctioning and/or easy disassembly.
	Smart materials/systems		
ENV.	Eco-friendly materials		
	Reclaimed materials		
	High recyclability / reusability rate		
	Reducing impact on site		The structural system is designed to minimize the effects on the natural setting.
SOC.	Traditional style		Spatial timber structures: with fractal geometries inside the pavilion reflects the traditional style.
	Traditional materials		Timber is a traditional material of Turkey.
ECON.	Light-weight materials		Timber and dry-wall
	Standardized modules		Standardized modules is the key principle of the design of the pavilion.
	Prefabricated units		Prefabricated panels and structural components are utilized in the construction of the pavilion.
	Reversible connections		The connections are reversible to ease the dissambly.
ROLE IN SUSTAINABLE POST-EXPO USE PROCESS		++	Simple structural system for easy disassambly in the post-expo period.







(2) Spatial timber structures: with fractal geometries inside the pavilion

REFERENCES:
(1) http://www.expo2005.or.jp/en/nations/3m.html
(2) https://www.hassa.com/en/project/expo-2005-aichi-turkey-pavilion

- **Construction Features: Structural System and Building Materials**

The pavilion has a steel frame structure consisting of three 18x18 m modules, cladded with turquoise panels, a color representing Turkish identity. The façade of the exhibition space is completely solid, which creates an entirely dark interior space enlightened with artificial light. The transparent and lightweight timber structures inside the pavilion carry up the two-dimensional geometries to the third dimension to create semi-open spaces inside the pavilion (*"Nature's Wisdom Award" Expo 2005 Aichi, Turkey Pavillion*, 2005).

- **Sustainable Construction Features and Their Role in Post-Expo Use**

The pavilion has a modular steel frame structure like other national pavilions for easy disassembly. The materials were sent back to Turkey to be used for the History Museum in Istanbul after the Expo (*Turkey Pavilion,* 2004).

5.3.4. Philippines Pavilion (2005)



Figure 5.14: Philippines Pavilion (2005) (http://www.expo2005.or.jp/fr/nations/6h.html)

The 324 m² pavilion (see Figure 5.14 and Table 5.12), consisting of one module, received Architectural Quality Golden Award in category C, which contains pavilions smaller than 324 sqm. The coconut is used as the base material of the theme "Usbong: Seeds of Life" since the Philippines is one of the biggest exporters of coconut. The architectural design of the seven main exhibition areas portrays a coconut tree. A 7 m diameter small dome-shaped pavilion in the interior, resembling a coconut, is called a 'health and wellness cocoon', and it functions as a spa and healing center. Throughout the exhibition, the country's past, present, and future, together with developments and successes in environmental protection and sustainability, are emphasized (*RP Bags Top Prize in Japan Expo, 2005)*.

Table 5.12: Philippines Pavilion (2005)

EXPO	EXPO 2005 AICHI - JAPAN
NAME:	PHILIPINNES PAVILION
Architecture:	*Not Found*
Engineering:	*Not Found*

DESIGN AIM		POST-EXPO SITUATION						THEME & FUNCTION
		PERMANENT			TEMPORARY			
PERMANENT	TEMPORARY	IN USE	NO USE	DEMOLISHED	RECYCLED / REUSED	RELOCATED	DISMANTLED	THEME: Usbong: Seeds of Life
	■							POST-EXPO USE: Dismantled

(1) EXPO IMAGE	(2) POST-EXPO IMAGE
	-

GENERAL INFORMATION & GRAPHICS

Foot-print Area: 324 m² Floor: Not Found
Length: 18 m - Width: 18 m - Height: Not Found Max. Span: 18 m



(2) Dome-shaped small pavilion in the interior: walls and ceiling covered with fabrics and textiles of "silk cocoon"

STRUCTURAL SYSTEM AND MATERIALS

STRUCTURAL SYSTEM	SECTION ACTIVE	FRAME	**Main Pavilion:** Steel frame
		BEAM SYSTEM	
		SLAB SYSTEM	
	SURFACE ACTIVE	LOAD-BEARING WALL	
		FOLDED-PLATE	
		SHELL	**Dome-shaped small pavilion:** inside the main pavilion.
	FORM ACTIVE	CABLED	
		MEMBRANE	
		PNEUMATICS	
		ARCH	
	VECTOR ACTIVE	2D TRUSS	
		3D TRUSS / SPACE FRAME	
		GEODESIC DOME	
		OTHERS:	
STRUCTURAL MATERIALS		STEEL	**Main Pavilion:** Steel frame
		TIMBER	
		REINFORCED CONCRETE	
		STRUCTURAL GLASS	
		FABRIC	
		OTHERS:	
NON-STRUCTURAL MATERIALS		STEEL	
		ALUMINIUM	**Main Pavilion:** Precision-cut aluminum panel strips for cladding
		TIMBER	
		GLASS	
		PLASTIC	
		CONCRETE	
		FABRIC	**Dome-shaped small pavilion:** walls and ceiling covered with fabrics and textiles of "silk cocoon"
		OTHERS: COCONUT, SILK COCCOON	**Coconut:** Exhibition areas and flooring **Silk coccoon:** Fabric for walls

STRUCTURAL SYSTEM & BUILDING MATERIAL PROPERTIES

FUNC.	Significant structure	
	Significant material	Coconut and silk-caccoon used for interior applications are significant materials.
	Optimized design	
	Enabling adaptability	The standardized and simple design of the pavilion enables both refunctioning and/or easy disassembly.
ENV.	Smart materials/systems	
	Eco-friendly materials	Silk cacoon and coconut used for cladding in exhibition areas and flooring are natural and eco-friendly
	Reclaimed materials	
	High recyclability / reusability rate	
	Reducing impact on site	The structural system is designed to minimize the effects on the natural setting.
SOC.	Traditional style	
	Traditional materials	Silk cacoon and coconut are traditional materials.
ECON.	Light-weight materials	Aluminum, dry-wall, silk cacoon and coconut
	Standardized modules	Standardized modules is the key principle of the design of the pavilion.
	Prefabricated units	Prefabricated panels and structural components are utilized in the construction of the pavilion.
	Reversible connections	The connections are reversible to ease the dissambly.
ROLE IN SUSTAINABLE POST-EXPO USE PROCESS	++	Simple structural system for easy disassambly in the post-expo period.

REFERENCES:
(1) http://www.expo2005.or.jp/en/nations/6h.html, (2) https://www.flickr.com/photos/expomuseum/59519579

- **Construction Features: Structural System and Building Materials**

18 m wide and 18 m long steel frame structure is utilized. The steel frame is cladded with perforated "precision-cut aluminum panel strips using water jet technology" (*Philippines Pavilion,* 2004), allowing diffused daylight. The 7 m diameter sphere inside the pavilion is cladded with pieces of fabric, while the walls and ceiling are also covered with weaving panels made of Philippine fabrics and 'silk cocoon' textile. The modernly engineered coconut is also utilized for cladding the floors (*Philippines Pavilion,* 2004).

- **Sustainable Construction Features and Their Role in Post-Expo Use**

The post-expo use of this pavilion after the disassembly is not clearly determined. The simple structural system and lightweight building materials allow easy construction and disassembly. Using natural materials like cocoon silk, fabric, and coconut flooring allows for low carbon emission in the production phase and recycling.

5.3.5. Spain Pavilion (2005)



Figure 5.15: Spain Pavilion (2005) (https://worldarchitecture.org/architecture-projects/hhpg/spanish-pavillion-at-expo-2005-aichi-project-pages.html)

The pavilion (see Figure 5.15 and Table 5.13), designed by Foreign Office Architects (FOA), received Architectural Quality Silver Award in category A. It consists of 5 modules with two floors. The exhibition spaces, trade areas and tapas bars, restaurant, VIP lounge, reading and multimedia room, and offices are the functions in the pavilion (Sirica, 2006). The architects aim to reflect the hybridization of Christian and Islamic cultures that has existed in Spain throughout history in the design of architectural and

Table 5.13: Spain Pavilion (2005)

EXPO	EXPO 2005 AICHI - JAPAN
NAME:	SPAIN PAVILION
Architecture:	Foreign Office Architects
Engineering:	*Not Found*

DESIGN AIM		POST-EXPO SITUATION						THEME & FUNCTION
		PERMANENT			TEMPORARY			
PERMANENT	TEMPORARY	IN USE	NO USE	DEMOLISHED	RECYCLED / REUSED	RELOCATED	DISMANTLED	THEME: The Geometry of Nature
								POST-EXPO USE: Ceramic tiles were donated to the kindergartens and municipalities, and other building materials were sold in online auction.

(1) EXPO IMAGE	(2) POST-EXPO IMAGE
	-

GENERAL INFORMATION & GRAPHICS

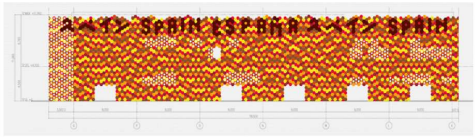
Foot-print Area: 1620 m²
Length: 54 m - Width: 36 m - Height: 9 m
Floor: 2
Max. Span: 18 m

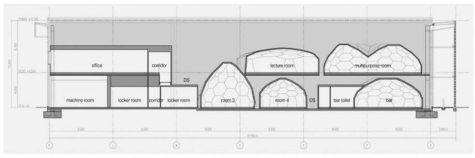
STRUCTURAL SYSTEM AND MATERIALS

STRUCTURAL SYSTEM	SECTION ACTIVE	FRAME		**Exterior Structure:** Steel frame structure
		BEAM SYSTEM		
		SLAB SYSTEM		
	SURFACE ACTIVE	LOAD-BEARING WALL		
		FOLDED-PLATE		
		SHELL		**Interior Structure:** Small pavilions in the form of vaulted-bubbles (Material: *Not Found*)
	FORM ACTIVE	CABLED		
		MEMBRANE		
		PNEUMATICS		
		ARCH		
	VECTOR ACTIVE	2D TRUSS		
		3D TRUSS / SPACE FRAME		
		GEODESIC DOME		
		OTHERS:		
STRUCTURAL MATERIALS		STEEL		**Exterior Structure:** Steel frame structure
		TIMBER		
		REINFORCED CONCRETE		
		STRUCTURAL GLASS		
		FABRIC		
		OTHERS:		
NON-STRUCTURAL MATERIALS		STEEL		
		ALUMINIUM		**Exterior Structure - Façade:** Aluminum frame for hanging ceramic tiles
		TIMBER		
		GLASS		
		PLASTIC		
		CONCRETE		
		FABRIC		
		OTHERS: CERAMIC		**Exterior Structure - Façade:** Hexagonal glazed ceramic tiles

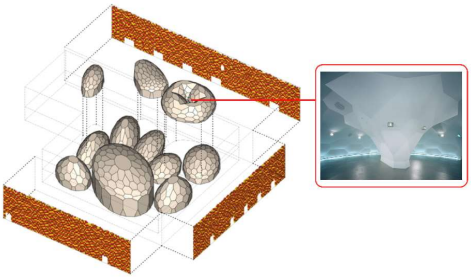
STRUCTURAL SYSTEM & BUILDING MATERIAL PROPERTIES

FUNC.	Significant structure		Both interior small pavilions and façade of the pavilion have significant design.
	Significant material		
	Optimized design		
	Enabling adaptability		The standardized and simple design of the pavilion enables both easy disassembly and refunctioning.
ENV.	Smart materials/systems		
	Eco-friendly materials		
	Reclaimed materials		
	High recyclability / reusability rate		The unique ceramic units provides a unique function as garden sculptures after the disassembly.
	Reducing impact on site		The structural system is designed to minimize the effects on the natural setting.
SOC.	Traditional style		Small vaulted bubble pavilions and ceramic façade are modern reinterpretation of traditional Spanish architecture.
	Traditional materials		Glazed ceramic used in the façade is a widespread material in Spain.
ECON.	Light-weight materials		
	Standardized modules		The puzzle-like ceramic tiles allows for easier disassamble of the façade.
	Prefabricated units		Prefabricated ceramic panels and structural components are used.
	Reversible connections		The connections are reversible to ease the dissambly.
ROLE IN SUSTAINABLE POST-EXPO USE PROCESS		++	The unique features of the façade used as garden sculptures as a memory of the Expo.

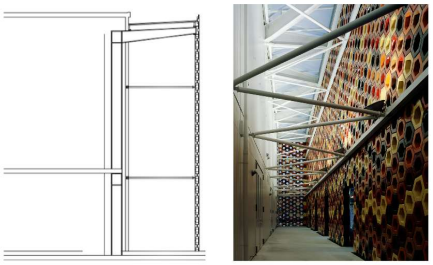




(2) Elevation and section



(3) Axonometric view:
Interior Vaulted Bubbles & Ceramic Façade



(4) Extruded façade:
Hexagonal ceramic tiles hang on aluminum frame



(5) Hexagonal ceramic tiles

REFERENCES:
(1) https://www.archilovers.com/projects/155810/gallery?1309212
(2-3-4-5) https://www.ceramicarchitectures.com/obras/spanish-pavilion-expo-2005/

structural features of the pavilion (*Spanish Pavilion at the 2005 World Expo, Aichi, Japan*, n.d.). The modernized versions of "spatial elements: patios, churches and chapels, structural elements: arches and vaults, and decorative elements: gratings and insets" (Sirica, 2006, p.102) belong to Spanish architecture are combined in the design. The pavilion consists of seven interconnected spaces arranged around a central space which resembles the relationship between the nave and the chapels in cathedrals. The chapels with different functions are designed like bubbles by combining Gothic vaults, Islamic domes, and modern spheres (Sirica, 2006). The vaulted bubbles are surrounded by a perforated envelope made of hexagonal ceramics that reflect a contemporary interpretation of the traditional lattice of Islamic and Christian architecture. The lattice frame covers the circulation core of the pavilion together with vaulted bubbles. This creates a transitional space between the inside and the outside while preventing the direct sunlight, which resembles Japanese engawa (in-between space) (*Spanish Pavilion at the 2005 World Expo, Aichi, Japan*, n.d.).

- **Construction Features: Structural System and Building Materials**

The pavilion, consisting of five 18x18x19 meters steel frame modules, is surrounded by an aluminum frame on three sides of its façade, which is cladded with ceramic tiles (*Spanish Pavilion, Aichi - FOA: Foreign Office Architects*, 2020). The aluminum frame is offset from the main structure 1 meter in the west and 3.5 meters in the east and north directions and connected to the main structure with trussed steel tubes. The hexagonal ceramic tiles, so-called celosias, are reinterpretations of decorative motifs of Gothic, Islamic, and Japanese cultures (Sirica, 2006). They are assembled with steel wires and fastened to the aluminum frame. The ceramic tiles are designed in six different shapes and colors that can be assembled in different geometrical combinations, allowing for a non-repetitive pattern through the façade. The 15,000 panels are made of ceramic, a common material in both Spain and Japan, and produced by hand in Spain using the glazed ceramic technique (Bonet, 2016). The production process required high technical specialty due to the complexity of the shapes and their unique assembly pattern (*Spanish Pavilion Expo 2005,* 2020). The six colors are different tones of the Spanish flag (red and yellow) which symbolize wine, blood, roses, sun, and sand associated with Spain (Sirica, 2006).

- **Sustainable Construction Features and Their Role in Post-Expo Use**

Like all other national pavilions, the Spain pavilion is also disassembled after the Expo. Since the hexagonal pieces are connected with steel wires and adjustable bindings, they were dismantled easily. The pavilion took attention among other pavilions with its traditional architectural features and modern construction techniques, especially in the façade system. The ceramic tiles in the façade are considered unique elements, that their efficient post-expo use should be ensured. Therefore, one-third of the ceramic tiles (5000) were “donated to the kindergartens of Nagoya for the children to play with and to the municipalities of the region for use as garden sculptures” (*Spanish Pavilion, Aichi - FOA: Foreign Office Architects*, 2020), while rest of the tiles and other building materials are set to sale (*The Spanish pavilion at Expo Aichi 2005 puts the hexagon ceramics and other materials up for sale,* 2005).

5.3.6. Mexico Pavilion (2005)



Figure 5.16: Mexico Pavilion (2005) (https://www.pinterest.de/pin/330099847664690423/)

The pavilion (see Figure 5.16 and Table 5.14) consisted of three modules arranged linearly and received Architectural Quality Silver Award in category B. The theme "Complicatedly Intertwined Diversity: Changing Nature and Culture" represents Mexico's unique culture that respects the environment and existence of animals and plants, national land richness, and Mexican biodiversity via videos and images (*Mexico Pavilion*, 2004). The four major ecosystems in Mexico -sea, desert, forest, and jungle- are experienced via museography resources, videos and images by walking through platforms and mezzanines (*Mexico Pavilion opens its doors in the Expo, 2005).*

Table 5.14: Mexico Pavilion (2005)

EXPO	EXPO 2005 AICHI - JAPAN
NAME:	MEXICO PAVILION
Architecture:	*Not Found*
Engineering:	*Not Found*

DESIGN AIM		POST-EXPO SITUATION						THEME & FUNCTION
		PERMANENT			TEMPORARY			
PERMANENT	TEMPORARY	IN USE	NO USE	DEMOLISHED	RECYCLED / REUSED	RELOCATED	DISMANTLED	THEME: Complicatedly Intertwined Diversity: Changing Nature and Culture
								POST-EXPO USE: Dismantled

STRUCTURAL SYSTEM AND MATERIALS				
STRUCTURAL SYSTEM	SECTION ACTIVE	FRAME		Steel frame
		BEAM SYSTEM		
		SLAB SYSTEM		
	SURFACE ACTIVE	LOAD-BEARING WALL		
		FOLDED-PLATE		
		SHELL		
	FORM ACTIVE	CABLED		
		MEMBRANE		
		PNEUMATICS		
		ARCH		
	VECTOR ACTIVE	2D TRUSS		
		3D TRUSS / SPACE FRAME		
		GEODESIC DOME		
		OTHERS:		
STRUCTURAL MATERIALS		STEEL		Steel frame
		TIMBER		
		REINFORCED CONCRETE		
		STRUCTURAL GLASS		
		FABRIC		
		OTHERS:		
NON-STRUCTURAL MATERIALS		STEEL		
		ALUMINIUM		**Façade:** Aluminum cladding
		TIMBER		
		GLASS		Glazing in façade
		PLASTIC		
		CONCRETE		
		FABRIC		**Façade:** Translucent fabric screen
		OTHERS:		

STRUCTURAL SYSTEM & BUILDING MATERIAL PROPERTIES			
FUNC.	Significant structure		
	Significant material		
	Optimized design		
	Enabling adaptability		The standardized and simple design of the pavilion enables both refunctioning and/or easy disassembly.
ENV.	Smart materials/systems		
	Eco-friendly materials		
	Reclaimed materials		
	High recyclability / reusability rate		
	Reducing impact on site		The structural system is designed to minimize the effects on the natural setting.
SOC.	Traditional style		
	Traditional materials		
ECON.	Light-weight materials		Aluminum, and fabric
	Standardized modules		Standardized modules is the key principle of the design of the pavilion.
	Prefabricated units		Prefabricated panels and structural materials are utilized in the construction of the pavilion.
	Reversible connections		The connections are reversible to ease the dissambly.
ROLE IN SUSTAINABLE POST-EXPO USE PROCESS		+	Simple structural system for easy disassambly in the post-expo period.

(1) EXPO IMAGE	(2) POST-EXPO IMAGE
	-

GENERAL INFORMATION & GRAPHICS

Foot-print Area: 972 m²
Length: 54m - Width: 18m - Height:12m
Floor: 2
Max. Span:18 m





(2) Exterior view - Translucent Fabric Screen Façade: images representing the living species in the wide ecosystems of Mexico are projected to the façade

REFERENCES:
(1) https://www.pinterest.de/pin/330099847664690423/
(2) https://www.urbipedia.org/hoja/Pabellón_de_México_en_la_Expo_2005_Aichi#/media/File:PabellónMéxicoExpo2005Aichi.2.jpg

- **Construction Features: Structural System and Building Materials**

The pavilion comprises three 18 m long, 18 m wide, and 12 m high prefabricated steel frame structure modules. The façade is designed with a translucent fabric screen with images representing the living species in the wide ecosystems of Mexico. The appearance of the façade changes through lighting from day to night (*Performance of Mexico at the 2005 Aichi*, 2005).

- **Sustainable Construction Features and Their Role in Post-Expo Use**

The modular steel frame and translucent fabric façade allow easy disassembly and relocation. Although it was planned that some parts of the exhibition would be relocated to be displayed in museums in Mexico, the plan was not executed for unknown reasons (*Mexico Pavilion at Expo 2005 Aichi,* 2019).

5.4. Shanghai World Expo Pavilions (2010)

Theme: Better City, Better Life

Time Period: 01 May – 31 October 2010 (6 Months)

Area: 528 ha.

Number of Participant Nations: 192

Total Visitors: 73.085.000

The Shanghai World Expo 2010 is the first expo focusing on sustainable urban development to solve the problems of the city while being the largest, most visited, and most expensive World Expo ever held. It is also the first expo held in a developing country, China. It is organized in the southern part of the city along both sides of the Huangpu River of 15 km (see Figure 5.17) (Pletcher, 2010). With this aim, intensive urban redevelopment implications had been conducted, including renovation of over 200 factories, upgrading the infrastructure, conducting extensive road improvements, expanding the existing city rail system while adding new lines, training 1.7 million workers, and removing the industrial development from the city center to remediate the land around the Huangpu River within the city while causing the relocation of thousands of residents from the neighborhood (Pletcher, 2010; Krupar, 2018). The

urban redevelopment mission of the Expo is promoted by proposing solutions to achieve environmentally friendly cities “through urban economic prosperity, innovations in science and technology, improved interactions between rural and urban areas, and personal reflections on urban community” (Krupar, 2018, p. 92). The Expo is a huge showcase for the use of new materials, energy-efficient and eco-friendly technologies, renewable and clean energy systems (solar, wind, biomass, fuel cells, geothermal energy), energy-efficient technologies especially in the building sector, artificial intelligence technologies, low-carbon transportation systems, and vehicles, as well as water and waste treatment systems (Technolog, 2014). Many of these technologies and advancements are applied to the pavilions, even though most of the pavilions are temporary. Among the awarded pavilions, the top five pavilions in the Pavilion Design category (see Section 4.1) are selected to be examined in this study and the host-country pavilion.

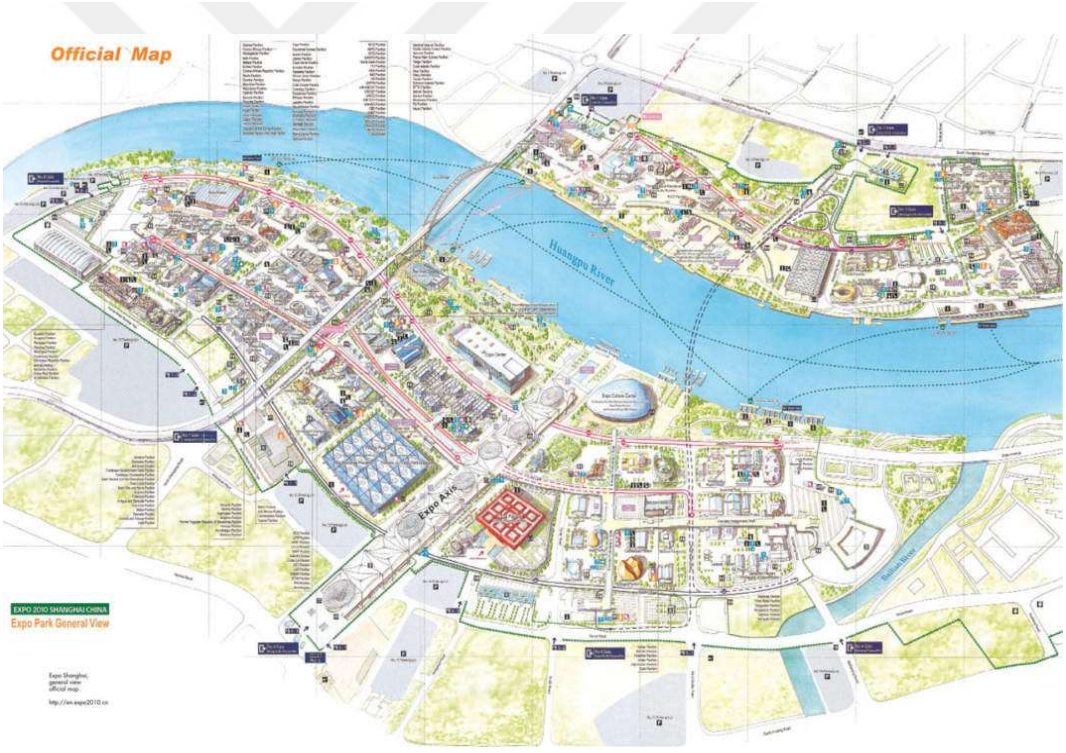


Figure 5.17: Shanghai World Expo (2010) Site (https://www.area-arch.it/en/masterplan-expo-shanghai/)

5.4.1. China Pavilion (2010)



Figure 5.18: China Pavilion (2010)
(https://tr.m.wikipedia.org/wiki/Dosya:China_Pavilion_of_Expo_2010.jpg)

The host-country pavilion, is designed by He Jingtang and called 'Oriental Crown' referring to its inverted trapezoid form (see Figure 5.18 and Table 5.15). All green applications used in the Shanghai World Expo, mentioned in Section 5.3, are implemented in the pavilion for energy saving, energy generation, and waste treatment (Technolog, 2014). The 69 m high pavilion is a giant structure that encloses over 150.000 sqm. floor area, which is the biggest national pavilion in the Expo and three times higher than any other pavilion (Deng, 2013). The architectural and structural characteristics of the pavilion aim to reflect the cultural aspects of China. The reason for choosing the bright red color is referring to Chinese culture. The pavilion combines one of the oldest and most common traditional Chinese structures with modern technology and materials, *Dougong*, used for carrying the roof with the help of ancient joinery techniques for nearly three thousand years. The dougong system of the pavilion consists of 56 interlocking wooden brackets representing 56 ethnic minority groups of China (Drury, 2010). Adapting a traditional structure into a modern one allows for approximately 5600 sqm of free space on the ground floor of the pavilion, which is integrated with the outside area to host 31 joint provincial pavilions (Wu et al., 2014). Since 2012, it "has reopened as China Fine Arts Palace to the public, providing ten times the exhibit space of the original Shanghai Art Museum" (Deng, 2013, p. 111).

- **Construction Features: Structural System and Building Materials**

The pavilion has a high-rise reinforced concrete (RC) structure with four gigantic RC columns and 56 steel beams (brackets) interlocked in 7 levels that carry steel-concrete

Table 5.15: China Pavilion (2010)

EXPO	EXPO 2010 SHANGHAI - CHINA
NAME:	CHINA PAVILION (HOST)
Architecture:	He Jingtang
Engineering:	*Not Found*

DESIGN AIM		POST-EXPO SITUATION						THEME & FUNCTION
		PERMANENT			TEMPORARY			
PERMANENT	TEMPORARY	IN USE	NO USE	DEMOLISHED	RECYCLED / REUSED	RELOCATED	DISMANTLED	THEME:"The Crown of the East" Chinese wisdom in urban development
■		■						POST-EXPO USE: China Fine Arts Palace - exhibition space for Shanghai Art Museum

(1) EXPO IMAGE	(2) POST-EXPO IMAGE
	

GENERAL INFORMATION & GRAPHICS

Built Area: 160.000 m² — Floor: 7
Length:113 m - Width:113 m - Height:63 m — Max. Span:113 m

STRUCTURAL SYSTEM AND MATERIALS

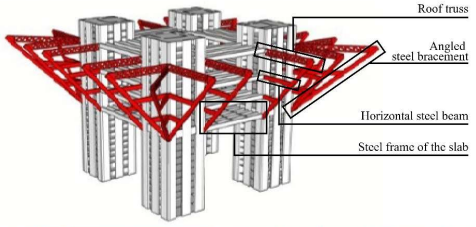
STRUCTURAL SYSTEM	SECTION ACTIVE	FRAME		
		BEAM SYSTEM		
		SLAB SYSTEM		
	SURFACE ACTIVE	LOAD-BEARING WALL		
		FOLDED-PLATE		
		SHELL		
	FORM ACTIVE	CABLED		
		MEMBRANE		
		PNEUMATICS		
		ARCH		
	VECTOR ACTIVE	2D TRUSS		
		3D TRUSS / SPACE FRAME		
		GEODESIC DOME		
		OTHERS: DOUGONG		**Dougong:** 56 interlocking brackets in 7 levels that carry slabs
STRUCTURAL MATERIAL		STEEL		**Steel beams(brackets):** interlocked in 7 levels to carry steel-concrete slabs
		TIMBER		
		REINFORCED CONCRETE		Reinforced concrete columns and slabs
		STRUCTURAL GLASS		
		FABRIC		
		OTHERS:		
NON-STRUCTURAL MATERIAL		STEEL		
		ALUMINIUM		**Exterior Cladding**: Chinese red quadro-clad textured sandwich panels
		TIMBER		
		GLASS		
		PLASTIC		
		CONCRETE		
		FABRIC		
		OTHERS: UPM-PROFI		**Interior finishing:** An innovative composite material made of recycled paper and plastic

STRUCTURAL SYSTEM & BUILDING MATERIAL PROPERTIES

FUNC.	Significant structure		Dougong is a reinterpretation of a traditional system providing a wide span.
	Significant material		
	Optimized design		
	Enabling adaptability		Wide span structure provides a huge column-free area that can be used for different functions.
ENV.	Smart materials/systems		Photovoltaic painting that produces energy
	Eco-friendly materials		Eco-friendly & energy saving materials
	Reclaimed materials		UPM-Profi is an innovative composite material made of recycled paper and plastic.
	High recyclability / reusability rate		
	Reducing the impact on the site		
SOC.	Traditional style		Dougong system is a reinterpretation of a traditional system.
	Traditional materials		
ECON.	Light-weight materials		
	Standardized modules		
	Prefabricated units		
	Reversible connections		
ROLE IN SUSTAINABLE POST-EXPO USE PROCESS		+	Wide span structure provides a huge column-free area that can be used for exhibitions.

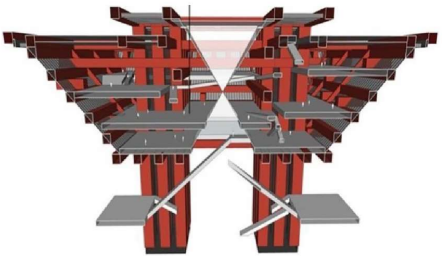



(3) Dougong Structure: Interlocking beams






(4) Details of the structure



(5) Perspective section



(6) Floor plans: Gradually expanding

REFERENCES:
(1) https://tr.m.wikipedia.org/wiki/Dosya:China_Pavilion_of_Expo_2010.jpg; (2) https://en.wikipedia.org/wiki/China_Art_Museum#/media/File:China_Art_Museum,_Shanghai.jpg; (3-4-5-6) Yun , J., Zhou, G., Xia , J., & Tang, R. (2018). The China pavilion of Shanghai Expo. Retrieved May 17, 2022, from http://faculty.arch.tamu.edu/anichols/courses/applied-architectural-structures/projects-631/Files/11-27%20presentation%20Structure%20Case%20Study.pdf

composite slabs. The plan has discontinuities in which the floors below the ground floor are hollow, “while the upper floors are unfolding outwards level by level, forming a shape of an inverted trapezoid”, “resulting in a cantilever span of about 33 m at the roof level” (Yang et al., 2012, p. 266). To support the cantilever roof, “20 inclined columns consisting of concrete-filled rectangular steel tube are placed on the perimeter of the cores as the vertical support of the big-span steel beams on the floors” at the level of the ground floor’s ceiling (Yang et al., 2012, p. 266). To reduce the extreme stress caused by the long cantilever, prestressing technique is implemented on the materials in the horizontal direction of the roof (Wu et al., 2014). For the cladding of the entire building, a huge amount of Chinese red quadroclad textured panels (35.000 sqm.) and quadroclad sandwich panels (21.000 sqm.) are utilized (Hounter Douglas, n.d.). In the interior of the building, UPM-Profi, an innovative composite material made of recycled paper and plastic, is preferred (Technolog, 2014).

- **Sustainable Construction Features and Their Role in Post-Expo Use**

As stated before, the pavilion incorporates several sustainable strategies both in design considerations and material choices. First, the huge column-free area generated by the long-span structure increases the adaptability of the pavilion to respond to commercial exhibitions in the future. Besides, passive design techniques are also considered in the structural system design in which the segregation of beams provides passive ventilation and daylighting (Zhe et al., 2011). Among the low-energy and energy-saving materials (cladding and glazing) and applications (lighting, HVAC, and other building systems), the wood fiber (paper)-plastic composite cladding material, UPM-Profi, used in the interior is an innovative recycled material produced from the wastes of the plastic self-adhesive label. The material is an eco-friendly material that turns waste into valuable material. It can be bio-degraded without causing plastic pollution while combining the advantages of durability, scalability, and strength (Technolog, 2014).

Moreover, a solar power generation system with high color solar cell modules is applied to the building, which is the most efficient system applied to a building till that time. Besides, the exposed wall of the pavilion is sprayed with a painting that can produce electric power from sunlight and store it for lighting (Technolog, 2014). All

these material and structural system characteristics are crucial in the post-expo use, when it is considered that the pavilion is permanent.

Despite the fact that the sustainable properties aim to reduce the energy use in the building operation over its lifetime and provide adaptability, the construction of the pavilion requires a huge amount of material and resources while the materials have high-embodied energy when production and construction processes are considered. Besides, using concrete restrains the flexibility of the pavilion in the long term since it could not be dismounted if it won't be used at some point.

5.4.2. United Kingdom Pavilion (2010)



Figure 5.19: United Kingdom Pavilion (2010) (https://www.designboom.com/architecture/uk-pavilion-at-shanghai-world-expo-2010-2/)

The pavilion, so-called Seed Cathedral (see Figure 5.19 and Table 5.16), is designed by Heatherwick Studio and received the Pavilion Design Golden Award in category A. Its architectural design refers to the Expo theme, *Feeding the Planet*, with its 60.000 glassy acrylic rods in 7.5 m length filled with 250.000 seeds (*Heatherwick Studio: UK Pavilion,* n.d.). The 225 sqm pavilion sits on a 6000 sqm concrete multi-layered landscape designed with different themes to reflect the importance of green spaces in the city (Warmann, 2010b). Since the United Kingdom has established the world's first major botanical institution, the Royal Botanic Gardens at Kew with a Millennium Seedbank, to compile the plant seed species around the world, the pavilion has become a representation of this attempt in the Expo (*Heatherwick Studio: UK Pavilion,* n.d.). The pavilion sits on a 6000 m^2 multi-layered concrete landscape covering only 1/25 of the landscape area. The open public landscape is articulated with three different open exhibition concepts: green city, open city, and living city, to represent how the UK

Table 5.16: United Kingdom Pavilion (2010)

EXPO NAME:	EXPO 2010 SHANGHAI - CHINA UNITED KINGDOM PAVILION
Architecture:	Heatherwick Studio
Engineering:	Adams Kara Taylor

DESIGN AIM		POST-EXPO SITUATION						THEME & FUNCTION
		PERMANENT			TEMPORARY			
PERMANENT	TEMPORARY	IN USE	NO USE	DEMOLISHED	RECYCLED / REUSED	RELOCATED	DISMANTLED	THEME: Building on the Past, Shaping our Future - "Seed Cathedral" POST-EXPO USE: Rods filled with seeds are planted and most of the materials are recycled
	■				■			

STRUCTURAL SYSTEM AND MATERIALS				
STRUCTURAL SYSTEM	SECTION ACTIVE	FRAME	■	Timber diaphragm frame strengthened by steel pipes
		BEAM SYSTEM		
		SLAB SYSTEM		
	SURFACE ACTIVE	LOAD-BEARING WALL		
		FOLDED-PLATE		
		SHELL		
	FORM ACTIVE	CABLED		
		MEMBRANE		
		PNEUMATICS		
		ARCH		
	VECTOR ACTIVE	2D TRUSS		
		3D TRUSS / SPACE FRAME		
		GEODESIC DOME		
		OTHERS:		
STRUCTURAL MATERIAL		STEEL	■	Steel pipes strengthen the main structure
		TIMBER	■	1-m thick timber diaphragm structure
		REINFORCED CONCRETE		
		STRUCTURAL GLASS		
		FABRIC		
		OTHERS:		
NON-STRUCTURAL MATERIAL		STEEL		
		ALUMINIUM	■	Aluminium sleeves that acrylic tubes pass through
		TIMBER		
		GLASS		
		PLASTIC	■	60.000 clear acrylic fiber optic tubes filled with 250.000 seeds
		CONCRETE		
		FABRIC		
		OTHERS: SEEDS	■	Acrylic tubes are filled with seeds is the main building materials of the pavilion
STRUCTURAL SYSTEM & BUILDING MATERIAL PROPERTIES				
FUNC.		Significant structure		
		Significant material	■	Acrylic fiber optic tube filled with seeds is a unique building material.
		Optimized design	■	Computerized design to provide precise form and wavy appearance with tubes.
		Enabling adaptability	■	The main building material provides a significant future adaptability of the function.
ENV.		Smart materials/systems		
		Eco-friendly materials	■	The acrylic tubes filled with seeds: eco-friendly in production and reuse processes
		Reclaimed materials		
		High recyclability / reusability rate	■	The acrylic rods filled with seeds provide a unique reuse process.
		Reducing impact on site		
SOC.		Traditional style		
		Traditional materials	■	The seeds inside the tubes are from Royal Botanic Gardens at Kew, which has a traditional speciality for the UK.
ECON.		Light-weight materials	■	The pavilion has lightweight structure and building materials.
		Standardized modules	■	The pavilion is constructed out of standardized components.
		Prefabricated units	■	All units are prefabricated which assembled on site.
		Reversible connections	■	Pavilion is designed to ease the dissambly process.
ROLE IN SUSTAINABLE POST-EXPO USE PROCESS			++	Planting the seeds: unique reuse process. Recycable building materials, except the concrete landscape, which damages the sustainable post-expo performance.

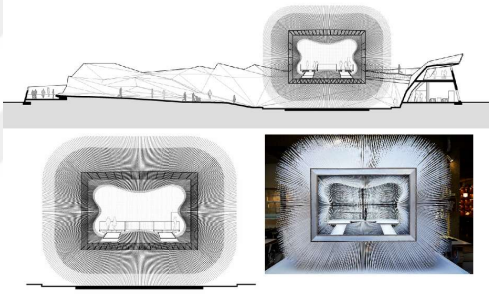
(1) EXPO IMAGE	POST-EXPO IMAGE
	-

GENERAL INFORMATION & GRAPHICS

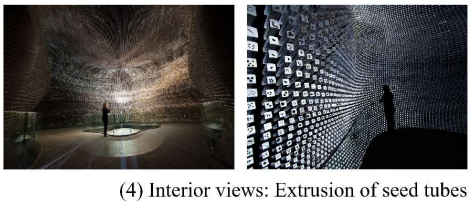
Built Area: 6000 m² Total Floor Area: 225 m² Floor: 1
Length: 15 m - Width: 15 m - Height: 20 m Max. Span: 15 m



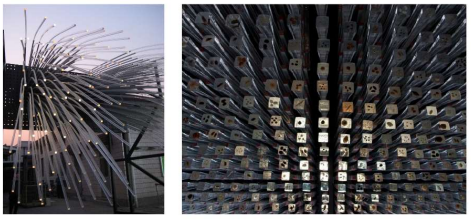
(2) Exterior views: Landscape & Pavilion



(3) Sections: Landscape & Pavilion



(4) Interior views: Extrusion of seed tubes



(5) Seed tubes

NOTE: The concrete landscape damage the sustainable design of the pavilion since it complicates the dismantling process and increase the harm given to the site.

REFERENCES: (1) https://www.akt-uk.com/projects/uk-pavilion-expo-2010/; (2.1) https://www.dezeen.com/2010/03/31/uk-pavilion-at-shanghai-expo-2010-by-thomas-heatherwick-2/ (2.2) https://www.architecturalrecord.com/articles/6767-world-expo-2010-shanghai-united-kingdom-pavilion;(3) https://www.heatherwick.com/project/uk-pavilion/; (4-5) https://www.archdaily.com/58591/uk-pavilion-for-shanghai-world-expo-2010-heatherwick-studio

integrates green spaces into the urban environment and how green spaces in cities are crucial for the sake of our future. The parks, trees, and plants of the UK's four cities are drawn on the ceiling in the *green city* section. At the same time, transparent models of building typologies are suspended upside down from the top in the *open city* area. In the *living city* part, there is a crack filled with greenery in addition to representation of imaginary species and innovative ideas for the future to enhance the relationship between nature and urban development (Warmann, 2010a).

- **Construction Features: Structural System and Building Materials**

The pavilion has a timber diaphragm structure with a 1 m thickness strengthened by steel pipes. The timber diaphragm structure has 20 mm holes in the façade, which acryclic tubes filled with seeds pass through. To achieve geometrically accurate holes in that tubes are placed, the timber diaphragm is modeled with a 3D modeling program and perforated using a computer-controlled milling machine (Warmann, 2010b). The seed tubes extended through the interior are made of fiber optic acrylic, which is a transparent material that transmits the daylight both from the outside to the interior and vice versa. In this way, the pavilion is illuminated by the daytime sunlight and glows at night-time. Besides, since fiber optic tubes are very lightweight, they can wave smoothly in the wind and give the pavilion a lively appearance (*Heatherwick Studio: UK Pavilion,* n.d*.;* Higgins, 2010).

- **Sustainable Construction Features and Their Role in Post-Expo Use**

The simple design of the pavilion combines lightweight materials and is easily dismountable, which reduces the overall energy use in both construction and deconstruction processes. Besides, "all the construction materials used in the UK Pavilion could be recycled, with zero carbon dioxide emission in the whole building" except the vast concrete landscape, which damages the sustainable post-expo performance of the pavilion (Technolog, 2014, p. 5). The pavilion has a unique reuse process, when it is considered that the acrylic rods filled with seeds were distributed to many schools after the Expo, to be planted and revived (Warmann, 2010b).

5.4.3. Finland Pavilion (2010)



Figure 5.20: Finland Pavilion (2010) (https://jkmm.fi/work/finland-pavilion-shanghai-expo-2010/)

The Finland pavilion (see Figure 5.20 and Table 5.17), with the name Kirnu (Giant's Kettle), is designed by JKMM Architects as a miniature of a sustainable city with features from Finland and received the Pavilion Design Golden Award in category B. The visitors are directed to the pavilion via a bridge towards the main entrance. A spiral ramp inside the pavilion located between interior and exterior walls provides the interior circulation (*Shanghai Expo 2010 Finland Pavilion "Kirnu" JKMM Architects*, n.d.). The design of the pavilion is inspired by nature. For instance, the pavilion is surrounded by pools to resemble an island, while the form of the pavilion with a big atrium in its center is inspired by large cavities that occurred during the last Ice Age (*Finland Pavilion Shanghai Expo 2010*, 2022). The atrium enlightens the pavilion while drawing air through interior exhibition spaces to cool down the pavilion. Besides, cladding panels are formed like fish scales to refer again to nature (Pearson, 2010).

- **Construction Features: Structural System and Building Materials**

The pavilion is constructed with bolted steel trusses in which two circular truss frames, one is in the exterior side of the inner wall, and the other is in the interior of the outer wall, are "connected using round HSS members with bolted plate connections" (Meyer Boake, 2013, p. 232). The structure is clad with 25.000 injection-molded shingles made of UPM-Profi, which is an innovative material used also in the interior of the China Pavilion (2010) (Technolog, 2014).

Table 5.17: Finland Pavilion (2010)

EXPO NAME:	EXPO 2010 SHANGHAI - CHINA FINLAND PAVILION
Architecture:	JKMM Architects
Engineering:	*Not Found*

DESIGN AIM		POST-EXPO SITUATION						THEME & FUNCTION
		PERMANENT			TEMPORARY			
PERMANENT	TEMPORARY	IN USE	NO USE	DEMOLISHED	RECYCLED / REUSED	RELOCATED	DISMANTLED	THEME: Kirnu (Giant's Kettle)
	■							POST-EXPO USE: Dismantled to be reerected, if needed in the future

(1) EXPO IMAGE	POST-EXPO IMAGE
	-

GENERAL INFORMATION & GRAPHICS

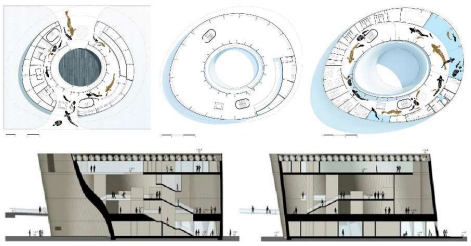
Built Area: 3400 m² — Floor: 4
Length: 38 m - Width: 43 m - Height: 34 m — Max. Span: 10 m

STRUCTURAL SYSTEM AND MATERIALS

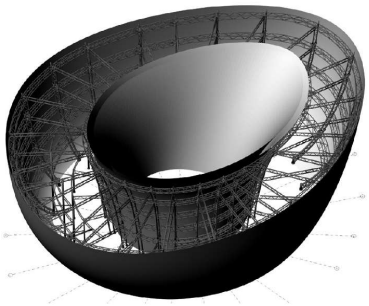
STRUCTURAL SYSTEM	SECTION ACTIVE	FRAME		
		BEAM SYSTEM		
		SLAB SYSTEM		
	SURFACE ACTIVE	LOAD-BEARING WALL		
		FOLDED-PLATE		
		SHELL		
	FORM ACTIVE	CABLED		
		MEMBRANE		
		PNEUMATICS		
		ARCH		
	VECTOR ACTIVE	2D TRUSS		
		3D TRUSS / SPACE FRAME	■	Bolted tubular steel truss
		GEODESIC DOME		
		OTHERS:		
STRUCTURAL MATERIAL		STEEL	■	Bolted tubular steel truss
		TIMBER		
		REINFORCED CONCRETE		
		STRUCTURAL GLASS		
		FABRIC		
		OTHERS:		
NON-STRUCTURAL MATERIAL		STEEL		
		ALUMINIUM		
		TIMBER		
		GLASS		
		PLASTIC		
		CONCRETE		
		FABRIC		
		OTHERS: UPM-PROFI		**Cladding:** 25.000 injection-molded white shingles

STRUCTURAL SYSTEM & BUILDING MATERIAL PROPERTIES

FUNC.	Significant structure		
	Significant material	■	UPM-Profi is an innovative composite material made of recycled paper and plastic.
	Optimized design		
	Enabling adaptability	■	The bolted steel frame enables disassembly.
ENV.	Smart materials/systems		
	Eco-friendly materials		
	Reclaimed materials	■	UPM-Profi made of recycled paper and plastic.
	High recyclability / reusability rate	■	Steel, UPM-Profi
	Reducing impact on site		
SOC.	Traditional style		
	Traditional materials		
ECON.	Light-weight materials		
	Standardized modules	■	Both structural and cladding components are in standardized dimensions.
	Prefabricated units	■	Both structural and cladding components are prefabricated.
	Reversible connections	■	Pavilion is designed to ease the dissambly process.
ROLE IN SUSTAINABLE POST-EXPO USE PROCESS		++	The bolted connections and light-weight materials allows for easy assembly and disassembly. The pavilion can be either reerected or recycled after the expo.



(2) Floor plans & Sections



(3) Structural system



(4) Interior views



(5) Injection-molded white shingles on façade

REFERENCES:
(1) https://commons.wikimedia.org/wiki/File:Finland_Pavilion_of_Expo_2010_2.jpg; (2.1 - 5.2) https://jkmm.fi/work/finland-pavilion-shanghai-expo-2010/ (2.2) https://harni-takahashi.com/architecture/finnish-pavilion/; (3 - 4) https://www.archdaily.com/40816/finland-pavillion-for-shanghai-world-expo-2010?ad_medium=gallery; (5.1) https://www.architecturalrecord.com/articles/6770-world-expo-2010-shanghai-finland-pavilion

- **Sustainable Construction Features and Their Role in Post-Expo Use**

The lightweight materials and bolted connections of steel trusses allow to dismantle pavilion and reconstruct it somewhere else with low-energy consumption after the Expo (Meyer Boake, 2013). The most distinctive and sustainable solution is its innovative cladding material, UPM-Profi, which is a paper-plastic composite material produced mainly from plastic waste, allowing for "100% recovery of reproduction" (Technolog, 2014: 202). The material combines the advantages of wood fabric and plastic with good strength, water and corrosion resistance, long service life, size and form flexibility, and ultraviolet light stability, which makes it a good fit for cladding. Besides, "the 'Kirnu' is designed according to standard of permanent construction so that it can be easily demolished after the World Expo and reconstructed somewhere else in the future" (Technolog, 2014, p. 132). These features allow the pavilion to be either relocated or recycled after the Expo based on the circumstances.

5.4.4. Portugal Pavilion (2010)



Figure 5.21: Portugal Pavilion (2010) (https://www.amorim.com/en/media/news/portugal-pavilion-at-the-expo-shanghai-wins-design-award/963/)

The pavilion, designed by Carlos Couto, received the Pavilion Design Golden Award in category C (see Figure 5.21 and Table 5.18). It has a wrapping paper form. The demountable steel frame is clad with a black agglomerated cork board produced in Portugal. The construction material of the pavilion has a prominent role in its design, especially with its smell and texture. The material is considered a representation of Portugal, demonstrating the potential of cork as a construction material (*Portugal Pavilion at the Expo Shanghai,* n.d.).

- **Construction Features: Structural System and Building Materials**

Table 5.18: Portugal Pavilion (2010)

EXPO	EXPO 2010 SHANGHAI - CHINA
NAME:	PORTUGAL PAVILION
Architecture:	Carlos Couto
Engineering:	*Not Found*

DESIGN AIM		POST-EXPO SITUATION						THEME & FUNCTION
		PERMANENT			TEMPORARY			
PERMANENT	TEMPORARY	IN USE	NO USE	DEMOLISHED	RECYCLED / REUSED	RELOCATED	DISMANTLED	THEME: *Not Found*
	■						■	POST-EXPO USE: Disassembled - could be recycled

(1) EXPO IMAGE	POST-EXPO IMAGE
	-

GENERAL INFORMATION & GRAPHICS

Built Area: < 2000 m² Floor: Not Found
Length -Width - Height: Not Found Max. Span: Not Found

STRUCTURAL SYSTEM AND MATERIALS

STRUCTURAL SYSTEM	SECTION ACTIVE	FRAME	■	Bolted steel frame
		BEAM SYSTEM		
		SLAB SYSTEM		
	SURFACE ACTIVE	LOAD-BEARING WALL		
		FOLDED-PLATE		
		SHELL		
	FORM ACTIVE	CABLED		
		MEMBRANE		
		PNEUMATICS		
		ARCH		
	VECTOR ACTIVE	2D TRUSS		
		3D TRUSS / SPACE FRAME		
		GEODESIC DOME		
		OTHERS:		
STRUCTURAL MATERIAL		STEEL	■	Bolted steel frame
		TIMBER		
		REINFORCED CONCRETE		
		STRUCTURAL GLASS		
		FABRIC		
		OTHERS:		
NON-STRUCTURAL MATERIAL		STEEL		
		ALUMINIUM	■	Aluminum profiles of the façade
		TIMBER		
		GLASS		
		PLASTIC		
		CONCRETE		
		FABRIC		
		OTHERS: CORK	■	**Exterior cladding:** Insulation cork-board **Interior finishing:** Wood-cork board







(2) Details of cork panel façade



(3) Night view

STRUCTURAL SYSTEM & BUILDING MATERIAL PROPERTIES

FUNC.	Significant structure		
	Significant material	■	Cork is a significant building material with varied eco-friendly characteristics.
	Optimized design		
	Enabling adaptability	■	The reversible structure and recyclable materials allows for disassembly and recycling.
ENV.	Smart materials/systems		
	Eco-friendly materials	■	Cork is a moisture-proof, abrasion-proof, non-flammable impermeable, heat-insulating, and sound-proofing material.
	Reclaimed materials		
	High recyclability / reusability rate	■	Steel and cork
	Reducing impact on site		
SOC.	Traditional style		
	Traditional materials	■	Cork is a locally significant Portuguese material.
ECON.	Light-weight materials	■	Cork is a very light-weight material.
	Standardized modules		
	Prefabricated units	■	Both structural and main building materials are prefabricated.
	Reversible connections	■	Bolted frame structure has reversible connections.
ROLE IN SUSTAINABLE POST-EXPO USE PROCESS		++	The demountable structure and recyclable materials allows for an efficient post-expo use.

REFERENCES:
(1-2-3) https://www.amorim.com/en/media/news/portugal-pavilion-at-the-expo-shanghai-wins-design-award/963/

The pavilion has a simple demountable steel structure. More than 5500 sqm of cork is used for exterior cladding, interior exhibition areas, flooring, and acoustic solutions. The entire façade is clad with 3640 sqm, weighs approximately 28.000 kg, insulation cork board (*Portugal Pavilion at the Expo Shanghai,* n.d.). Inside the pavilion, cork flooring, cork-wood composite flooring, and rubber-cork composite acoustic core materials are utilized in different areas based on the needs (*Shanghai Portuguese Pavilion Expo*, n.d.). The material "mainly features light-weight, large buoyancy, strong elasticity, and compression resistance" as a building material (Technolog, 2010, p. 67). It is also considered one of the best insulation solutions with moisture-proof, abrasion-proof, non-flammable impermeable, heat-insulating, and sound-proofing characteristics (Technolog, 2010).

- **Sustainable Construction Features and Their Role in Post-Expo Use**

Demountable characteristics of the structure allow for a low-required energy dismantling process, especially when coupled with lightweight cork. Utilizing a raw and/or low-processed material with a high recyclability rate in the entire building, which requires low energy and causes low carbon emission both in production and recycling processes. This makes cork an appropriate choice for temporary building (APCOR, 2010). However, utilizing locally significant Portuguese material required to transport 28.000 kg of cork from Portugal to China, which consumes resources while causing extreme carbon emissions and harms the sustainable image of the pavilion. Overall, thanks to its characteristics, the pavilion is easily dismantled, and its materials could be recycled after the Expo.

5.4.5. Republic of Korea Pavilion (2010)



Figure 5.22: Republic of Korea Pavilion (2010)

(https://www.e-architect.com/images/jpgs/shanghai/korean_pavilion_m170510_ykk17.jpg)

The pavilion designed by Minsuk Cho - Mass Studies received the Pavilion Design Silver Award in category A (see Figure 5.22 and Table 5.19). The form of the pavilion is composed of the Korean Alphabet's signs, with multiple pop-outs and cut-outs which provides a dynamic 3D organization of interior exhibition areas. Visitors can explore the articulation of geometry in the internal organization of exhibition areas with horizontal, vertical, and diagonal movements. Referring to its form, the main theme of the pavilion is 'convergence', which converges sign and space: "signs become spaces, and simultaneously, spaces become signs" (Carta, 2013, p. 395). The use of signs continues in the façade design of the pavilion in which the façade is covered with aluminum panels carved out with Han-geul letters from the Korean Alphabet, in addition to colorful art-pixel panels (Jacobson, 2010). By installing sequential lighting applications behind the Hangul letter panels in the façade, the 3D letters in the form of the pavilion are animated as a sign or text message to reflect the theme of the pavilion (Korean Pavilion, n.d.) again.

- **Construction Features: Structural System and Building Materials**

Although there is not much information about the structural system and materials, from the observations of photographs, it is assumed that the three-story pavilion has a steel beam structure. At the same time, circulation cores are made of reinforced concrete. The pavilion has a lightweight façade system in which more than 40.000 façade panels of two different types (Han-geul letters and Art-Pixels) are clipped to the steel rods hanging on beams. "Han-geul Pixels are white panels with a relief of letters in four different sizes whose combination forms the majority of the exterior, mainly the peripheral surfaces" with grey, black and white colors, while Art Pixels are 45 by 45 cm aluminum panels in different bright colors designed by a Korean artist, Ik-Joong Kang (*Korean Pavilion,* n.d.).

- **Sustainable Construction Features and Their Role in Post-Expo Use**

The selection of structural material and design of the overall structural system have a conventional style in which no special consideration or strategy is applied for the post-expo use of the pavilion. On the other hand, since the pavilion is temporary and dismantled after the exhibition, the simple and lightweight façade system with low durability allows for quick assembly and disassembly (Meyer Boake, 2013).

Table 5.19: Republic of Korea Pavilion (2010)

EXPO	EXPO 2010 SHANGHAI - CHINA
NAME:	REPUBLIC OF KOREA PAVILION
Architecture:	Mass Studies - Minsuk Cho,
Engineering:	*Not Found*

DESIGN AIM		POST-EXPO SITUATION						THEME & FUNCTION
		PERMANENT			TEMPORARY			
PERMANENT	TEMPORARY	IN USE	NO USE	DEMOLISHED	RECYCLED / REUSED	RELOCATED	DISMANTLED	THEME: Convergence "Friendly City, Colorful Life."
	■						■	POST-EXPO USE: Dismantled, yet its future use is not clearly defined.

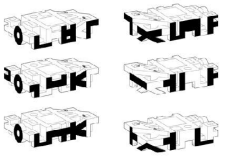
(1) EXPO IMAGE	POST-EXPO IMAGE
	-

GENERAL INFORMATION & GRAPHICS

Built Area: 5780 m² Floor: 3
Length: 25.5 m - Width: 47.8 m - Height: 20m Max. Span: 40 m

STRUCTURAL SYSTEM AND MATERIALS				
STRUCTURAL SYSTEM	SECTION ACTIVE	FRAME	■	Steel frame
		BEAM SYSTEM		
		SLAB SYSTEM		
	SURFACE ACTIVE	LOAD-BEARING WALL		
		FOLDED-PLATE		
		SHELL		
	FORM ACTIVE	CABLED		
		MEMBRANE		
		PNEUMATICS		
		ARCH		
	VECTOR ACTIVE	2D TRUSS		
		3D TRUSS / SPACE FRAME		
		GEODESIC DOME		
	OTHERS:			
STRUCTURAL MATERIAL	STEEL		■	Steel frame
	TIMBER			
	REINFORCED CONCRETE			
	STRUCTURAL GLASS			
	FABRIC			
	OTHERS:			
MAIN BUILDING MATERIALS	STEEL		■	**Steel rods:** for clipping the panels
	ALUMINIUM		■	**Art Pixels:** 45cm x 45cm colored panels **Han-geul Pixels:** White panels with a relief of letters
	TIMBER			
	GLASS			
	PLASTIC			
	CONCRETE			
	FABRIC			
	OTHERS:			

STRUCTURAL SYSTEM & BUILDING MATERIAL PROPERTIES			
FUNC.	Significant structure		
	Significant material		
	Optimized design		
	Enabling adaptability	■	The structural design of the pavilion and the significant façade system enables easy disassembly.
ENV.	Smart materials/systems		
	Eco-friendly materials		
	Reclaimed materials		
	High recyclability / reusability rate	■	Aluminum and steel
	Reducing impact on site		
SOC.	Traditional style		
	Traditional materials		
ECON.	Light-weight materials	■	The pavilion has a lightweight façade system in which aluminium façade panels are clipped to the steel rods hanging on beams.
	Standardized modules		
	Prefabricated units	■	All components are prefabricated and assembled in the site.
	Reversible connections	■	The connections are reversible, since the pavilion is designed to ease the dissambly process.
ROLE IN SUSTAINABLE POST-EXPO USE PROCESS		+	The simple façade system allows for easy diassembly and recycling.



(2) Articulation of the mass




(3)Steel rods of the façade for clipping panels




(4) Han-geul Pixels: White panels with a relief of letters




(5) Art Pixels: 45cm x 45cm colored panels

REFERENCES:
(1) https://archello.com/nl/story/207/attachments/photos-videos/1
(2-3-4-5) https://www.designboom.com/architecture/korean-pavilion-at-shanghai-world-expo-2010/

5.4.6. Norway Pavilion (2010)



Figure 5.23: Norway Pavilion (2010) (https://www.architecturenorway.no/projects/culture/shanghai-pavilion-2010/)

The pavilion, designed by Helen & Hard Architects, received the Pavilion Design Silver Award in category B (see Figure 5.23 and Table 5.20). The pavilion consists of fifteen tree-like timber structures connected via the arms of the threes. They are covered with a tensile membrane, while each member is autonomous yet combinatory. Its theme "Norway powered by nature" aims to reflect the close relationship between Norwegian culture and nature via five different exhibition contents: 'coast, forest, fjords, mountains and arctic landscapes of the country' (Hounsgaard, 2010). The architectural and structural design of the pavilion is highly influenced by the post-expo use consideration in which the pavilion can be separated into 15 individual structures to provide adaptability. The tree-like structures are designed statically determinate to be also utilized separately, which makes the pavilion "the first large scale tensile membrane structure which can be reconfigured in an entirely different setup, yet using parts of the same manufactured membrane roof" (Lienhard et al., 2010, p. 6). Each member works as a "structure, infrastructure, furniture, exhibition, playground, and information display" (*Norwegian pavilion in Expo Shanghai 2010*, n.d.).

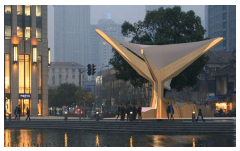
- Construction Features: Structural System and Building Materials

The pavilion has a timber structure with a membrane roof. The tree-like structures made of Norwegian certified glue-laminated timber are manufactured as prefabricated units in Norway and transported to China, consisting of a membrane roof, four cantilever branches, a trunk-body, and two or four roots work as bracing (Wu et al., 2010). Although it is planned to use an innovative and more rapidly-renewable material, GluBam, which "is a high strength glue-laminated timber made of native Chinese bamboo" (Lienhard et al., 2010, p. 4), since it is not on the list of the Chinese

Table 5.20: Norway Pavilion (2010)

EXPO	EXPO 2010 SHANGHAI - CHINA
NAME:	NORWAY PAVILION
Architecture:	Helen& Hard Architects
Engineering:	Tongji University cooperating with SHZF

DESIGN AIM		POST-EXPO SITUATION						THEME & FUNCTION
		PERMANENT			TEMPORARY			
PERMANENT	TEMPORARY	IN USE	NO USE	DEMOLISHED	RECYCLED / REUSED	RELOCATED	DISMANTLED	THEME: Norway Powered by Nature
	■					■		POST-EXPO USE: Relocated to different locations in China as shaded sitting units, playgrounds.

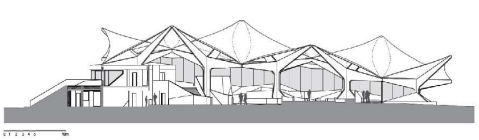
(1) EXPO IMAGE	(2) POST-EXPO IMAGE
	

GENERAL INFORMATION & GRAPHICS

Built Area: 1525 m² Floor: 2
Length: 56 m - Width: 34 m - Height: 13.5 m Max. Span: 11.3m

STRUCTURAL SYSTEM AND MATERIALS				
STRUCTURAL SYSTEM	SECTION ACTIVE	FRAME		
		BEAM SYSTEM		
		SLAB SYSTEM		
	SURFACE ACTIVE	LOAD-BEARING WALL		
		FOLDED-PLATE		
		SHELL		
	FORM ACTIVE	CABLED		
		MEMBRANE	■	**Membrane structure:** PTFE membrane over 15 timber tree-columns
		PNEUMATICS		
		ARCH		
	VECTOR ACTIVE	2D TRUSS		
		3D TRUSS / SPACE FRAME		
		GEODESIC DOME		
	OTHERS:			
STRUCTURAL MATERIAL	STEEL			
	TIMBER		■	**Tree columns:** Glue-laminated timber of norwegian pine
	REINFORCED CONCRETE			
	STRUCTURAL GLASS			
	FABRIC		■	**Membrane:** PTFE yarn fabric coated with fluoropolymer (TENARA fabric) **Polyester Belts:** Cables
	OTHERS:			
MAIN BUILDING MATERIALS	STEEL			
	ALUMINIUM			
	TIMBER			
	GLASS		■	Glazing in some parts of the façade
	PLASTIC			
	DRYWALL			
	FABRIC			
	OTHERS: CHINESE BAMBOO		■	**Exhibition areas, surfaces:** GluBam – Glue-laminated Bamboo

STRUCTURAL SYSTEM & BUILDING MATERIAL PROPERTIES			
FUNC.	Significant structure	■	The first large scale tensile membrane structure allows for reconfiguration.
	Significant material	■	The membrane and secondary structure material are both innovative.
	Optimized design	■	Each fifteen member works as "structure, infrastructure, furniture, exhibition, playground and information display".
	Enabling adaptability	■	The pavilion can be separated into 15 individual structures to provide adaptability.
ENV.	Smart materials/systems		
	Eco-friendly materials	■	The pavilion constructed by renewable and durable materials.
	Reclaimed materials		
	High recyclability / reusability rate	■	Timber, bamboo and fabric
	Reducing impact on site	■	The pavilion requires no foundation under the ground.
SOC.	Traditional style		
	Traditional materials	■	Norwegian certified glu-laminated timber
ECON.	Light-weight materials	■	Timber, bamboo and fabric
	Standardized modules	■	The pavilion constructed out of 15 standarized modules.
	Prefabricated units	■	All components are prefabricated.
	Reversible connections	■	Polyester belts allows for reversibility to seperate 15 modules.
ROLE IN SUSTAINABLE POST-EXPO USE PROCESS		++ +	Optimal space covering in transportation and structurally efficient and determinant design allowing for adaptability.



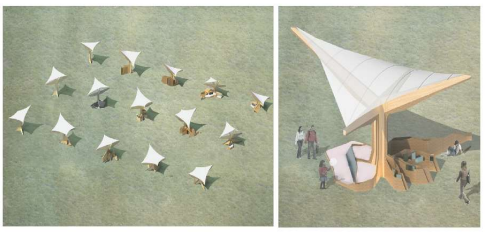
(3) Elevation



(4) Interior timber components: GluBam timber



(5) Axonometric diagram



(6) Post-expo use configurations

REFERENCES:
(1-2-4-6) https://www.archdaily.com/57891/norway-pavilion-for-shanghai-world-expo-2010; (3-5) https://archello.com/project/norwegian-pavillion-in-expo-shanghai-2010 ; (3-5) http://architypereview.com/project/norwegian-pavilion/

to use Norwegian certified glue-laminated timber. Thus, GluBam boards are utilized as a secondary structure in which "air conditioning, water-and energy supply, lighting, display- screens and all technical installations are integrated", in addition to nearly all surfaces in exhibition areas and most of the interior surfaces (*Norwegian pavilion in Expo Shanghai 2010*, n.d.).

The membrane used is a PTFE fabric coated with the fluoropolymer, which developed as an innovative membrane type (TENARA fabric) with high flexibility, fire resistance, recyclability rate, translucency (20-40%), allowing for diffuse lighting, dirt-repellent, and durable than other coated glass fibers or PVC fabrics (Wu et al., 2010). The autonomous characteristics of individual units are achieved "with a pre-stressed membrane that works as a patchwork of small membrane units with different pre-stress levels" (Lienhard et al., 2010, p. 6). Polyester belts are utilized as edge cables as a reinforcement to ease the deconstruction process, which also "have the advantage of a comparatively low young modulus which leads to smaller reaction forces in the timber structure" (Wu et al., 2010; Lienhard et al., 2010, p. 4). Besides, there is also a glass façade which "lines up with the outer tree stems, therefore some large triangular spaces had to be closed with flap membranes that are linearly connected to the curved soft edge of the roof membrane and the tree arms" (Lienhard et al., 2010, p. 2).

- **Sustainable Construction Features and Their Role in Post-Expo Use**

Since the pavilion is designed with the consideration of providing post-expo use adaptability and equipped with innovative systems and materials, it has varied sustainable characteristics that makes post-expo use process highly efficient, including: easily assembly and disassembly, prefabricated units for easier transportation and optimal space covering, light-weight materials to reduce structural bulk, innovative membrane fabric that is more durable and requiring low maintenance, structurally efficient and statically determinant design allowing for adaptability, etc. Besides, the layout for the dividing membrane into small pieces is designed to create a pattern "that uses the maximum width of the raw material for a maximum number of strips" with minimum cut-offs while "guaranteeing maximal stiffness of the membrane, by positioning the warp direction of the fabric and the welding seams between the high points" (Lienhard et al., 2010, p. 6). After the Expo, the tree

structures were reconstructed separately at various locations of China as shaded sitting areas, playgrounds, or social meeting places (Lienhard et al., 2010).

5.5. Milan World Expo Pavilions (2015)

Theme: Feeding the Planet, Energy for Life

Time Period: 01 May – 31 October 2010 (6 Months)

Area: 200 ha.

Number of Participant Nations: 145

Total Visitors: 22.200.000

The Milan World Expo 2015 in Italy (see Figure 5.24) is centered around the global food issue in terms of lacking healthy, secure, and sufficient nutrition for all members of the planet. The theme is interrelated with the efforts of the United Nations' 2030 Agenda to reach a more sustainable way of production and consumption by all means. The Expo aimed to create a field for the use of innovative techniques and technologies, as well as public participation (Ministry of Ecological Transition, 2015). With this aim, the circular economy approach is embraced by all stakeholders including food, trash, transportation, building construction, and operation (lighting, cooling, etc.) to reduce the use of energy and materials at any stage. The most prominent measures are taken for the post-expo use of the Expo site by embracing the "mobility, flexibility and reversibility" principles and preparing construction guidelines for the pavilions by reinterpreting the LEED criteria of the United States. The guidelines recommended creating open and green spaces in one third of the pavilion, implementing a green roof, designing no more than 17 meters and using at least half of the building materials from reclaimed substances (EXPO 2015 S.p.A., 2018). Based on these characteristics, pavilions are evaluated by the Expo committee at the end of the Expo. The host country pavilion and the top five pavilions of the Architecture & Landscape Award (see Section 4.1) are selected to be examined in this study.



Figure 5.24: Milan World Expo (2015) Site (https://commons.wikimedia.org/wiki/File:130528_MSP_EXPO2015_wiki.jpeg)

5.5.1. Italy Pavilion (2015)

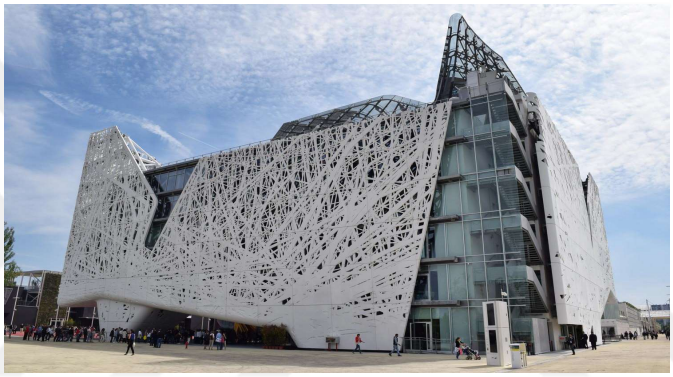


Figure 5.25: Italy Pavilion (2015) (https://arquitecturaviva.com/works/italian-pavilion-expo-milano-2015)

The host pavilion, the so-called Palazzo Italia (see Figure 5.25 and Table 5.21), is among the few permanent pavilions in the Expo and was designed by Nemesi & Partners. With a height of 35 meters, it is the highest pavilion on the Expo site (Architizer Journal, 2021). It is a multifunctional building consisting of exhibition spaces, administrative offices, auditoriums, and meeting rooms. Besides, there are also four small pavilions named Cardo, serving as exhibition spaces. The pavilion is a representative net-zero energy pavilion (nZEB) at the Expo with its innovative sustainable materials and design principles of caring for the environment and energy efficiency. The energy need of the pavilion is met by renewable sources, including geothermal (groundwater) energy and "an innovative veil of glass solar panels system" (de Santoli et al., 2014, p. 534). Besides, a bioclimatic courtyard works as a lung for the building, which sucks air from the outside and transmits it to the air conditioning units to provide a good quality temperature and humidity levels compared to the outside air (de Santoli et al., 2014).

Table 5.21: Italy Pavilion (2015)

EXPO	EXPO 2015 MILAN - ITALY
NAME:	ITALY PAVILION - PALAZZO ITALIA
Architecture:	Nemesi & Partners
Engineering:	Proger and BMS Progetti

DESIGN AIM		POST-EXPO SITUATION						THEME & FUNCTION
		PERMANENT			TEMPORARY			
PERMANENT	TEMPORARY	IN USE	NO USE	DEMOLISHED	RECYCLED / REUSED	RELOCATED	DISMANTLED	THEME: House of Italian Identity POST-EXPO USE: Human Technopole foundation
■		■						

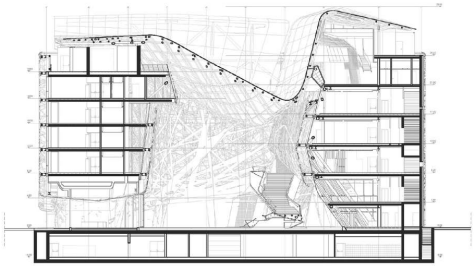
(1) EXPO IMAGE	POST-EXPO IMAGE
	NOT FOUND

GENERAL INFORMATION & GRAPHICS

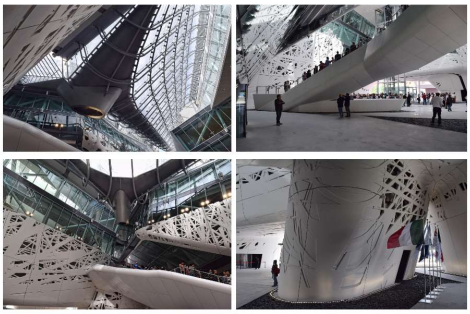
Foot-print Area: 3306 m² Built Area: 14.400 m² Floor: 6
Length: 57m - Width: 58m - Height: 35m Max. Span: Not Found

STRUCTURAL SYSTEM AND MATERIALS

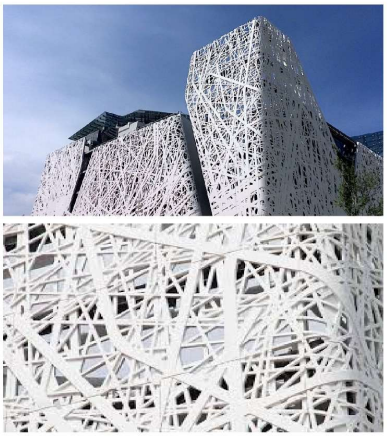
STRUCTURAL SYSTEM	SECTION ACTIVE	FRAME		
		BEAM SYSTEM	■	Steel Beam System
		SLAB SYSTEM		
	SURFACE ACTIVE	LOAD-BEARING WALL		
		FOLDED-PLATE		
		SHELL		
	FORM ACTIVE	CABLED		
		MEMBRANE		
		PNEUMATICS		
		ARCH		
	VECTOR ACTIVE	2D TRUSS		
		3D TRUSS / SPACE FRAME		
		GEODESIC DOME		
		OTHERS:		
STRUCTURAL MATERIAL		STEEL	■	Steel Beam System: 400 tons of steel
		TIMBER		
		REINFORCED CONCRETE		
		STRUCTURAL GLASS		
		FABRIC		
		OTHERS:		
MAIN BUILDING MATERIALS		STEEL		
		ALUMINIUM		
		TIMBER		
		GLASS	■	Glazing: 4.000 m2 - approx. 450 tons Photovoltaic Glass on the Roof: 650 m2
		PLASTIC		
		CONCRETE		
		FABRIC		
		OTHERS: active-BIODYNAMIC CEMENT	■	900 plane & curved panels: 600 fixed & 300 varied dimensions - 2.000 tons in total Fixed panel size: 4 x 4.2 m Panel weight from 1 to 4 tons



(2) Section of the pavilion



(3) Interior views



(4) Façade: active-BIODYNAMIC CEMENT

STRUCTURAL SYSTEM & BUILDING MATERIAL PROPERTIES

FUNC.	Significant structure		
	Significant material	■	Biodynamic cement that can catch the pollution in the air is an innovative material.
	Optimized design		
	Enabling adaptability	■	Architectural design of the pavilion coupled with durable materials and high-span structure allows for refunctioning.
ENV.	Smart materials/systems	■	Active titanium dioxide technology: Activated via light, turn air pollution into inert salts.
	Eco-friendly materials		
	Reclaimed materials	■	Biodynamic cement is made of 80% recycled aggregates (marble, cement), which can be recycled again if needed.
	High recyclability / reusability rate		
	Reducing impact on site		
SOC.	Traditional style		
	Traditional materials		
ECON.	Light-weight materials		
	Standardized modules		
	Prefabricated units		
	Reversible connections		
ROLE IN SUSTAINABLE POST-EXPO USE PROCESS		+	The architectural design features have more influence on the post-expo use of the pavilion, than its structural and material features.

REFERENCES:
(1) https://architizer.com/blog/projects/italy-pavilion-milan-expo-2015/; (2-3) https://www.archdaily.com/630901/italy-pavilion-milan-expo-2015-nemesi; (4.1) https://www.archipanic.com/milan-expo-2015-architecture/; (4.2) https://www.archiobjects.org/expo-2015-italy-pavilion/

- **Construction Features: Structural System and Building Materials**

The pavilion has a steel frame structure cladded with biodynamic cement panels with photocatalytic properties, glass, and photovoltaic glass (La Tegola et al., 2019; EXPO 2015 S.p.A., 2018). The most remarkable property of the pavilion is the biodynamic cement panels that are activated by sunlight. They "can capture certain pollutants in the air, turning them into inert salts and thus helping to free the atmosphere of smog" with the form of sculptural ramified skin that resembles tree branches to refer to the environment (EXPO 2015 S.p.A., 2018, p. 322). The biodynamic cement is patented as *i.active BIODYNAMIC*, a mixture of plastic, cement, and titanium dioxide. This material is "reached to form pre-made hard plates that are easy to work and configure" (Al-Zaidi & Markaryan, 2020, p. 2228). The cement contains 80% recycled aggregates, including marble fragments, making it shinier than ordinary cement (EXPO 2015 S.p.A., 2018, p. 322). The pavilion roof has a distinctive architectural identity in which a substantial conical-shaped glass roof is suspended over the center of the interior plaza. The roof consisted of photovoltaic glass in flat and curved geometric shapes (Architizer Journal, 2021).

- **Sustainable Construction Features and Their Role in Post-Expo Use**

Since the pavilion is permanent, the post-expo use is directly related to the architectural features, while the sustainability of the pavilion is more related to long-term design strategies, including passive design and green energy generation. However, one of the most crucial sustainable features of the pavilion is the innovative primary building material, biodynamic cement, which is beneficial for the environment for the entire lifetime of the pavilion. After some renovations were completed for the functional adaptability in 2019, the pavilion was refunctioned to house for Human Technopole Foundation (*Palazzo Italia - Human Technopole Foundation*, n.d.).

5.5.2. France Pavilion (2015)



Figure 5.26: France Pavilion (2015) (https://www.archdaily.com/502460/milan-expo-2015-x-tu-designs-latticed-fertile-market-for-french-pavilion)

The pavilion, designed by XTU Architects, received the Landscape and Architecture Golden Award in category A. The pavilion has an outstanding design with its inverted French landscape form constructed by a series of interlocking timber girders and pillars that form a curvilinear grid in three-dimension (see Figure 5.26 and Table 5.22). The pavilion is designed as an 'archetypal fertile market' with an innovative French approach where production, purchasing, and consumption can occur simultaneously (Capitanucci, 2015). The pavilion consists of exhibition spaces on the ground floor, production areas on the roof and façade, offices and event rooms in the mezzanine, and a restaurant on the terrace. The timber contours of the structure create curved recesses filled with 16 different types of French plants and agricultural products. The crops and plants are produced on the roof with an innovative 'hydroponic production' system that uses water instead of soil. The products are suspended from the ceiling as ready to be harvested in different months and seasons (Frearson, 2015c). The structure creates a vaulted interior space in which every vault is a different exhibition space where both real and digital elements related to "regional gastronomic specialties, scientific and biotechnology research, agroecology projects, new farming technology, genetic innovations, life chemistry, and flora" are exhibited (EXPO 2015 S.p.A., 2018, p. 352). Besides, an innovative biofaçade system is also utilized in the roof in which micro-algae production in waterjets with a few cm depths. This system creates a symbiosis between micro-algae and building, which "improves the building's environmental properties (energy performance, CO2 capture, sewage recovery, reduction of heat islands and urban sprawl, short circuits)" (*French Pavilion Expo Milano 2015: XTU Architects*, n.d.).

Table 5.22: France Pavilion (2015)

EXPO	EXPO 2015 MILAN - ITALY
NAME:	FRANCE PAVILION
Architecture:	XTU Architects
Engineering:	SIMONIN SAS

DESIGN AIM		POST-EXPO SITUATION						THEME & FUNCTION
		PERMANENT			TEMPORARY			
PERMANENT	TEMPORARY	IN USE	NO USE	DEMOLISHED	RECYCLED / REUSED	RELOCATED	DISMANTLED	THEME: Different Ways of Producing and Providing Food
	■					■		POST-EXPO USE: Relocated to France to reuse the pavilion as a covered market

(1) EXPO IMAGE	POST-EXPO IMAGE
	NOT FOUND

GENERAL INFORMATION & GRAPHICS

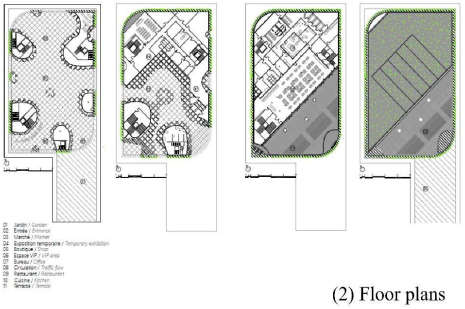
Built Area: 3592 m²
Length: 56.7m - Width: 35m - Height: 12m
Floor: 3
Max. Span: Not Found

STRUCTURAL SYSTEM AND MATERIALS

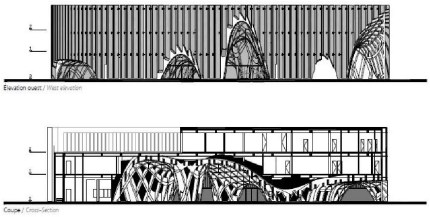
STRUCTURAL SYSTEM	SECTION ACTIVE	FRAME		
		BEAM SYSTEM		
		SLAB SYSTEM		
	SURFACE ACTIVE	LOAD-BEARING WALL		
		FOLDED-PLATE		
		SHELL		
	FORM ACTIVE	CABLED		
		MEMBRANE		
		PNEUMATICS		
		ARCH		
	VECTOR ACTIVE	2D TRUSS		
		3D TRUSS / SPACE FRAME		
		GEODESIC DOME		
	OTHERS: GRIDSHELL		■	Interlocked single- and double-curved beams and columns in a grid pattern
STRUCTURAL MATERIAL	STEEL			
	TIMBER		■	2400 m³ glue-laminated girders and pillars
	REINFORCED CONCRETE			
	STRUCTURAL GLASS			
	FABRIC			
	OTHERS:			
MAIN BUILDING MATERIALS	STEEL		■	Steel screws, connectors and tension rods
	ALUMINIUM			
	TIMBER			
	GLASS			
	PLASTIC			
	CONCRETE			
	FABRIC			
	OTHERS:			

STRUCTURAL SYSTEM & BUILDING MATERIAL PROPERTIES

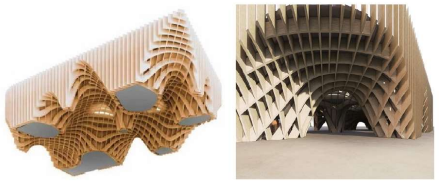
FUNC.	Significant structure	■	Innovative reinterpretation of gridshell, demonstrating advances in engineered free form timber structures.
	Significant material		
	Optimized design	■	Maximized efficiency with computer modelling and the use of digitally controlled robot in manufacturing.
	Enabling adaptability	■	The structural system and materials are configured to combine mobility & durability.
ENV.	Smart materials/systems	■	Rain collecting system for vertical farming in which the plants become a building material.
	Eco-friendly materials		
	Reclaimed materials		
	High recyclability / reusability rate	■	Growing plants can be harvested and grow repeatedly through the life-cycle of the building.
	Reducing impact on site		
SOC.	Traditional style		
	Traditional materials	■	French spruce and larch
ECON.	Light-weight materials	■	The pavilion is considered light-weight structure compared to steel and concrete structures.
	Standardized modules		
	Prefabricated units	■	All components are prefabricated and assembled in the site which is also valid for relocation process.
	Reversible connections	■	All connections and fixings between members are reversible.
ROLE IN SUSTAINABLE POST-EXPO USE PROCESS		++	Pavilion allows for easy disassembly and reassembly.



(2) Floor plans



(3) Section and elevation



(4) Timber structure & close view



(5) Interior views - suspended gardens

REFERENCES: (1-2-3-4.1) https://archello.com/project/french-pavilion-expo-milano-2015; (4.2) https://www.dezeen.com/2014/04/29/milan-expo-2015-xtu-architects-france-pavilion/; (5.1) https://www.archipanic.com/french-pavilion-at-milan-expo/france-pavilion-inside/; (5.2) https://www.archdaily.com/502460/milan-expo-2015-x-tu-designs-latticed-fertile-market-for-french-pavilion

- **Construction Features: Structural System and Building Material**

The pavilion has a gridshell structure designed with a different interpretation. It is made of timber girders and pillars with "varying curves and counter-curves, " creating a vast cavernous ceiling standing on six pillars created by the parts that touch the ground (Frearson, 2015c). Timber components are "oriented at 45° to the building façades", "spaced at 4.5 m and braced by a supporting framework slotted in every 1.5 m. The result is a series of highly uniform right-angle cubicles" (Chilton & Tang, 2016, p. 232). The single- and double-curved beams in varying depths (between 380 mm and 2.4 meters) create vaulted spaces of different widths and heights under the roof, serving different exhibition spaces. The entire structure is made of glue-laminated spruce and larch. All pieces in the structure are interlocked and fixed with steel screws, connectors with glued-in threaded rods, and tension rods (Chilton & Tang, 2016; Frearson, 2015c).

- **Sustainable Construction Features and Their Role in Post-Expo Use**

The demountable gridshell structure made of prefabricated timber members is considered an example of low-carbon construction with its materials and way of assembly, while it has an innovative approach in terms of the design of the gridshell. It is differentiated from other gridshells by converting small sections of regular gridshells into single- or double-curved beams with deeper cross-sections. The timber beams are interlocked in a "square grid plan from a mixture of continuous and discrete prefabricated elements, which are connected with sophisticated mechanical joints; the form, which is not funicular, is required to resist bending as well as compression stresses" (Chilton & Tang, 2016, p. 229). This innovative gridshell structure is achieved thanks to the "advances in engineered timber production and jointing systems, digital structural and geometrical design, manufacture, planning and fabrication" which is considered as an example of how technology enables free form timber structures with high-level durability (Chilton & Tang, 2016, p. 229). It has a lightweight and low-tech system in which all parts are interlocked to minimize the use of additional fixings and bracings (Bonenberg, 2018). The use of demountable joints allows the pavilion to be reusable, which is dismantled and rebuilt in France as a covered marketplace (Winston, 2016). The use of computer modeling and cutting components with a digitally controlled robot allows for an optimized design which

increases the static efficiency of structural components and provides economical manufacturing, construction, and deconstruction processes while saving resources and time (Chilton & Tang, 2016). The design of the structure with holes in the roof provides cross-ventilation and naturally cooled space, which reduces the energy consumption of the building in both Expo and post-expo uses (*French Pavilion Expo Milano 2015: XTU Architects,* n.d.).

5.5.3. United Kingdom Pavilion (2015)



Figure 5.27: United Kingdom Pavilion (2015) (https://www.archdaily.com/627728/uk-pavilion-milan-expo-2015-wolfgang-buttress)

The UK Pavilion, so-called The Hive, is designed by artist Wolfgang Buttress in collaboration with executive architects BDP Manchester and structural engineer Tristan Simmonds. The structure is fabricated by Stage One in York, England, and transported to the Expo site. It received Landscape and Architecture Golden Award in category B. In responding to the Expo theme 'Feeding the Planet', the concept of the pavilion is focused on the importance of bees in the food safety and biodiversity since "70 out of 100 cultivated products that produce 90% of the world food, are pollinated by bees" (EXPO 2015 S.p.A., 2018, p. 386). The site is articulated with a labyrinth-like route to demonstrate and simulate bees' daily routines. There is an orchard with various trees at the entrance, followed by a meadow with typical British wildflowers and an amphitheater with resting units at the end that allow watching the Hive (Capitanucci, 2015). The journey ends with the Hive (see Figure 5.27 and Table 5.23).

Table 5.23: United Kingdom Pavilion (2015)

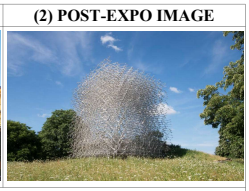
EXPO	**EXPO 2015 MILAN - ITALY**
NAME:	**UK PAVILION - THE HIVE**
Architecture:	Artist: Wolfgang Buttress - Executive Architect: BDP
Engineering:	Tristan Simmonds - Simmonds Studio

DESIGN AIM		POST-EXPO SITUATION						THEME & FUNCTION
		PERMANENT			TEMPORARY			
PERMANENT	TEMPORARY	IN USE	NO USE	DEMOLISHED	RECYCLED / REUSED	RELOCATED	DISMANTLED	THEME: Following the Buzz of a Bee Is Easier Than Expected
	■					■		POST-EXPO USE: Relocated to the Kew Gardens in London

(1) EXPO IMAGE



(2) POST-EXPO IMAGE

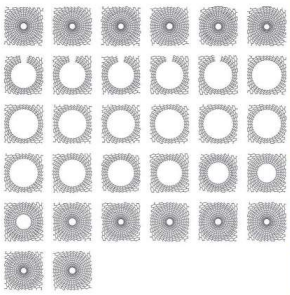


GENERAL INFORMATION & GRAPHICS

Built Area: 1910 m²
Length: 14 m - Width: 14 m - Height: 17 m
Floor: 2
Max. Span: 14 m

STRUCTURAL SYSTEM AND MATERIALS

STRUCTURAL SYSTEM	SECTION ACTIVE	FRAME		
		BEAM SYSTEM		
		SLAB SYSTEM		
	SURFACE ACTIVE	LOAD-BEARING WALL		
		FOLDED-PLATE		
		SHELL		
	FORM ACTIVE	CABLED		
		MEMBRANE		
		PNEUMATICS		
		ARCH		
	VECTOR ACTIVE	2D TRUSS		
		3D TRUSS / SPACE FRAME		32 horizontal layers of aluminium components linked by truss assemblies.
		GEODESIC DOME		
		OTHERS:		
STRUCTURAL MATERIAL		STEEL	2ND	**18 hollow section steel columns:** 139.7mm × 5mm, height: 5 meters **Ring beam:** 10.8 meter diameter
		TIMBER		
		REINFORCED CONCRETE		
		STRUCTURAL GLASS		**Slab:** Structural glass on floor that sit on the ring beam
		FABRIC		
		OTHERS: ALUMINIUM	1ST	Rods, Bolts, Studs Segments 10mm thick aluminium sheet,15mm and 8mm gauged aluminium
MAIN BUILDING MATERIALS		STEEL		
		ALUMINIUM		
		TIMBER		
		GLASS		
		PLASTIC		
		CONCRETE		
		FABRIC		
		OTHERS:		



(3) 32 levels of structure on plan



(4) Illuminated hollow core



(5) Hexagonal assembly of components



(6) Trussed connections between layers



(7) Columns lift-up the pavilion



(8) Close view of hexagonal elements



(9) - 9m diamater hollow space inside the pavilion
- Ring beam on floor level with hexagonal pattern

STRUCTURAL SYSTEM & BUILDING MATERIAL PROPERTIES

FUNC.	Significant structure	■	Complex, delicate, multi-layered, sculptural structure
	Significant material		
	Optimized design	■	Computational design allows for optimal & efficient design: number, material & size of members.
	Enabling adaptability	■	The structural system and materials are configured to combine mobility & durability.
ENV.	Smart materials/systems		
	Eco-friendly materials		
	Reclaimed materials		
	High recyclability / reusability rate	■	The aluminum and steel %100 recyclable, which can be recycled if needed.
	Reducing impact on site		
SOC.	Traditional style		
	Traditional materials		
ECON.	Light-weight materials	■	Very thin & light-weight aluminum members.
	Standardized modules		
	Prefabricated units	■	All components are prefabricated.
	Reversible connections	■	All bolted connections and fixings between members are reversible.
ROLE IN SUSTAINABLE POST-EXPO USE PROCESS		++	Pavilion allows for easy disassembly and reassembly, while materials can be recycled up to 100% if needed.

REFERENCES: (1-4-7-8) https://architizer.com/blog/projects/uk-pavilion-milan-expo/; (2) https://www.kew.org/kew-gardens/whats-in-the-gardens/the-hive
(3-5-6) Stacey, M. (2016). Bees Are Sentinels of the Earth: The Hive–A Responsive Ecology. WHITE PAPERS, 300.; (9) https://www.archdaily.com/627728/uk-pavilion-milan-expo-2015-wolfgang-buttress

The Hive simulates how is the feeling of being inside a beehive with the sounds and vibrations of bees, promoted by the impulses of 1.000 small LED lights that are "connected with real bees in a hive in the United Kingdom" (EXPO 2015 S.p.A., 2018, p. 386).

- **Construction Features: Structural System and Building Material**

The pavilion is a cubic aluminum lattice structure constructed with 32 stacked horizontal layers comprised of 169.300 members of chords, rods, and nodes. The members are assembled in a hexagonal pattern, creating a circumferential layout with macro-level repetitions on every level. The pavilion is risen 3 meters above the ground level by columns which have 5 meters in height since they are connected with the ring beam placed in the sixth horizontal layer of the pavilion. The level at which the ring beam is placed creates the pavilion floor. The floor plane is made of glass to provide transparency between layers, promoting the delicacy and low-density of the structure together with very thin aluminum components that create a silhouette with loosed corners (Cull, 2015; Comşa & Mihăilă, 2016). "The pattern of radial and circumferential lines is analogous to the flow pattern of stress and so defines horizontal lines of the structure. The layering of the sculpture allows these radial and circumferential lines of structure to be joined to form truss-like assemblies" (Architonic, 2015). The fully-braced structure prevents bending in nodes. Computationally designed components are in optimal width, which causes variations at the microscale to provide efficiency (Architonic, 2015).

- **Sustainable Construction Features and Their Role in Post-Expo Use**

The pavilion was disassembled and relocated to Royal Kew Gardens in London, with a new landscape, while the plants in the Expo site were donated to the Politecnico di Milano (Winston, 2016). The sustainable relocation process is ensured thanks to the pavilion's modular bolted structure, which is a significant example in the field of complex 'design for disassembly' (DfD) structures. Besides, the computational design optimizes the structure and creates a more robust design that saves time, energy, and material. The simulations and testing allow changing the material from steel to aluminum, which is more economical, has lower unit weight, and has easier machining and forming processes (Stacey, 2016). These structural and material advantages

provide more manageable and economical transportation, while light-weightiness is a great advantage also for the reassembly. However, since every material changes slightly and has its own place in the structure, it creates a complicated reassembly process when it is combined with a great number of materials.

5.5.4. Bahrain Pavilion (2015)



Figure 5.28: Bahrain Pavilion (2015) (https://www.archipanic.com/bahrain-pavilion-at-expo-2015/)

The pavilion designed by Studio Anne Holtrop in collaboration with landscape architect Anouk Vogel received Landscape and Architecture Silver Award in category B. In the design of the pavilion, architectural and landscape features are interconnected in which ten different orchards of Bahrain's typical fruits are recreated and intersect with roofed exhibition spaces (see Figure 5.28 and Table 5.24). Referring to the theme of the Expo, each of the orchards had blossomed and produced fruits in different time periods throughout the six months of the Expo, which demonstrates the seasonal progress of nature and creates a lively pavilion at any time (EXPO 2015 S.p.A., 2018). The pavilion reflects the country's cultural heritage, which has a close relationship with nature and agriculture, while the form of the pavilion is an abstract interpretation of the country's archaeological temple ruins from ancient times (Studio Anne Holtrop, 2015).

- **Construction Features: Structural System and Building Material**

The pavilion has a very simple design and structural system, which consists of 350 white precast concrete panels assembled like a puzzle in a layout comprised of curvilinear and straight lines. The hundreds of interlocked panels of walls, floors, and roofs are loosely assembled and braced with brass fittings. The loose connections between the panels are exposed completely (Studio Anne Holtrop, 2015; Frearson, 2015a).

Table 5.24: Bahrain Pavilion (2015)

EXPO	EXPO 2015 MILAN - ITALY
NAME:	BAHRAIN PAVILION
Architecture:	Anouk Vogel & Studio Anne Holtrop
Engineering:	*Not Found*

DESIGN AIM		POST-EXPO SITUATION						THEME & FUNCTION
		PERMANENT			TEMPORARY			
PERMANENT	TEMPORARY	IN USE	NO USE	DEMOLISHED	RECYCLED / REUSED	RELOCATED	DISMANTLED	THEME: Archaeologies of Green
	■					■		POST-EXPO USE: Relocated to Bahrain to be used as a botanical garden

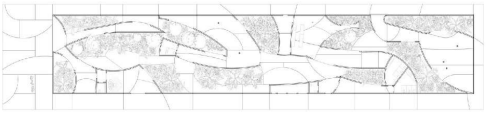
STRUCTURAL SYSTEM AND MATERIALS				
STRUCTURAL SYSTEM	SECTION ACTIVE	FRAME		
		BEAM SYSTEM		
		SLAB SYSTEM		
	FORM ACTIVE	LOAD-BEARING WALL	■	Precast concrete panels
		FOLDED-PLATE		
		SHELL		
	FORM ACTIVE	CABLED		
		MEMBRANE		
		PNEUMATICS		
		ARCH		
	VECTOR ACTIVE	2D TRUSS		
		3D TRUSS / SPACE FRAME		
		GEODESIC DOME		
		OTHERS:		
STRUCTURAL MATERIAL		STEEL		
		TIMBER		
		REINFORCED CONCRETE	■	Precast concrete panels
		STRUCTURAL GLASS		
		FABRIC		
		OTHERS:		
MAIN BUILDING MATERIALS		STEEL		
		ALUMINIUM		
		TIMBER		
		GLASS		
		PLASTIC		
		CONCRETE		
		FABRIC		
		OTHERS: BRASS	■	Fixings and dry joints

STRUCTURAL SYSTEM & BUILDING MATERIAL PROPERTIES			
FUNC.	Significant structure		
	Significant material		
	Optimized design	■	Optimized connections strong enough to keep structure balanced but loosely attached to allow easy disassemble.
	Enabling adaptability	■	The structural system and materials are configured to combine mobility & durability.
ENV.	Smart materials/systems		
	Eco-friendly materials		
	Reclaimed materials		
	High recyclability / reusability rate		
	Reducing impact on site		
SOC.	Traditional style		
	Traditional materials		
ECON.	Light-weight materials		
	Standardized modules		
	Prefabricated units	■	All components are prefabricated and assembled in the site which saves energy both assembly and re-assembly.
	Reversible connections	■	Pre-cast concrete panels are loosely attached with reversible connections.
ROLE IN SUSTAINABLE POST-EXPO USE PROCESS		+	Pavilion allows for easy disassembly and reassembly.

(1) EXPO IMAGE	POST-EXPO IMAGE
	NOT FOUND

GENERAL INFORMATION & GRAPHICS

Built Area: 2.010 m²
Length - Width - Height: Not Found
Floor: 1
Max. Span: Not Found



(2) Plan




(3) Puzzle-like pre-cast concrete panels





(4) Exposed connections between panels







(5) Interior & exterior views

REFERENCES:
(1) http://expo2015-milano.blogspot.com/2014/11/
(2-4-5) https://www.archdaily.com/631908/bahrain-pavilion-expo-milano-2015-studio-anne-holtrop?ad_medium=gallery
(3) https://www.archilovers.com/projects/155031/bahrain-pavilion-at-expo-milano-2015.html

- **Sustainable Construction Features and Their Role in Post-Expo Use**

The pavilion is designed to be dismantled and reassembled in Bahrain to serve as a botanical garden (Frearson, 2015a). The simplicity of the configuration of structural systems and materials, reversible connections, and prefabricated modular units allows the pavilion to be easily disassembled and transported economically. Despite its advantageous features for temporary use and relocation, the pavilion is designed to be permanent at its new location which all components are finished with brass except the concrete panels to increase durability (Studio Anne Holtrop, 2015).

5.5.5. Chile Pavilion (2015)



Figure 5.29: Chile Pavilion (2015) (https://www.archdaily.com/892070/chile-pavilion-at-expo-milan-2015-undurraga-deves-arquitectos)

The Chile Pavilion, designed by Undurraga Devés Architecture, received the Architecture and Landscape Silver Award in category B, an elevated timber box surrounded by a double skeleton timber frame structure (see Figure 5.29 and Table 5.25). It has a monumental scale exterior structure while articulated on the inside to reach the human scale (*Pabellón Expo Milán 2015*, 2019). The pavilion is lifted 4-meter above the ground to create a semi-public space under the structure by ensuring fluidity between the urban space and the pavilion, which is a traditional Mediterranean architectural style that many examples can be found in central Chile. It provides both visual access and free movement while inviting people to a 50-meters-long table to share Chilean foods (*Chilean Pavilion - Expo Milano 2015*, n.d.). The exhibition spaces mainly consist of audiovisual installations projected on panels that visitors can reach via an escalator from the semi-open ground space. There are also a small auditorium and multipurpose rooms with independent access to serve different activities without interrupting the flow of the exhibition (EXPO 2015 S.p.A., 2018).

Table 5.25: Chile Pavilion (2015)

EXPO	EXPO 2015 MILAN - ITALY
NAME:	CHILE PAVILION
Architecture:	Cristian Undurraga - Undurraga Devés Arquitectos
Engineering:	F&M Ingegneria

DESIGN AIM		POST-EXPO SITUATION						THEME & FUNCTION
		PERMANENT			TEMPORARY			
PERMANENT	TEMPORARY	IN USE	NO USE	DEMOLISHED	RECYCLED / REUSED	RELOCATED	DISMANTLED	THEME: El Amor de Chile - Love for Chile
	■					■		POST-EXPO USE: Rebuilt in Chile as a cultural and tourist center for the Araucania Region.

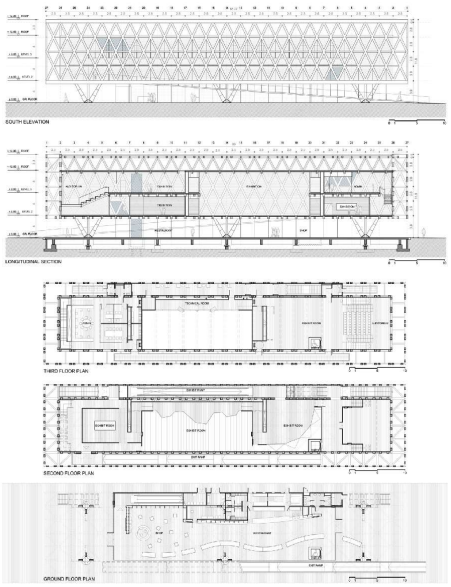
STRUCTURAL SYSTEM AND MATERIALS				
STRUCTURAL SYSTEM	SECTION ACTIVE	FRAME		
		BEAM SYSTEM		
		SLAB SYSTEM		
	SURFACE ACTIVE	LOAD-BEARING WALL		
		FOLDED-PLATE		
		SHELL		
	FORM ACTIVE	CABLED		
		MEMBRANE		
		PNEUMATICS		
		ARCH		
	VECTOR ACTIVE	2D TRUSS		
		3D TRUSS / SPACE FRAME		
		GEODESIC DOME		
	OTHERS: DIAGRID		■	Timber diagrid structure
STRUCTURAL MATERIAL	STEEL		■	Six steel pillars, each composed of three arms
	TIMBER		■	Monterey pine: Laminated Timber
	REINFORCED CONCRETE			
	STRUCTURAL GLASS			
	FABRIC			
	OTHERS:			
MAIN BUILDING MATERIALS	STEEL		■	Steel connection and bracing
	ALUMINIUM			
	TIMBER		■	Timber walls, floors
	GLASS		■	Glazing in façade
	PLASTIC			
	CONCRETE			
	FABRIC			
	OTHERS:			

STRUCTURAL SYSTEM & BUILDING MATERIAL PROPERTIES			
FUNC.	Significant structure	■	Diagrid structural system is adapted to the timber material.
	Significant material		
	Optimized design	■	Optimized diagrid structure, provides efficiency for longer span.
	Enabling adaptability	■	Provide mobility&durability while allowing different layouts for different functions.
ENV.	Smart materials/systems		
	Eco-friendly materials		
	Reclaimed materials		
	High recyclability / reusability rate		
	Reducing impact on site		
SOC.	Traditional style	■	Elevating the pavilion on columns and creating open space in ground is a traditional style.
	Traditional materials	■	Monterey pine is one of Chile's most exported quality timbers.
ECON.	Light-weight materials	■	The pavilion is considered light-weight structure compared to steel and concrete structures.
	Standardized modules	■	The structure consists of inclined components that creates 'X' shape and repeats several times.
	Prefabricated units	■	All components are prefabricated and assembled in the site which saves energy both assembly and re-assembly.
	Reversible connections	■	All connections and fixings between members are reversible.
ROLE IN SUSTAINABLE POST-EXPO USE PROCESS		++	Pavilion allows for easy disassembly and reassembly while providing column-free area for refunctioning.

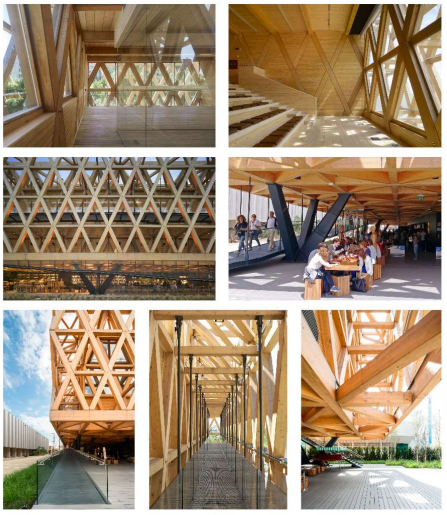
(1) EXPO IMAGE	POST-EXPO IMAGE
	NOT FOUND

GENERAL INFORMATION & GRAPHICS

Built Area: 1.910 m² Floor: 3
Length: 65m - Width: 15m - Height: 14.8m Max. Span: 65m



(2) Section, elevation & floor plans



(3) Detailed views of structure

REFERENCES:
(1-2-3.1) https://www.archdaily.com/892070/chile-pavilion-at-expo-milan-2015-undurraga-deves-arquitectos
(3.2) https://divisare.com/projects/294833-undurraga-deves-arquitectos-filippo-poli-chilean-pavilion-expo-milano-2015

- **Construction Features: Structural System and Building Material**

The pavilion has a double façade glue-laminated timber diagrid structure made of Monterey pine, one of Chile's most exported quality timbers", which rests on six steel columns providing vertical and lateral support for the system, each composed of three inclined arms like a tripod (EXPO 2015 S.p.A., 2018, p. 346). The three-dimensional diagrid structure consists of two diagrid frames connected via timber elements. The inner and outer diagrid frames are composed of diagonal columns creating an 'X' shape and trussed beams "attached horizontally through hidden connections and then vertically through steel connections to transfer the force without bending" (Loostrom & Glaeser, 2018, p. 7). Each X shape is connected by the "interlocking wood connection system and tightened with screws through all connecting pieces to create rigid connections", creating a pattern of rhombuses (Loostrom & Glaeser, 2018, p. 7; Comşa & Mihăilă, 2016). Overall system provides a 15 x 65 m column-free area in the height of 15 m which shows the capability of timber in diagrid structures since existing diagrid structures till that time were primarily made in steel or concrete (Gidlund, 2020).

- **Sustainable Construction Features and Their Role in Post-Expo Use**

The pavilion has a variety of sustainable design strategies, especially considering its post-expo use. Firstly, the used material is a rapidly renewable and eco-friendly material since Chile has one of the highest reforestation rates in the world (Tapia, 2018). Besides, the pavilion is designed as a flexible box that can be adapted for different uses both during and after the exhibition. This is a crucial feature since it is dismounted and relocated to a national park in Chile as a cultural and tourist center. Since over one hundred square meters of laminated timber is utilized in the construction, architects decided that the life cycle of the pavilion should be longer than six months to be considered sustainable (Loostrom & Glaeser, 2018). The structure is demountable to be reconstructed somewhere else, which is ensured by different connection systems. While the inclined beams creating the 'X' form have rigid wooden connections which stays together, the metal pin connections surrounding the 'X's are detachable. The dimensions of components are arranged by considering the fact that the components should fit into a 12-meter-long shipping container in the relocation

process. Moreover, since it is removed from the site, elevating the pavilion from the ground reduces the impact on the site (*Pabellón Expo Milán 2015*, 2019).

5.5.6. China Pavilion (2015)



Figure 5.30: China Pavilion (2015) (https://www.archdaily.com/627497/china-pavilion-milan-expo-2015-tsinghua-university-studio-link-arc)

The pavilion designed by Studio Link-Arc in collaboration with Tsinghua University received the Architecture and Landscape Bronze Award in category A (see Figure 5.30 and Table 5.26). The project has an outstanding design with the form of its roof by merging the profiles of a Chinese city skyline on the building's north side through rectilinear rows and contours of the Chinese mountains on the south side with a curvilinear form. By merging two traditionally opposite concepts under the theme of "The Land of Hope", it is aimed to emphasize the importance of the harmonious co-existence of city and nature (Frearson, 2015b). The exhibition's focal points are environmentally-friendly agricultural technology, human, food, the earth, the environment, and sustainable development, which are mainly reflected in two levels of the pavilion. On the ground floor, there is a reinterpretation of the wheat landscape consisting of 20.000 LED lights which is the main feature of the exhibition that aims to reflect sustainable agriculture by using technological developments. A gently sloping ramp from the wheatland leads visitors to the multimedia room on the upper floor that demonstrates short films centering on the exhibition's focal points (Aguilar, 2015).

- **Construction Features: Structural System and Building Material**

The roof is one of the most crucial design elements of the pavilion, which refers to the raised-beam structures of traditional Chinese architecture. It is built via contemporary glulam technology and modern construction techniques that allow for long spans without any columns in the interior space. The structure consists of curvilinear glue-

Table 5.26: China Pavilion (2015)

EXPO	EXPO 2015 MILAN - ITALY
NAME:	CHINA PAVILION
Architecture:	Tsinghua University & Studio Link-Arc
Engineering:	Simpson Gumpertz & Heger + F&M Ingegneria

DESIGN AIM		POST-EXPO SITUATION						THEME & FUNCTION
		PERMANENT			TEMPORARY			
PERMANENT	TEMPORARY	IN USE	NO USE	DEMOLISHED	RECYCLED / REUSED	RELOCATED	DISMANTLED	THEME: Land of Hope, Food for Life
	■					■		POST-EXPO USE: Relocated to the sea coast in Qingdao, China

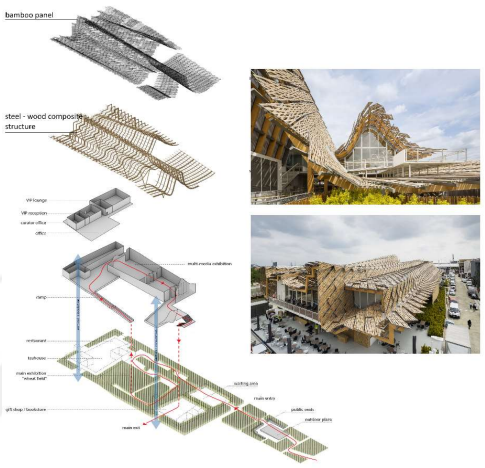
(1) EXPO IMAGE	(2) POST-EXPO IMAGE
	NOT FOUND

GENERAL INFORMATION & GRAPHICS

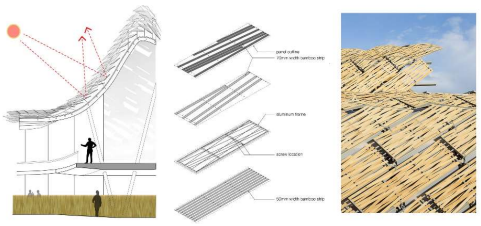
Built Area: 4590 m² — Floor: 2
Length: 72m - Width: 29m - Height: 18m — Max. Span: 27m

STRUCTURAL SYSTEM AND MATERIALS				
STRUCTURAL SYSTEM	SECTION ACTIVE	FRAME		
		BEAM SYSTEM	■	Raised beam system: Curvilinear glue-laminated timber cross-beams (primary rafters and secondary purlins)
		SLAB SYSTEM		
	SURFACE ACTIVE	LOAD-BEARING WALL		
		FOLDED-PLATE		
		SHELL		
	FORM ACTIVE	CABLED		
		MEMBRANE		
		PNEUMATICS		
		ARCH		
	VECTOR ACTIVE	2D TRUSS		
		3D TRUSS / SPACE FRAME		
		GEODESIC DOME		
	OTHERS:			
STRUCTURAL MATERIAL	STEEL		2ND	Some steel beams between the timber beams
	TIMBER		1ST	Glue-laminated timber cross-beams (primary rafters and secondary purlins)
	REINFORCED CONCRETE			
	STRUCTURAL GLASS			
	FABRIC			
	OTHERS:			
MAIN BUILDING MATERIALS	STEEL			
	ALUMINIUM		■	Extruded aluminum profiles attached to rafters to be clad with roof membrane
	TIMBER			
	GLASS			
	PLASTIC			
	CONCRETE			
	FABRIC		■	Translucent and water-proof membrane sheets
	OTHERS: BAMBOO		■	1.000 woven bamboo panels on top of membrane

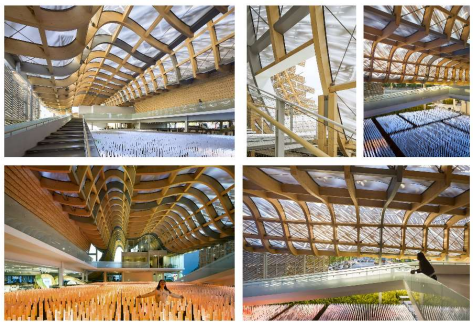
STRUCTURAL SYSTEM & BUILDING MATERIAL PROPERTIES			
FUNC.	Significant structure	■	Curvelinear timber beams span long distances referring to the traditional raised-beam systems.
	Significant material		
	Optimized design	■	3D parametric design techniques allows for optimization of members and provides efficiency.
	Enabling adaptability	■	Long-span structure creates wide column free area that can be adapted for different functions.
ENV.	Smart materials/systems		
	Eco-friendly materials	■	Bamboo roof panels
	Reclaimed materials		
	High recyclability / reusability rate		
	Reducing impact on site		
SOC.	Traditional style	■	Traditional raised-beam structure is reinterpreted.
	Traditional materials	■	Bamboo & timber
ECON.	Light-weight materials		
	Standardized modules		
	Prefabricated units	■	All units are prefabricated and come to the site as ready-to-assembly.
	Reversible connections	■	All connections are reversible.
ROLE IN SUSTAINABLE POST-EXPO USE PROCESS		++	Pavilion allows for easy disassembly and reassembly. However the low-durability of roof members needed to be replaced to be used in the long-term.



(2) Axonometric plan & two sides of the roof



(3) Roof details - Bamboo panels



(4) Interior views & timber-steel raised beam structure

REFERENCES:
(1) https://www.dezeen.com/2015/05/05/beijing-skyline-mountain-range-roof-china-milan-expo-2015-pavilion-studio-link-arc-tsinghua-university-bamboo/
(2-3-4) https://www.archdaily.com/627497/china-pavilion-milan-expo-2015-tsinghua-university-studio-link-arc?ad_medium=gallery

laminated timber cross-beams (primary rafters and secondary purlins) connected with disguised joints. Most of the beams are made of glulam timber, while there are some steel beams between these timber members. Designing the roof with curved beams "that base their geometry on the elastic deformation of their initially straight or planar elements" provides resistance against bending stress and longer spans (Golański & Góra, 2018, p. 763). The rafters are designed with slightly different curvilinear forms to acquire the mountain silhouette in overall form. They are located with 2 meters spacing in between and braced with steel members and diagonal steel cables, allowing for longer spans (*China Pavilion Expo Milano 2015*, 2021). The roof is clad with translucent and water-proof membrane sheets attached to aluminum profiles between two rafters. Utilizing a translucent membrane rather than the glass has the advantage of being lightweight and allowing faster construction over the glass (Collina, 2015; Frearson, 2015b). The membrane is then covered with over one thousand woven bamboo panels in hundreds of variations to provide shading in the interior spaces while referring to the traditional terra-cotta roofs of China (Aguilar, 2015).

- **Sustainable Construction Features and Their Role in Post-Expo Use**

The pavilion is relocated to the sea coast in Qingdao, China, which is ensured by its reversible connections and consolidated by the pavilion's traditional architectural characteristics and materials (Winston, 2016). Thanks to the digital parametric tools used in the design process coupled with the modern construction technologies, the sizes of the structural members are optimized, which helps to achieve a cost-effective form of construction and transportation in the relocation of the pavilion (Golański & Góra, 2018). Besides, the modern timber-steel composite raised beam structure provides a huge column-free interior with its long-span capability that can be adapted for different functions for post-expo use. Despite these sustainable features for the post-expo use, some changes are made to the structure in the rebuilt phase by replacing most of the glulam timbers with steel which was not approved by the design team of the pavilion. Replacing the primary structural material damages the sustainable image of the pavilion by creating additional work, increasing consumed energy, and waste of resources. This situation shows the importance of the durability of materials even for the temporary pavilions since they also have a post-expo life.

5.6. Evaluation of World Expo Pavilions considering the analyses

The analysis of pavilions considering the information gathered from literature, allows us to determine the sustainable properties of the structural system and material configurations. The role of structural systems and materials in sustainable post-expo use of pavilions are evaluated in this section by considering the sustainable properties from four aspects of sustainability (functional, environmental, socio-cultural, and economic).

For the Hannover World Expo 2000 (see Table 5.27), it is observed that half of the pavilions are utilized as they were designed, while one is refunctioned as an office building (German pavilion), the other two are dismantled, and their parts are recycled or reused (Japan and Switzerland pavilions). The two recycled/reused cases have almost all sustainable properties in the criteria except a few, which have a high-level role (+++) in sustainable post-expo use. They have common characteristics as integrating all aspects of sustainability with innovative post-expo solutions. For instance, the Japan pavilion has a grid shell structure made of paper cardboard tubes. The pavilion can easily be removed from the site thanks to its foundation made of steel boxes filled with sand and can be recycled up to 100% to be turned into newspapers and notebooks. The other case, the Switzerland pavilion, is made of timber lumbers stacked by cables and springs without requiring any nails and bolts. Thanks to its system, the lumbers get no damage and can be directly used as a construction material without requiring any processing.

On the other hand, the other three cases cannot achieve their post-expo use plans (Netherlands, Hungary, and Poland pavilions). The Hungary pavilion, for instance, was designed as permanent but was not used for eight years. However, it can be relocated to Abu Dhabi thanks to being a membrane structure, in which the structural system and materials play a low-level role without any consideration for sustainability. The Poland pavilion was also not used for fifteen years, then demolished in which relocation or recycling could not be an option due to its vast concrete columns. The last one is the Netherlands pavilion, which has a specific structural design that changes every floor to follow the concept, such as concrete dunes on one floor and sloped tree-trunk columns on another. Therefore, it is hard to refunction the pavilion. As a result,

Table 5.27: Evaluation of Hannover World Expo (2000) Pavilions

Germany Pavilion (2000)



Long-term life plan: **Structural System:** Steel 3D Truss

Post-expo situation: **Primary Materials:** Steel, structural glass, timber

Post-use: Refunctioned as an office

Role in sustainable post-expo use: Low-level (+)

Functional: 2 | Environmental: 0 | Soc.:0 | Economic: 3

Netherlands Pavilion (2000)





Long-term life plan: **Structural System:** RFC Frame - Beam - Slab - Load Beraing Wall

Post-expo situation: 2020 **Primary Materials:** Reinforced Concrete

Post-use: Renovation is started in 2020

Role in sustainable post-expo use: No/Negative (-)

Functional: 1 | Environmental: 1 | Soc.:0 | Economic: 0

Hungary Pavilion (2000)



Long-term life plan: **Structural System:** Steel frame load bearing walls - membrane

Post-expo situation: 2008 **Primary Materials:** Steel, fabric, timber

Post-use: Entrance building in UAE

Role in sustainable post-expo use: Low-level (+)

Functional: 1 | Environmental: 0 | Soc.:1 | Economic: 3

Poland Pavilion (2000)



Long-term life plan: **Structural System:** Steel Frame with RFC columns - 3D Truss

Post-expo situation: 2015 **Primary Materials:** Reinforced concrete, steel, structural glass

Post-use: Demolished

Role in sustainable post-expo use: No/Negative (-)

Functional: 1 | Environmental: 0 | Soc.:0 | Economic: 1

Japan Pavilion (2000)





Long-term life plan: **Structural System:** Paper cardboard Gridshell

Post-expo situation: **Primary Materials:** Paper, timber

Post-use: Recycled to notebook & newspaper

Role in sustainable post-expo use: High-level (+++)

Functional: 4 | Environmental: 4 | Soc.:1 | Economic: 3

Switzerland Pavilion (2000)





Long-term life plan: **Structural System:** Timber stacked beams

Post-expo situation: **Primary Materials:** Timber

Post-use: Construction material - with no processing

Role in sustainable post-expo use: High-level (+++)

Functional: 4 | Environmental:3 | Soc.:1 | Economic: 4

In-Use | No-use | Demolished (Permanent) | Recycled/Reused | Relocated | Dismounted (Temporary)

Section-active | Surface-active | Form-active | Vector-active | Multiple systems

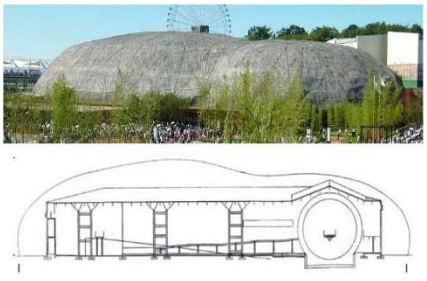
the pavilion had stayed empty for twenty years and was then bought by its designers to protect the memory of the Expo, yet the renovation works continue. Therefore, the role of structural systems and materials of the last two examples are evaluated as no/negative-level.

Since the Aichi World Expo 2005 took lessons from previous failures, all pavilions are built as temporary with modular components by integrating reduce, reuse and recycle principles, to ease the construction and disassembly (see Table 5.28). From the selected cases, all pavilions, except the Japan pavilion, have steel frame structures clad with prefabricated panels. Since most pavilions have basic and rectangular forms, some have small interior pavilions built with significant forms and materials like silk cocoon, coconut, or ceramic, as in the Philippines, Spain, and Turkey pavilions. Only the host country pavilion (Japan pavilion) has an organic form made of knitted bamboo mesh. The Japan pavilion is also a double-layered pavilion in which the exterior is the bamboo cage, and the interior rectangular pavilion is where all functions are configured. The structural systems and materials of the pavilion have a high-level role (+++) thanks to having an innovative connecting method of structural members which utilizes connectors made of laminated bamboo rather than metal. This system increases the load capacity and bonding effect between parts while allowing to recycle the dismantled timber beams and columns without requiring to separate connectors from dismantled parts, saving both energy and time. All other pavilions, except the Mexico pavilion, have a mid-level role in a sustainable post-expo use process thanks to their conventional demountable structural systems and significant eco-friendly materials. Since there is no significant implementation neither in the structural system nor in the materials, the Mexico pavilion's structural system and materials have a low-level role in the post-expo use process by enabling easy dismount only.

The Shanghai World Expo 2010 is a massive showcase for using new materials, energy-efficient and eco-friendly technologies, renewable and clean energy systems, low-carbon transportation systems, and more. Many of these technologies and advancements are applied to the pavilions, even though most of the pavilions are temporary. All the selected pavilions in the Expo achieve their post-use plans while pavilion is designed as permanent, and the rest are temporary (see Table 5.29). The pavilions generally have conventional systems clad with innovative materials like

Table 5.28: Evaluation of Aichi World Expo (2005) Pavilions

Japan Pavilion (2005)



Functional: 3 | Environmental: 5 | Soc.:1 | Economic: 3

Long-term life plan:	**Structural System:** Timber box beams(Int.) - Arched Truss (Ext.)
Post-expo situation:	**Primary Materials:** Timber, bamboo, biodegredable materials
Post-use: Sold in online auction for re-use	
Role in sustainable post-expo use: High-level (+++)	

South Korea Pavilion (2005)



Functional: 2 | Environmental: 1 | Soc.:1 | Economic: 4

Long-term life plan:	**Structural System:** Steel Frame
Post-expo situation:	**Primary Materials:** Steel, aluminum, Korean paper (Int.)
Post-use: Dismantled - no specified use	
Role in sustainable post-expo use: Mid-level (++)	

Turkey Pavilion (2005)



Functional: 1 | Environmental: 1 | Soc.:1 | Economic: 4

Long-term life plan:	**Structural System:** Steel Frame
Post-expo situation:	**Primary Materials:** Steel, dry-wall, timber (int.)
Post-use: Materials are used in İstanbul History Museum	
Role in sustainable post-expo use: Mid-level (++)	

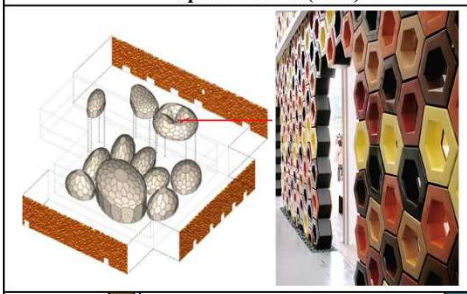
Philippines Pavilion (2005)



Functional: 2 | Environmental: 2 | Soc.:1 | Economic: 4

Long-term life plan:	**Structural System:** Steel Frame
Post-expo situation:	**Primary Materials:** Steel, aluminum, coconut & silk caccoon (int.)
Post-use: Dismantled - no specified use	
Role in sustainable post-expo use: Mid-level (++)	

Spain Pavilion (2005)



Functional: 2 | Environmental:2 | Soc.:2 | Economic: 3

Long-term life plan:	**Structural System:** Vaulted bubbles (Int.) - Steel Frame (Ext.)
Post-expo situation:	**Primary Materials:** Steel, ceramic
Post-use: Ceramic tiles were refunctioned	
Role in sustainable post-expo use: Mid-level (++)	

Mexico Pavilion (2005)



Functional: 1 | Environmental: 1 | Soc.:0 | Economic: 4

Long-term life plan:	**Structural System:** Steel Frame
Post-expo situation:	**Primary Materials:** Steel, aluminum, fabric
Post-use: Dismantled - no specified use	
Role in sustainable post-expo use: Low-level (+)	

In-Use | No-use | Demolished | Recycled/Reused | Relocated | Dismounted

Permanent | Temporary

Section-active | Surface-active | Form-active | Vector-active | Multiple systems

Table 5.29: Evaluation of Shanghai World Expo (2010) Pavilions

China Pavilion (2010)



Long-term life plan:

Structural System: Dougong - 56 interlocking brackets in 7 levels

Post-expo situation:

Primary Materials: Steel, reinforced concrete

Post-use: China Fine Arts Palace - exhibition space

Role in sustainable post-expo use: Low-level (+)

Functional: 2 | Environmental: 3 | Soc.:1 | Economic: 0

United Kingdom Pavilion (2010)



Long-term life plan:

Structural System: Timber diaphragm strengthened by steel

Post-expo situation:

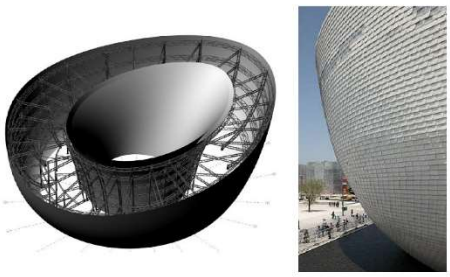
Primary Materials: Acrylic tubes filled with seeds, timber, steel

Post-use: Rods filled with seeds are planted

Role in sustainable post-expo use: Mid-level (++)

Functional: 3 | Environmental: 3 | Soc.:0 | Economic: 4

Finland Pavilion (2010)



Long-term life plan:

Structural System: 3D Truss

Post-expo situation:

Primary Materials: Steel, UPM-Profi (paper-plastic composite)

Post-use: Dismantled to be reerected, if needed

Role in sustainable post-expo use: Mid-level (++)

Functional: 2 | Environmental: 2 | Soc.:0 | Economic: 3

Portugal Pavilion (2010)



Long-term life plan:

Structural System: Bolted steel frame

Post-expo situation:

Primary Materials: Cork, steel

Post-use: Disassembled - could be recycled

Role in sustainable post-expo use: (++)

Functional: 2 | Environmental: 2 | Soc.:1 | Economic: 3

South Korea Pavilion (2010)



Long-term life plan:

Structural System: Steel frame

Post-expo situation:

Primary Materials: Steel, aluminum

Post-use: Dismantled - no specified use

Role in sustainable post-expo use: Low-level (+)

Functional: | Environmental: | Soc.: | Economic:

Norway Pavilion (2010)



Long-term life plan:

Structural System: Membrane

Post-expo situation:

Primary Materials: Timber, fabric, glulam bamboo

Post-use: Relocated to different locations in China

Role in sustainable post-expo use: High-level (+++)

Functional: 4 | Environmental: 3 | Soc.:1 | Economic: 4

In-Use | No-use | Demolished | Recycled/Reused | Relocated | Dismounted

Permanent | Temporary

Section-active | Surface-active | Form-active | Vector-active | Multiple systems

paper-plastic composite materials, as in the cases of Finland and China pavilions, or cork, as in the example of the Portugal pavilion. Some pavilions provide unique post-use processes thanks to their significant structural systems or building materials. The United Kingdom pavilion, for instance, has acrylic tubes filled with seeds as a primary building material. The tubes will be planted after the Expo in different locations in China. The Norway pavilion is another example of an innovative system by being the first large-scale tensile membrane structure consisting of 15 components that can be separated and reconfigured using the same parts of the membrane roof. Each tree-like member works as a structure, infrastructure, and furniture. Each member is used as fifteen separate shading units in different locations. It is the only pavilion in which its structural system and materials have a high-level role in sustainable post-expo use, while other cases with innovative materials have a mid-level role, and the rest have a low-level role.

The last Expo, Milan World Expo 2015, took a series of measures for the post-expo use of the Expo site by embracing the "mobility, flexibility and reversibility" principles with a series of, in addition to its construction guidelines prepared by reinterpreting the LEED criteria of the United States. All post-expo use plans are accomplished in this Expo among the analyzed cases (see Table 5.30). Only the host-country pavilion is designed as permanent among the selected cases and refunctioned after the Expo, while all other selected cases are designed temporarily and relocated to their new locations. This Expo comes forward with innovative structures with lightweight and conventional materials, mainly timber, that ease the disassembly and relocation while providing a long span for refunctioning. Although there is a great emphasis on the post-expo use of pavilions and all plans regarding this issue are achieved, there is no pavilion among the cases that has a structural system and material configuration with a high-level role in sustainable post-expo use. This is mainly caused by using conventional materials for structural and non-structural components without considering any innovative sustainable solutions, except the Italy Pavilion uses smoke-absorbing cement as a non-structural material. Although it is the latest Expo among selected ones with a higher technological development level compared to previous years, it is interesting that there is no combination of structural systems and materials with innovative characteristics for sustainable post-expo use solutions.

Table 5.30: Evaluation of Milan World Expo (2015) Pavilions

Italy Pavilion (2015)



Functional: 2 | Environmental: 2 | Soc.:0 | Economic: 0

Long-term life plan:	**Structural System:** Steel Beam System
Post-expo situation:	**Primary Materials:** Steel, active-BIODYNAMIC cement
Post-use: Human Technopole foundation	
Role in sustainable post-expo use: Low-level (+)	

France Pavilion (2015)



Functional: 3 | Environmental: 2 | Soc.:0 | Economic: 3

Long-term life plan:	**Structural System:** Glulam timber gridshell
Post-expo situation:	**Primary Materials:** Glulam timber
Post-use: Relocated to France - covered market	
Role in sustainable post-expo use: (++)	

United Kingdom Pavilion (2015)



Functional: 3 | Environmental: 1 | Soc.:0 | Economic: 3

Long-term life plan:	**Structural System:** 32 horizontal layers linked by 3D trusses
Post-expo situation:	**Primary Materials:** Aluminum, steel
Post-use: Relocated to the Kew Gardens	
Role in sustainable post-expo use: Mid-level (++)	

Bahrain Pavilion (2015)



Functional: 2 | Environmental: 0 | Soc.:0 | Economic: 2

Long-term life plan:	**Structural System:** Precast concrete panels
Post-expo situation:	**Primary Materials:** Precast concrete
Post-use: Relocated to Bahrain - botanical garden	
Role in sustainable post-expo use: Low-level (+)	

Chile Pavilion (2015)



Functional: 3 | Environmental: 2 | Soc.:0 | Economic: 4

Long-term life plan:	**Structural System:** Timber Diagrid
Post-expo situation:	**Primary Materials:** Timber, steel
Post-use: Rebuilt in Chile - cultural & tourist center	
Role in sustainable post-expo use: Mid-level (++)	

China Pavilion (2015)



Functional: 3 | Environmental: 1 | Soc.:2 | Economic: 2

Long-term life plan:	**Structural System: Raised beam system**
Post-expo situation:	**Primary Materials:** Timber, steel, bamboo
Post-use: Relocated to the sea coast in China	
Role in sustainable post-expo use: Mid-level (++)	

In-Use | No-use | Demolished | Recycled/Reused | Relocated | Dismounted

Permanent | Temporary

Section-active | Surface-active | Form-active | Vector-active | Multiple systems

CHAPTER 6

DISCUSSION

In chapter 5, case studies are explained with their structural/sustainable properties. Following the data obtained from the analyses, this chapter focuses mainly on the analysis results from different perspectives regarding the five research questions mentioned in Section 1.2, including:

- different approaches of World Expos for the design of the pavilions regarding sustainability,
- the relationship between the temporariness/permanency of pavilions and their post-expo-use performances,
- selection of structural systems and materials (structural and non-structural) of pavilions for different post-expo uses,
- functional, environmental, socio-cultural, and economic sustainability properties of the configuration of structural systems and materials, and
- comparison of the pavilions regarding the role of structural systems and materials on efficient and sustainable post-expo use.

Then, in section 6.2, the inferences and conclusions about the sustainability performance of pavilions for their post-expo use are presented, concerning the

aforementioned discussions. Lastly, the limitations of the study and recommendations for further studies are remarked upon.

6.1. Discussion on the sustainability performance of structural systems and materials

Throughout the literature review about the World Expos and their pavilions in Chapter 3 and Chapter 5, it is realized that each World Expo has an attitude towards the articulation of the site, the theme of the Expo, and how the theme is reflected in the design of the pavilions. Therefore, in every Expo, the long-term life expectancy of pavilions (whether they are designed as permanent or temporary) and their post-expo uses are altered based on the sustainability strategies of the Expo. In analyzing the pavilions in terms of their efficient and sustainable post-expo use, the long-term life expectancy of pavilions plays a crucial role. The long-term life expectancy of pavilions ideally affects the design of the pavilions and, thus, the selection of the structural system type and building materials (structural and non-structural) are also affected. As a result, the configurations of the structural systems and materials play a determinative role in pavilions' sustainable features, which all contribute to the sustainable post-expo use process.

- **Different approaches of World Expos for the design of the pavilions regarding post-expo use:** As mentioned before, every Expo has its themes and predetermined design principles. In the Hannover World Expo with the sustainability theme assigned for the first time, the old fairground was utilized, and already-existing structures were transformed into pavilions. Among the newly constructed national pavilions, the permanent pavilions were more in number compared to the temporary ones. When the selected cases are considered, the permanent pavilions are more dominant, with four permanent pavilions over two temporary pavilions (see Table 6.1). However, out of four permanent cases, only one is utilized in the post-expo period as it is planned, while the rest has been abandoned for years. Then, one is demolished, one is relocated, and one is still unused, but renovation works are in progress for re-functioning (see Table 6.2).

Table 6.1: Long-term life expectancy of pavilions at World Expos

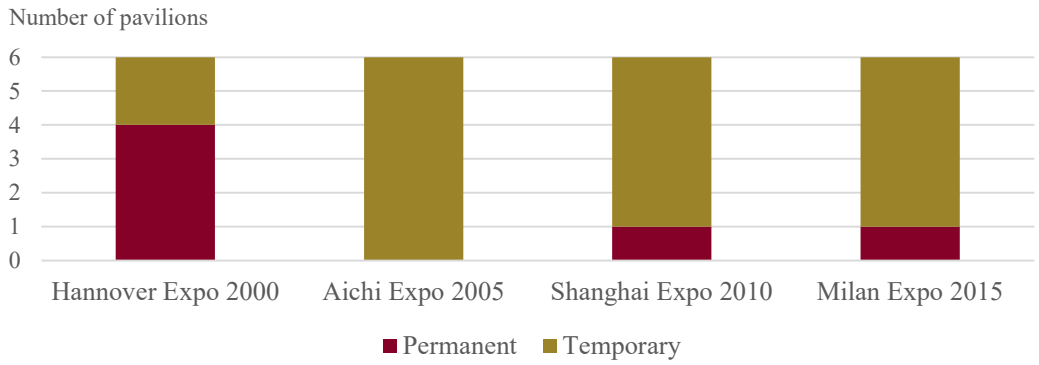
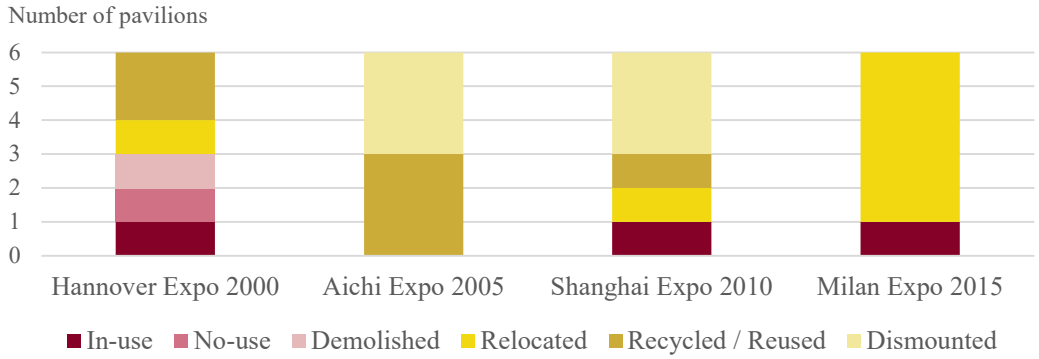


Table 6.2: Post-expo use of pavilions at World Expos

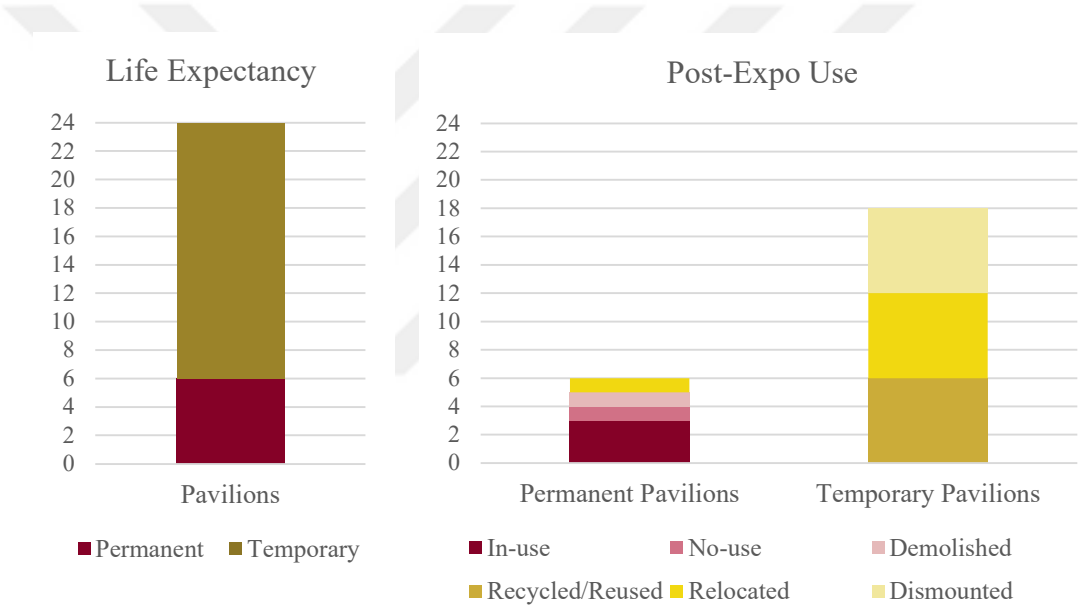


The following World Expo, Aichi 2005, considered the failures of post-expo uses in the Hannover Expo, and decided to build all national pavilions temporarily (see Table 6.1). All pavilions are designed with standardized prefabricated units by integrating "Reduce, Reuse, and Recycle" principles to ease the post-expo process. As a result, all examined cases are disassembled after the Expo, while the components and materials of the three are either recycled or reused. The other three pavilions' post-expo use has not been specified, except for the fact that they are all disassembled (see Table 6.2). The Shanghai 2010 and Milan 2015 World Expos followed the decision of the Aichi Expo by designing temporary national pavilions. However, they decided to keep a few pavilions on the site with predefined post-expo uses. Among the examined cases, the host-country pavilions of the Shanghai and Milan World Expos are designed as permanent and refunctioned after the Expos. The rest are temporary in both Expos (see Table 6.1). While all examined temporary pavilions of Milan World Expo 2015 are relocated, the temporary cases

of Shanghai Expo have a variety of post-expo uses, including dismantled, relocated, and reused pavilions (see Table 6.2).

- **The relationship between the temporariness/permanency of pavilions and their post-expo-use performances:** Out of twenty-four selected pavilions from four World Expos, six are designed as permanent and eighteen as temporary. However, the post-use of pavilions has not always been as envisioned as they were designed. Therefore, the selected pavilions demonstrate a variety of post-expo uses, including "in-use, no-use, demolished, recycled/reused, relocated and dismantled" pavilions (see Table 6.3).

Table 6.3: Long-term life expectancy vs. post-expo use of the pavilions



Among the six permanent pavilions, three of them are kept in the Expo sites and refunctioned after the Expo, which are called in-use pavilions (Germany (2000), China (2010), and Italy (2015) pavilions). Other permanent cases (Netherlands (2000), Poland (2000), and Hungary (2000) pavilions) have not been used for several years after the Hanover Expo. The Netherlands Pavilion, for instance, stayed empty until 2020 and then was bought by its architects to be renovated and refunctioned. However, since the pavilion was not used for 20 years, it required extensive energy, time, and resources to be repaired. Besides, as of 2022, the renovation works are still in progress (Expo Pavilion 2.0, n.d.). Therefore, the Netherlands pavilion is marked as a pavilion with 'no-use' in Table 7 in Appendices. The Poland Pavilion (2000) stayed empty for 15 years and was

demolished in 2015. Lastly, the Hungary Pavilion was not used until 2008 and relocated to the UAE as an entrance building.

Moreover, out of eighteen temporary pavilions:

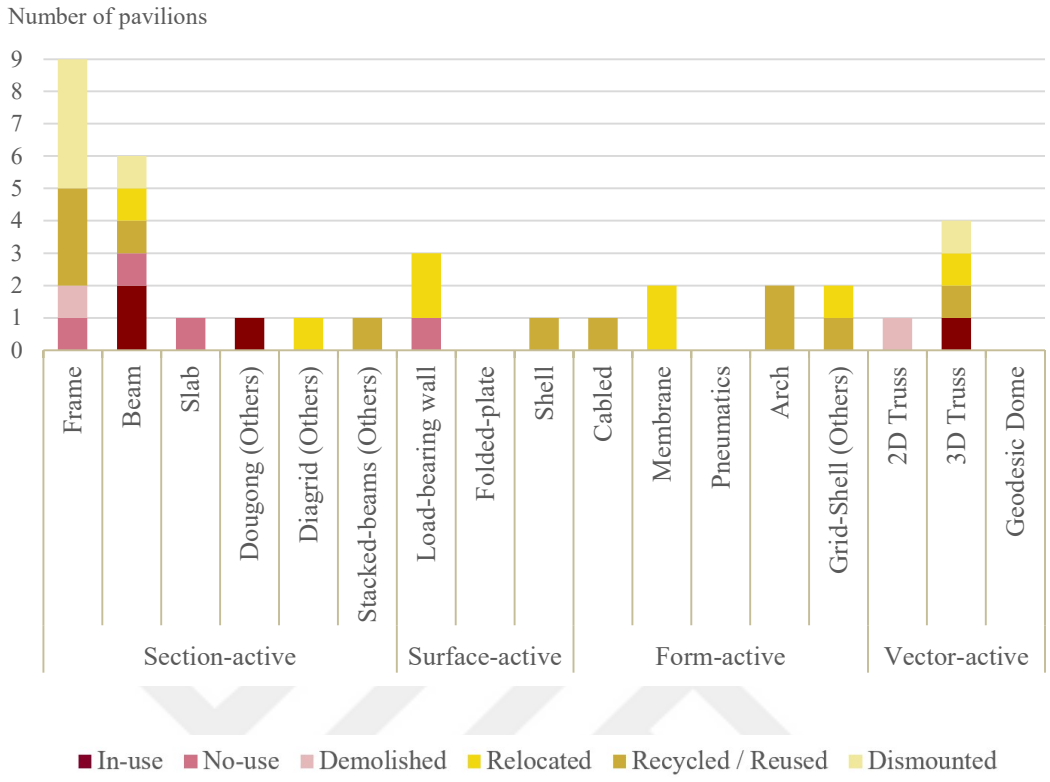
- six pavilions are relocated to be refunctioned somewhere else,
- six pavilions are demounted in which their parts are recycled or reused, and
- six pavilions are disassembled without any specification of their further use.

As a result, three out of six permanent pavilions (in-use pavilions) and twelve out of eighteen pavilions (recycled/reused and relocated pavilions) are "*used as planned"* in the post-expo period. The other six temporary pavilions were also disassembled as planned, although they do not have any specific further life scenarios. Only one pavilion became temporary by being relocated, although it was designed as permanent. Lastly, the two pavilions -Poland (demolished) and Netherlands (stayed empty for more than 20 years)- *"failed"* in terms of the execution of the post-expo use plan.

Overall, the selected cases demonstrate that temporary pavilions are preferred more to expedite the post-expo use process of World Expo pavilions. It is observed that designing temporary pavilions allow for an easy disassembly process while preserving the value of the building materials as much as possible. Even if the components or materials are not recycled or reused efficiently in some cases, it prevents pavilions from deteriorating in the old Expo sites. This minimizes the waste of time and resources for constructing and deconstructing the pavilions while reducing the adverse effects of World Expos on the urban scale.

- **Selection of structural systems and materials (structural and non-structural) for different post-expo uses:** Among the analyzed cases, section-active structures are the most common type (see Table 6.4). The section-active structures are considered one of the most basic structural systems due to linear elements arranged in a rectangular section. They are widely preferred in the construction industry due to their simple and well-known characteristics, which is also valid for the selected group of World Expo pavilions. However, when the iconic image and form of World Expo pavilions are considered, it is expected to encounter more free-form and long-span structures than the conventional systems.

Table 6.4: Structural system types of pavilions based on different post-expo uses

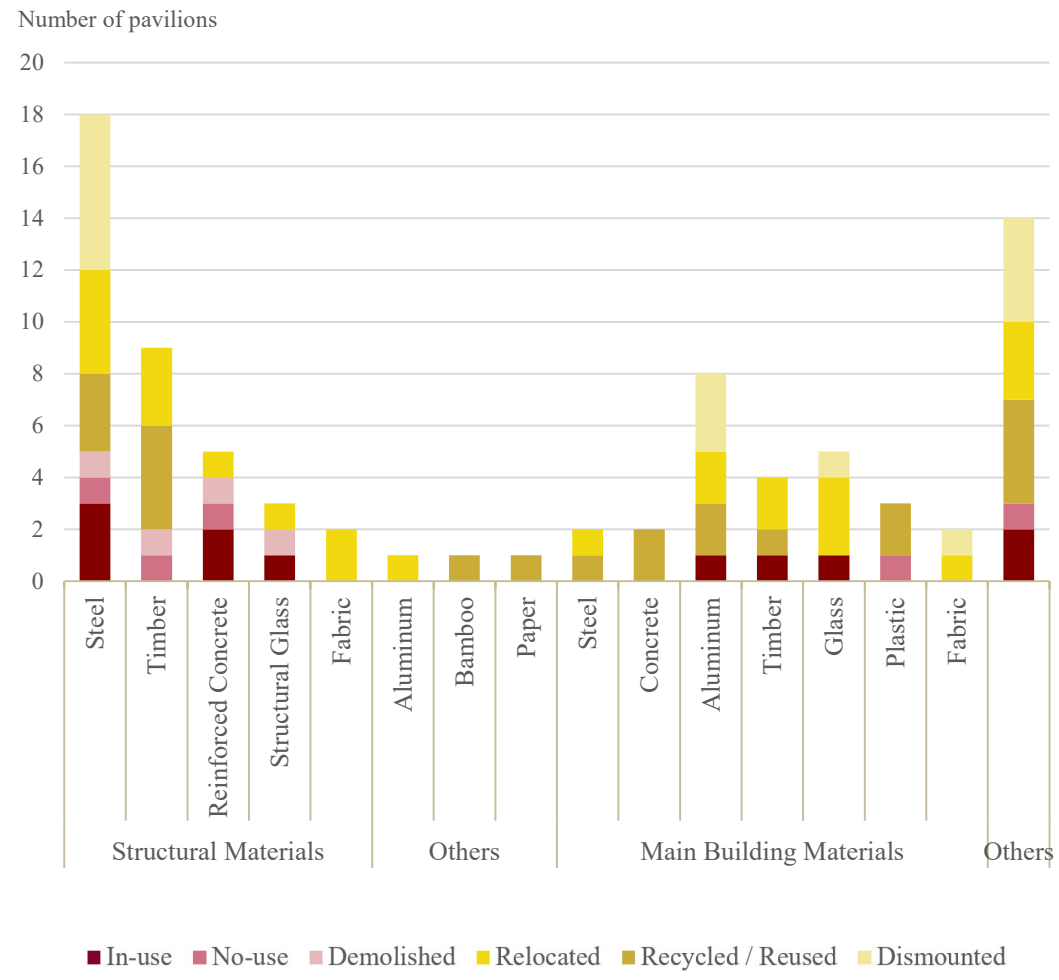


The analysis demonstrates that form-active structures follow the section-active structures in number among the examined pavilions when newly-developed structures' working principles are also considered (see Table 6.4). Form-active structures are considered the most efficient and economic systems to acquire wide spans (see Section 4.2.1.3). They are also lightweight structures (membrane, cable, pneumatic) compared to other structural types. Therefore, they can be considered a good fit for the World Expo pavilions when the need for wide openings in exhibitions and requirements of the sustainable design principles are considered. Besides, since they become robust through the form rather than the amount of material, they are preferable for temporary pavilions to reduce the resource consumption, energy, and time both in construction and disassembly processes.

The vector-active structures (specifically the 3D trusses) are also utilized widely among the examined cases to achieve longer spans. Column-free interior layouts provide flexibility in permanent and relocated pavilions for re-functioning in the post-expo period, making vector-active structures an appropriate option (see Table 6.4).

For the structural material choice, the most encountered material in the construction industry -steel- is the most preferred in pavilions. It is followed by timber, reinforced concrete, structural glass, and fabric by the numbers (see Table 6.5). When it is considered that most of the selected pavilions are temporary, it is expected to encounter more lightweight materials rather than steel and reinforced concrete. Timber, the second most preferred material, can be evaluated as a proper choice since it is a lightweight material that eases the relocation process while reducing the energy required for construction, deconstruction, and reassembly. Among the non-structural materials, aluminum is the most preferred (see Table 6.5). Since it is a durable, lightweight, and highly recyclable material, it fulfills the requirements of both permanent and temporary pavilions.

Table 6.5: Structural and non-structural materials based on different post-expo uses



For the permanent pavilions, the choice of steel, reinforced concrete, and structural glass as structural materials seems fair (see Table 6.5), since durability is a crucial

property for permanency, while unit-weight or recyclability is not as much. However, the three of the permanent cases designed as permanent, yet cannot be refunctioned after the Expo demonstrate that even the material choice of permanent pavilions should be made by considering that the pavilions may not be used in the future as expected. Among the three permanent cases, the one built with steel, timber, and fabric (Hungary 2000) was relocated thanks to its lightweight materials and reversible connections. However, the other two buildings made of concrete (Netherlands 2000 and Poland 2000) cannot be dismantled for recycling or relocation, which convicts them to stay unused on the site for years.

Overall, from Table 6.5, it has been observed that there is no significant division between structural and/or non-structural materials in terms of the post-expo use of pavilions. Besides, when the properties of materials mentioned in Section 4.3 are considered, all materials have their own pros and cons regarding sustainability. Therefore, the effect of structural and non-structural materials on the post-expo use of pavilions cannot be evaluated further without considering how they are configured with the structural systems in every case.

Moreover, when the innovativeness of structural systems and building materials (structural and non-structural) are considered, there are few significant structural systems and structural materials. On the other hand, innovative non-structural materials are in considerable number. This demonstrates that while more conventional solutions are applied for structural systems and materials, innovative solutions are more effective in non-structural building components. One of the reasons is the building codes and regulations that restrict the designers to use innovative materials as the main structural materials, as in the cases of Germany (2000), Japan (2000), and Norway (2010) pavilions (see Section 5.2.1, 5.2.5 and 5.3.6). However, these examples are also low in number when compared with the examples of structural achievements and material developments in the history of World Expos mentioned in Section 3.1. Therefore, it can be concluded that although World Expo pavilions are known for their structural achievements and innovative structural typologies and materials, the efforts have decreased away throughout the years.

- **Functional, environmental, socio-cultural, and economic sustainability properties of the configuration of structural systems and materials:** In the evaluation of properties of structural systems and materials for sustainable post-expo use, the pavilions are divided into four categories considering their planned post-expo uses:

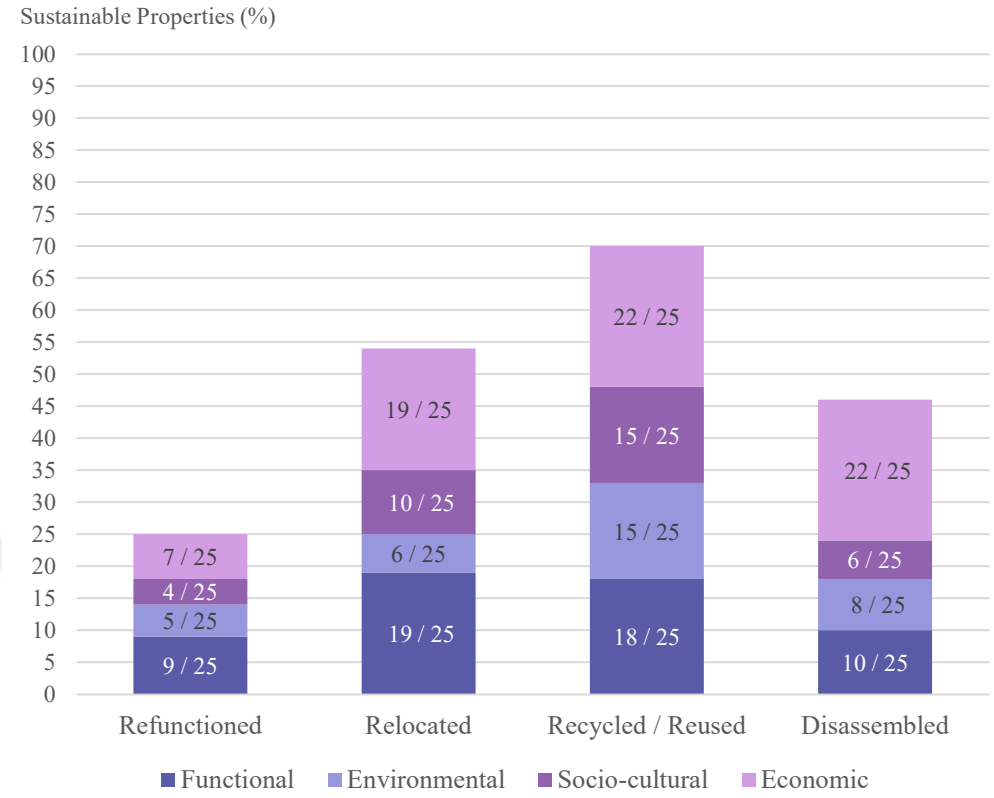
  – designed as permanent to be re-functioned,
  – designed as temporary to be relocated,
  – designed as temporary in which its parts will be recycled or reused,
  – designed as temporary to be disassembled without any further plan.

  The analysis and comparison are conducted by considering each sustainability category as 25% and calculating the number of sustainable properties in percentage. This helps us to observe the sustainability percentage of different post-expo uses while comparing the effect of each category in specific uses (see Table 6.6).

  When the sustainable properties of permanently designed cases are analyzed, it is observed that functional properties are more dominant than others. Since the main design aim of the permanent pavilions is to refunction them rather than disassemble them, the economic properties mostly related to easy assembly and disassembly remain in the background. Since permanent cases continue to be used by the public, socio-cultural properties are expected to have more importance than disassembled or recycled ones. However, it is observed that socio-cultural properties are considered much neither in the design nor material selection in permanent pavilions (see Table 6.6).

  Even though all permanent pavilions are designed to be refunctioned after the Expo, some failed to achieve their planned post-expo uses. It is observed that this failure is caused mainly by the lack of 'flexibility/adaptability' of pavilions ensured by the functional characteristics of the structural system and materials for re-functioning. When the pavilions cannot be refunctioned on the Expo site for some reason, they need to be disassembled for recycling or relocation. To be disassembled, they need to have at least 'reversible connections'. They deteriorate on the site and harm the urban environment when they do not.

Table 6.6: Sustainable properties of structural systems and building materials



In the design of the relocated pavilions, functional and economic properties play equal roles (see Table 6.6). This seems reasonable when we consider that the efficient post-expo use of relocated pavilions depends on both easy disassembly and reassembly of pavilions and the flexibility of the structure for refunctioning. Besides, significant structural systems are applied in almost all relocated pavilions to provide innovative solutions for both relocation and refunctioning processes. As a result, when the functional properties among different uses are compared, relocated pavilions have the highest ratio. Moreover, socio-cultural properties also have a high ratio, even compared to permanent pavilions, which can contribute to post-expo use of pavilions in their new location.

The analysis of recycled/reused pavilions shows that the economic properties are more dominant, which could be related to preserving the material's value by easing the construction and disassembly to increase the efficiency of the recycling process (see Table 6.6). Although socio-cultural properties are not that crucial because the pavilions are not functioning as a building after the Expo, it is interesting that they are considered as much as the environmental properties and very close to functional properties. When the pavilions are analyzed closely, it is realized that the natural

and recyclable materials used in the pavilions are generally belong to specific Nations, which increases the socio-cultural properties related to the material. Compared with the other type of usages, environmental properties have the highest ratio in recycled/reused pavilions which is reasonable since environmental properties are more related to the eco-friendly characteristics of materials over their life cycle.

Lastly, the analysis of the disassembled pavilions demonstrates that they have lower sustainable properties in their structural system design and material selection than the other temporary pavilions (see Table 6.6). As in the other temporary pavilion usages, economic properties have the utmost importance in easing the disassembly process. Since their exact use is not specified after the disassembly, there are fewer specific properties in other categories.

After completing the analysis of all pavilions (see Table 7 in Appendices), it is observed that permanent pavilions' structural systems and materials have lesser sustainable characteristics that affect the post-expo use of the pavilions than the temporary ones. The recycled pavilions have more sustainable features than other usage types, followed by relocated and disassembled ones (see Table 6.6). The analyses and comparison also revealed that the cruciality of the sustainable features might differ based on the usage of the pavilions, for instance:

- functional properties are more crucial for permanent pavilions,
- functional and economic properties are equally significant for relocated pavilions, and
- economic properties are essential for recycled and disassembled pavilions.

It is also striking that environmental properties have a lower ratio than expected in all use types, which is interesting since the environment is believed to be the main subject of sustainability. Overall, the economic sustainability properties have the highest ratio, as observed from the cases since the easy assembly and disassembly are the main focus of most pavilions.

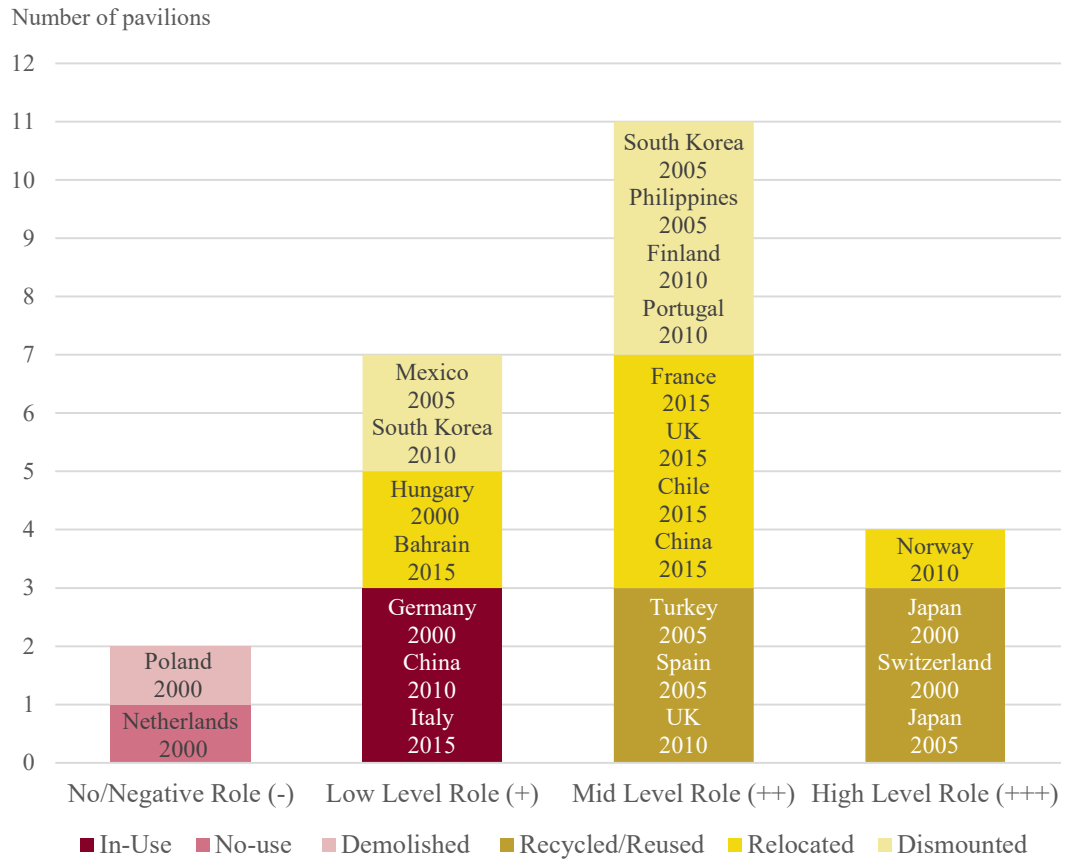
- **Comparison of the pavilions regarding the role of structural systems and materials on efficient and sustainable post-expo use:** As it is mentioned in Chapter 4, the role of structural systems and building materials in the efficient and

sustainable post-expo use is revealed based on the sum of sustainable property numbers of each pavilion accordingly:

- 1 to 3 sustainable properties: No/negative role (-)
- 4 to 6 sustainable properties: Low-level role (+)
- 7 to 10 sustainable properties: Mid-level role (++)
- 11 to 15 sustainable properties: High-level role (+++) (see Table 7 in Appendices).

With this determined scale, whether the post-expo process is considered in the configuration of structural systems and materials are observed and the role of structural systems and materials in the post-use of pavilions is evaluated. The results show that the structural systems and materials have no (even negative for some cases) or low role in the sustainable post-expo use of permanent pavilions (Table 6.7). On the contrary, they have a significant impact on the efficient use of temporary pavilions

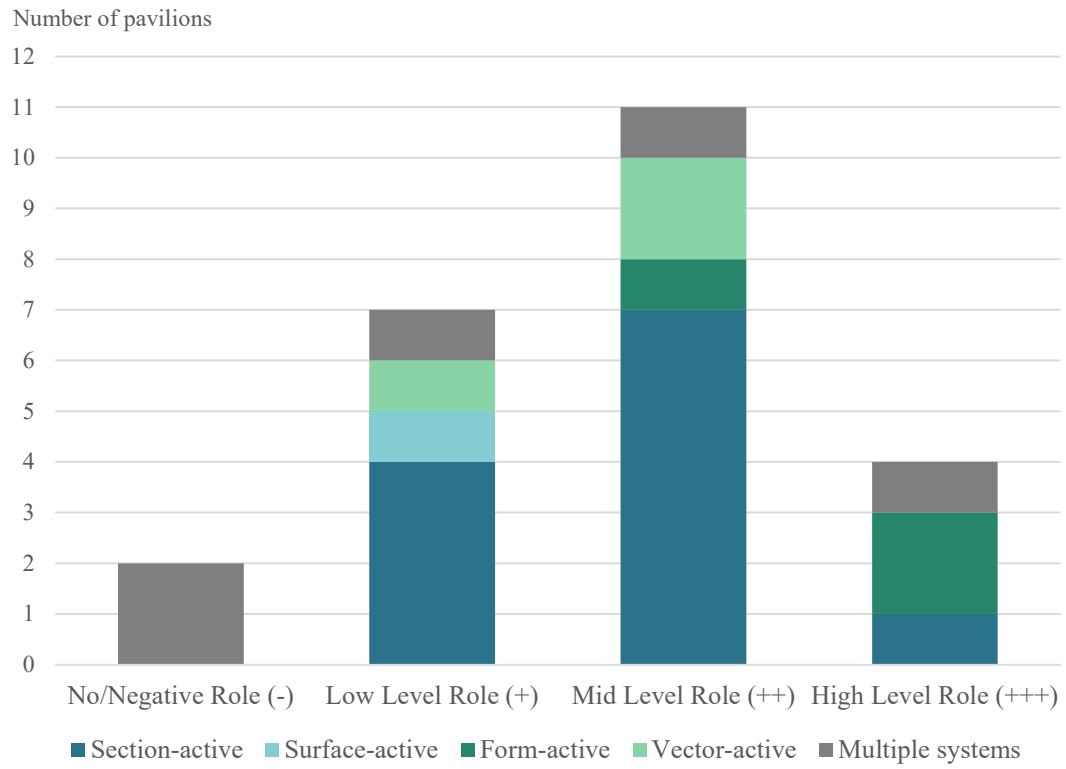
Table 6.7: The role of structural systems and materials in efficient and sustainable post-expo use



Moreover, when the relationship between structural type and the role of structural systems and materials in post-expo use is analyzed, it is observed that the form-active structures have the highest role in the efficient post-expo use of pavilions (see Table 6.8). It is observed that form-active structures, especially when they are configured with appropriate materials, have more sustainable properties compared to other structural types in providing efficient and sustainable post-expo uses for pavilions. When we consider that form-active structures are considered the most efficient structure type, as mentioned before, having the highest role in the efficient post-expo use of pavilions is what is expected, and thus, a reasonable result.

The section-active structures are more dominant among the structural systems with have low and mid-level role in post-use of pavilion, which may be related with the dominance of section-active structures in number among all structural types. The vector-active structures, known for their efficiency and long spans, follow section-active structures in the category of 'mid-level role', but have a small ratio (see Table 6.8).

Table 6.8: Relationship between structural system type and the role of structural system and materials on sustainable post-expo use



In order to understand the role of the structural systems and materials in the role of efficient post-expo use of pavilions more accurately and comprehensively, the pavilions are compared and contrasted by considering how they are configured and designed in the following:

- **No/Negative Role (-):** When the architectural and structural characteristics that obstruct further adaptability are combined with materials with irreversible connections (i.e., concrete), they cause usability issues in the post-expo period. These structural systems and materials have little or no positive role on the post-expo use of pavilions, while they might have even negative effect on the post-expo use. For instance, despite its green and smart building technologies, the Netherlands pavilion had stayed empty until 2020. It probably caused by its unique and interesting structural design that provides no flexibility for refunctioning, and thus, complicates the post-expo use process. Besides, the Poland pavilion also stayed empty for 15 years and then demolished, although it has a steel truss system combined with reinforced-concrete frame that enables a wide column-free area. This might be caused by being a completely transparent box that makes the structure inconvenient for the re-functioning due to excessive sunlight. Because both structures are mainly made of concrete, they could not be relocated or recycled efficiently, which shows the importance of structural system and material configurations to provide flexibility and alternative post-expo use scenarios to not to have negative role in post-use of pavilions.

- **Low-level Role (+):** The common characteristics of majority of the structural systems and materials with low-level role is providing long span and wide free-column area for permanent cases to increase the flexibility for changing needs after the Expo. Other than that, the structural systems and materials do not have major role in the permanent cases, because the post-use of permanent pavilions depend on varied factors beside the structural systems. However, the selected cases demonstrate that even if the pavilion is designed as permanent, it might not be utilized for some reason. Therefore, it is realized that structural system and material play still an important role in the permanent cases to change or re-adapt the post-expo use plan based on the circumstances. For instance, although the Hungary pavilion (2000) is designed as permanent, it was not used for almost

eight years. In that circumstance, the pavilion's simple and lightweight structure makes relocation an option, rather than convict it to remain idle further like Netherlands (2000) and Poland (2000) pavilions mentioned before.

For the temporary cases with structural systems and materials that have 'low-level' sustainable features commonly have conventional systems and materials like steel frame and pre-cast concrete load-bearing wall. Since they are designed as temporary, they enable disassembly with reversible connections. However, combining conventional systems and materials without any significant feature for easing the post-expo process do not contribute to provide sustainable solutions for post-expo process. Therefore, their role in post-use process is limited to 'low-level'.

- **Mid-level Role (++):** The pavilions with mid-level sustainable properties, which all are temporary with different post-expo uses, are high in number among the selected cases. They represent the group of pavilions that are designed to ease the disassembly process with a few implications in other categories. Most of the cases have either have conventional structural systems coupled with innovative materials or conventional materials combined with innovative structural systems. The section-active structures are dominant among these pavilions in which their post-expo use strategies are varied. It is observed that there is a relationship between the features of structural systems, building materials and planned post-expo use of pavilions which demonstrate that the configuration of the structural systems and materials is highly affected by the planned post-expo use of pavilions in this category.

  For instance, the pavilions that are disassembled at the end of the Expo and their parts are either recycled or reused have mainly demountable steel frame structures. Some of these structures, precisely the Aichi World Expo pavilions, are designed with modular and prefabricated steel frame units, yet without considering much about the iconic architectural design and innovative implementations that World Expos are famous for. As a result, although the disassembly processes in the post-expo period become much easier and more efficient, the pavilions do not have much architectural and structural significance. The cases with a simple form mostly have smaller pavilions inside

with distinctive characteristics and significant materials to sustain the impressive images of pavilions. However, this doubles the consumption of resources, money, time, and money both in the construction and disassembly processes. There are also some cases that couple conventional bolted steel frames with innovative and/or green building components as a sustainable strategy for post-expo use. Finland (2010) and Portugal (2010) pavilions are examples of sustainable material use with high recycling rates and low carbon emissions, which use paper-plastic composite material and cork as the cladding materials.

The pavilions that are relocated at the end of the Expo (France, United Kingdom, Chile and China at Milan Expo 2015) have demountable structures with significant structural design and innovational features that coupled with conventional materials like steel, glulam timber, and aluminum. The innovative characteristics of the structures mainly focused on the span of the structure to provide flexibility for their new functions. Since these pavilions are relocated after the Expo, functional and economic properties of pavilions come forward in these examples, while environmental properties stay behind, which causes them to be marked as 'mid-level'.

There are also some cases designed with innovative post-expo use solutions which increases their sustainable properties and make them remarkable among other pavilions: Spain (2005) and the United Kingdom (2010). They both have conventional Spain pavilion, for instance, is differentiated from other selected cases of the Aichi 2005 Expo with its distinct façade design and material. The ceramic tile panels in the façade are sold as garden sculptures after the disassembly. UK Pavilion also has a unique design and re-use approach. The acrylic tubes filled with seeds are the primary building materials planted in different locations after the Expo.

– **High-level Role (+++):** The pavilions with significant and/or innovative structural systems combined with eco-friendly materials have a high-level potential to achieve sustainable post-expo use, as in the examples of Japan (2000), Switzerland (2000), Japan (2005), and Norway (2015) Pavilions. The design and selection of structural systems and materials with sustainable properties eases the disassembly process, minimize the use of energy and resources in transportation, re-assembly and/or recycling, and enables efficient

post-expo uses while causing little or no harm to both the natural and urban environment.

For instance, the Japan Pavilion (2000), becomes one of the most significant examples of sustainable solutions for the post-expo period and its structural and material features. Its innovative structural design, the form-active grid shell structure minimizes the use of materials, while its primary structural material, paper cardboards, enables high-percent recycling which turned into newspapers and notebooks after the Expo. Similarly, Switzerland Pavilion (2000) also has a unique approach in its structural design, material selection, and construction techniques by considering the post-expo use process. The structure has a unique feature which works only with the friction between the beams ensured by tension rods and requires no nails or bolts. In this way, the timber beams get no damage, neither chemical treatment nor nails, and are directly used as construction material after the disassembly without any processing. The Japan Pavilion (2005) has also developed an innovative connection system called 'bamboo connectors' and combined it with other sustainable strategies like smart, reclaimed, and sustainably harvested materials. Using bamboo connectors rather than metal ones compounds the bonding level between structural components, increasing the load capacity. Besides, the system allows recycling the timber beams without separating connectors from dismantled parts, saving energy and time in the post-expo period. Lastly, the Norway Pavilion (2015) has an innovative structural design developed for increasing post-expo adaptability. The pavilion is the first large-scale tensile membrane structure consisting of 15 tree-like components that can be separated and reconfigured using the same parts of the membrane roof. Each member works as structure, infrastructure, and furniture, which saves material while allowing the use of individual units. Developing an innovative membrane fabric that is dirt-repellent and more durable also enables the long-term life of the pavilion with low maintenance.

The examples demonstrate that pavilions with an appropriate design considering the post-expo period can create prototypes to provide solutions for real-life issues. With the innovations in structural systems and material properties, they can also be evaluated as candidates to be the architectural and structural legacies of the Expos.

CHAPTER 7

CONCLUSION

World Expos are mega-events that have been initiated with the purpose of exchanging social, cultural, scientific, and technological development between different nations, which gradually evolve to address the shared values and issues of humankind. Through the evolution of Expos, the redevelopment of the urban environment becomes one of the main focuses, which creates significant changes in both urban and natural environments. The urban redevelopment led by the Expos comes with the construction of housing, entertainment, production, and exhibition settlements for the Fairgrounds, together with the infrastructure upgrade. These urban implementations lead to the transportation of materials worldwide, and dense construction, deconstruction, and relocation processes. If these processes are not planned and executed well, they cause excessive resource consumption, environmental pollution, and mismanagement of the urban environment. Even though the focus of World Expos has been shifted over time to more sustainable ways of living, their outcomes continue to create environmental issues, which mainly originate from a lack of proper planning for post-event periods.

Although various domains and parties might affect the post-expo use of the pavilions, including economic, social, or institutional, one of the primary factors that significantly impact the reusability in the post-expo period is the architectural and structural design of the pavilions. Therefore, to observe the role of structural systems and materials in the sustainable post-expo use of a selected group of pavilions, the following features are analyzed in this study:

- the design of structural systems,

- selection of structural and non-structural materials, and

- sustainable properties of the structural system and material configurations.

The analysis reveals that structural and material configurations have a crucial impact on the reusability of permanent and temporary pavilions from different perspectives. Regarding the five research questions mentioned in Section 1.2 and discussed in Chapter 6, some conclusions are driven by the following:

1. The first World Expo with the sustainability-related theme, Hannover (2000) Expo, has mostly permanent pavilions, which more than half fail to achieve their post-expo use plans. Taking into consideration, later World Expos mostly changed their attitudes and decided to build almost all pavilions as temporary, which is an appropriate strategy when it is considered that all temporary pavilions among selected cases achieve their planned post-expo uses.
2. The temporary pavilions are more consistent in terms of achieving planned post-expo plans. It is concluded that their post-expo options are more comprehensive compared to permanent pavilions, including recycling the materials, reusing the parts or some components, or reassembling them somewhere for refunctioning. Although the energy consumption is significantly increasing through these processes, these options are more reasonable than letting pavilions deteriorate on the sites.
3. When we analyze the selection of structural systems and building materials separately for the temporary and permanent pavilions, there is no clear distinction between the selection of structural system types. In contrast, building materials are significantly affected by the planned post-expo uses. Lightweight materials like timber, bamboo, and fabric are mainly used in temporary pavilions. In contrast, permanent pavilions are mainly made of steel, reinforced concrete, and structural glass since durability is crucial, while unit-weight or recyclability is not as much. On the other hand, among the cases analyzed within this study, it is observed that how the structural systems and materials are configured and how the overall system is designed are highly affected by the planned post-expo use of pavilions. While the focus is on combining

lightweight materials with reversible connections for temporary pavilions, the permanent pavilions mainly embrace the strategy of configuring durable materials with wide-span structures. Moreover, regarding the innovativeness of structural systems and building materials, it is concluded that although World Expo pavilions are known for their innovative and iconic developments in the structure and materials, this significantly has decreased, especially for the structural solutions.

4. The evaluation of specific features of the structural systems and materials in terms of four aspects of sustainability is made by categorizing pavilions under four categories based on their planned post-expo uses: refunctioned (permanent), relocated (temporary), recycled/reused (temporary) and disassembled (temporary). The results demonstrate that economic properties related to easing the post-use process by minimizing resource consumption (time, money, material, effort) are dominant in temporary pavilions with a considerably high percentage. For the permanent pavilions, functional properties related to the flexibility and adaptability of the pavilions are more dominant, which is reasonable since these features are crucial for refunctioning permanent cases. It is also interesting that environmental properties have a significantly low ratio among all use types, which is unexpected since the environmental features are the main subject of sustainability. Overall, the sustainable features of temporary pavilions are higher than permanent ones, which provides more sustainable post-expo uses.
5. The role of structural systems and materials of permanent pavilions in sustainable post-expo use of pavilions are limited mainly to the long-span capacity of structural systems in the analyzed cases, while most of the selected temporary cases have conventional demountable systems combined with eco-friendly materials to allow easy disassembly and recycling. Nevertheless, the cases with the highest number of sustainable properties like Japan (2000), Switzerland (2000), Japan (2005), and Norway (2010) pavilions demonstrate that the most efficient post-expo uses could be achieved with the use of innovative structural systems and material features which are explicitly configured with the consideration of post-expo process and sustainable design principles. However, when it is considered that only one-sixth of the selected pavilions are designed in this manner, we can conclude that there is still a

lacking of consideration in the design of World Expo pavilions for achieving high-level sustainability with innovative design solutions.

Moreover, some points take attention in the analysis, including:

- While temporary pavilions could be laboratories for innovative disassembly and recycling solutions, permanent pavilions can also provide opportunities for testing smart technologies throughout the long-life cycle of the pavilions. Therefore, permanent pavilions in World Expos should be equipped with more smart technologies to provide energy efficiency and environmental benefits, which is not well-applied in the selected cases.

- Some permanent pavilions, with rigid structures that restrict flexibility and future adaptability, were either abandoned or demolished after the Expos. Some of these cases are also equipped with varied sustainable features and technologies. However, the lacking functional and/or physical adaptability of these pavilions causes wasting the investment of such technologies since their post-expo sustainability could not be achieved. Therefore, it is concluded that the structural system and materials should be configured by considering reuse even for the permanent pavilions to allow them to exist permanently while enabling the disassembly of the structure if needed.

- There is a common issue observed among both permanent and temporary pavilions that damages their sustainable attitude, which is creating double-layered structures: an exterior cage and smaller pavilion(s) inside, like in the cases of Poland (2000), Japan (2005), Turkey (2005), South Korea (2005), and Spain (2005) pavilions. This strategy is mainly utilized to create a more basic exterior structure while impressing the visitors with interior pavilions with significant characteristics. However, this attitude cannot be considered sustainable since it wastes time, resources, and energy without a rational reason.

- Although the sustainable post-expo solutions are expected to be more advanced and efficient over the years from 2000 to 2015 with the technological development, the results obtained through the cases do not correspond with this assumption. Among the four pavilions with the highest number of sustainable properties and efficient post-expo use, two are from the Hannover World Expo 2000, one is from the Aichi World Expo 2005, and one is from Shanghai World Expo 2010. However, the only two

pavilions with no sustainable use are also at Hannover Expo, which creates a contradictory situation.

- Regarding the previous conclusion, Hannover World Expo 2000 have distinguished characteristic that contains half of the most successful pavilions in terms of sustainable post-expo use (Japan and Switzerland pavilions), while all the pavilions that fail to achieve their planned post-expo use (Hungary, Netherlands, and Poland) also belong to this Expo. This demonstrates that although there is an awareness in terms of efficient post-expo use and level of technologic and technic development for sustainable solutions in 2000, Hannover World Expo did not constitute the design guidelines in a well-established manner and could not compel the designers to follow the already-established guidelines.

To sum up, it is concluded that the well-conceived configuration of structural systems and building materials should be a requirement for all permanent and temporary pavilions to enable efficient resource management in all stages while reducing environmental damage by optimizing construction, disassembly, reuse, and recycling. The results justify the hypothesis mentioned in Section 1.2 and demonstrate that the configuration of the structural systems and materials is highly affected by the planned post-expo use of pavilions, respectively have a significant role in the post-expo usability. This study provides a general guideline for the design of pavilions and demonstrates the importance of integrating all sustainability categories in the design and promoting unique and innovative solutions. Although each World Expo provides guidelines for a sustainable post-expo use process, designing pavilions with conventional solutions for disassembly or refunctioning is not a sufficient solution for pavilions. Besides, the overall analysis reveals that most of the selected cases have sustainable properties from two or three categories that change based on the planned post-expo use. However, the pavilions with utmost post-expo use efficiency have sustainable properties from all categories. This demonstrates the importance of containing properties from all categories (functional, environmental, socio-cultural, and economic) that promote each other and increase the post-expo sustainability of the pavilions by optimizing every step in the post-expo period. Since the World Expos aim to promote novel ideas and innovations for a more sustainable environment, it is essential to present pioneer and more innovative design solutions and create

experimental models for real-life issues by incorporating all aspects of sustainability. As in the examples throughout history, the advanced structural typologies and iconic designs have been achieved in World Expos, which could be reflected in the sustainable solutions for a better environment.

There were some limitations while conducting the analysis of pavilions. First, since the pavilions are analyzed based on the images, drawings, diagrams, and information gathered through online resources and literature rather than physical observation of structures, there were some missing pieces of information. Although basic information could be achieved almost for all pavilions, some details about the structural systems, primary and secondary building materials, interior layout, and images of the post-expo situation of some pavilions could not be achieved. Therefore, there might be some misinterpretations and/or missing information in the analysis of the structural system and material properties, and consequently in their sustainable properties. Besides, since only a small percentage of pavilions are analyzed from each World Expo, the number of pavilions could be increased in further studies to achieve more comprehensive results in terms of the attitudes of World Expos for sustainable post-expo process and the progress in the innovative solutions. Also, the Dubai World Expo 2020 could be added to the scope since it has a 'sustainability district' that focuses directly on this issue with approximately 35 pavilions. Besides the World Expos, the methodology could be applied to other types of international fairs (Specialized Expos, and Horticultural Expos).

REFERENCES

"Nature's Wisdom Award" Expo 2005 Aichi, Turkey Pavillion. Hassa Architecture. (2005). Retrieved November 14, 2021, from https://www.hassa.com/en/bilgi/natures-wisdom-award-expo-2005-aichi-japan-turkey-pavillion.

Agenda 21: Sustainable Development Knowledge Platform - UN. United Nations. (n.d.). Retrieved January 23, 2022, from https://sustainabledevelopment.un.org/index.php?page=view&nr=23&type=400&menu=35.

Aguilar, C. (2015, May 5). *China Pavilion - Milan Expo 2015*. ArchDaily. Retrieved April 17, 2022, from https://www.archdaily.com/627497/china-pavilion-milan-expo-2015-tsinghua-university-studio-link-arc

Aichi 2005: The first Eco-Expo. (n.d.). UN Sustainable Development Goals. Retrieved May 8, 2022, from https://sustainabledevelopment.un.org/index.php?page=view&type=99&nr=157&menu=1449

All World Expos. (n.d.). Official Site of the Bureau International des Expositions. Retrieved April 29, 2022, from https://www.bie-paris.org/site/en/all-world-expos

Altieri, M. A. (1995). Agroecology: the science of sustainable agricultura. *Boulder: Westview Press Inc. 433p*.

Alvim, D. (2018). As the World Leaks into the Work: Composition and architecture. Organised Sound, 23(1), 51-60.

Al-Zaidi, B. M., & Markaryan, A. S. (2020). Eating air pollution using building's façade technology. *Periodicals of Engineering and Natural Sciences*, *8*(4), 2218-2231.

Ambrose, J., & Tripeny, P. (2011). *Building Structures*. John Wiley & Sons.

APCOR. (n.d.). *The Portugal Pavillion in expo shanghai 2010 is made of Cork*. Realcork RSS. Retrieved April 7, 2022, from https://www.apcor.pt/en/media-center/news-post/771/

Architizer Journal. (2021, May 31). *Italy Pavilion Milan Expo 2015*. Architizer . Retrieved April 9, 2022, from https://architizer.com/blog/projects/italy-pavilion-milan-expo-2015/

Architonic. (2015, July 1). UK Pavilion by Wolfgang Buttress: Temporary Structures. Architonic. Retrieved April 10, 2022, from https://www.architonic.com/en/project/wolfgang-buttress-uk-pavilion/5102388

Barbier, E. B. (1987). The concept of sustainable economic development. *Environmental conservation*, *14*(2), 101-110.

Barbier, E. B., & Burgess, J. C. (2017). The Sustainable Development Goals and the systems approach to sustainability. *Economics*, *11*(1).

Barney, G. O. (1980). *The Global 2000 Report to the President--entering the Twenty-first Century: The technical report* (Vol. 2). US Government Printing Office.

Basiago, A. D. (1995). Methods of defining 'sustainability'. *Sustainable development*, *3*(3), 109-119.

Basiago, A. D. (1998). Economic, social, and environmental sustainability in development theory and urban planning practice. Environmentalist, 19(2), 145-161.

BauNetz. (1998, September 29). Japanese Expo pavilion made of waste paper presented in Hanover. BauNetz. Retrieved December 10, 2021, from https://www.baunetz.de/meldungen/Meldungen-Japanischer_Expo-Pavillon_aus_Altpapier_in_Hannover_vorgestellt_4157.html.

Bay, J. H. (2010). Towards a fourth ecology: Social and environmental sustainability with architecture and urban design. *Journal of Green Building*, *5*(4), 176-197.

Bennetts, H., Radford, A., & Williamson, T. (2003). *Understanding sustainable architecture*. Taylor & Francis.

Berardi, U. (2012). Sustainability assessment in the construction sector: rating systems and rated buildings. Sustainable development, 20(6), 411-424.

BIE. (2015). *Official participants at Expo Milan 2015 receive awards*. Official Site of the Bureau International des Expositions. Retrieved February 28, 2022, from https://www.bie-paris.org/site/en/news-announcements/expo-milan-2015/official-participants-at-expo-milan-2015-receive-awards

BIE. (2020). *5 things you might not know about expo 2000 Hannover*. BIE. Retrieved February 26, 2022, from https://www.bie-paris.org/site/en/component/easyblog/entry/5-things-you-might-not-know-about-expo-2000-hannover?Itemid=1009

Blume, H. (2000). Re-use of the east site - Northern part. EXPOSEEUM - Das Expo-Museum an der Expo-Plaza. Retrieved December 9, 2021, from https://www.expo2000.de/index.php/expo-2000/gelaendenachnutzung/gelaende-ost-noerdl.html.

Bonenberg, A. (2018). Architectural Landscape in Mass Media Coverage. In *Cityscape in the Era of Information and Communication Technologies* (pp. 75-101). Springer, Cham.

Bonet, L. (2006). *Exhibition design*. Rockport Pub.

Bovill, C. (2014). Sustainability in architecture and urban design. Routledge.

Brandon, P. S., & Lombardi, P. (2010). *Evaluating Sustainable Development in the Built Environment*. John Wiley & Sons.

BRE Global Ltd. (2016). *BREEAM International New Construction 2016*. BREEAM. Retrieved March 6, 2022, from https://www.breeam.com/BREEAMInt2016SchemeDocument/#resources/output/10_pdf/a4_pdf/nc_pdf_printing/sd233_nc_int_2016_print.pdf

Brown, B. J., Hanson, M. E., Liverman, D. M., & Merideth, R. W. (1987). Global sustainability: Toward definition. Environmental management, 11(6), 713-719.

Brown, L. R. (1986). State of the World 1986. A Worldwatch Institute Report on Progress toward a Sustainable Society.

Brundtland, G. H., & Khalid, M. (1987). Our common future. Oxford University Press, Oxford, GB.

Bulut, D. M., & Gürani, F. Y. (2018). A STUDY OF SHIGERU BAN'S ENVIRONMENTALLY SENSITIVE ARCHITECTURAL DESIGN APPROACH. Gazi University Journal of Science Part B: Art Humanities Design and Planning, 6(3), 147-157.

Cabeza, L. F., Barreneche, C., Miró, L., Morera, J. M., Bartolí, E., & Fernández, A. I. (2013). Low carbon and low embodied energy materials in buildings: A review. *Renewable and Sustainable Energy Reviews*, *23*, 536-542.

Capitanucci, M. V. (2015). Milan architecture. *The city and Expo. Skira, Milan*.

Caradonna, J. L. (2014). Sustainability: A history. Oxford University Press.

Carta, S. (2013). The image of the Shanghai 2010 Expo the contribution of single pavilions to Shanghai's global image. *Frontiers of Architectural Research*, *2*(4), 387-399.

Charles, A. T. (2008). *Sustainable fishery systems*. John Wiley & Sons.

Chen, N. (2012). Branding national images: The 2008 Beijing summer olympics, 2010 Shanghai World Expo, and 2010 Guangzhou asian games. *Public Relations Review*, *38*(5), 731-745.

Chen, Y., Tu, Q., & Su, N. (2014). Shanghai's Huangpu Riverbank Redevelopment Beyond World Expo 2010. In *Proceedings AESOP 2014: Annual Conference" From control to co-evolution", Utrecht/Delft, The Netherlands, 9-12 July 2014; Authors version*. AESOP.

Chilean Pavilion - Expo Milano 2015. (n.d.). Divisare. Retrieved April 13, 2022, from https://divisare.com/projects/294833-undurraga-deves-arquitectos-fi

Chilton, J., & Tang, G. (2016). Timber Gridshells: Architecture, Structure and Craft. Routledge.

China Pavilion Expo Milano 2015. (2021, September 13). SGH. Retrieved April 17, 2022, from https://www.sgh.com/project/china-pavilion-expo-milano-2015/

Çimen, B., Çınarlı, N., & Topal, H. (2000). Expo National Pavilions *[Expo Ülke Pavyonları]*. Ege Mimarlık Dergisi, 35(3). Retrieved December 10, 2021, from https://egemimarlik.org/cevirim-ici-okuma/35/614.

Collina, L. M. V. (2015). Building the Expo.

Comsa, D. (2015). The relevance of world expos proposed topics in relation to architectural or urban achievements. In *Proceedings Book ICAR2015 International Conference, Bucharest: EUIM*.

Comşa, D., & Mihăilă, M. (2016). Food vs. Architecture. From The Architectural Form Expressivity to the Spatial Interpretation of a Concept: 2015 Milan Universal Exposition. EURAU 2016 European Symposium on Research in Architecture and Urban Design: In Between Scales. EURAU 2016 – PROCEEDINGS, ISBN 978-606-638-141-3

Cordero, E. (2001). *Sustainability in architecture* (Doctoral dissertation, Massachusetts Institute of Technology).

Correa, C. (2004). Designing with paper tubes. Structural engineering international, 14(4), 277-281.

Cull, N. J. (2015). Digesting the Milan Expo, 2015. https://link.springer.com/article/10.1057/pb.2015.10

Czarnecki, L., & Gemert, D. (2017). Innovation in construction materials engineering versus sustainable development. *Bulletin of the Polish Academy of Sciences. Technical Sciences*, *65*(6).

De Groote, P. (2005). A multidisciplinary analysis of world fairs (= expos) and their effects. *Tourism Review*.

de Santoli, L., Mancini, F., & Rossetti, S. (2014). The energy sustainability of Palazzo Italia at EXPO 2015: analysis of an nZEB building. *Energy and Buildings*, *82*, 534-539.

Deng, Y. (2013). Conceptualizing mega-event flagships—A case study of China Pavilion of Expo 2010 Shanghai China. *Frontiers of Architectural Research*, *2*(1), 107-115.

Deng, Y., & Poon, S. W. (2011). Mega-challenges for mega-event flagships. *Architectural Engineering and Design Management*, *7*(1), 23-37.

Dhir, R. K., de Brito, J., Silva, R. V., & Lye, C. Q. (2019). *Sustainable construction materials: recycled aggregates*. Woodhead Publishing.

Ding, G. K. (2008). Sustainable construction—The role of environmental assessment tools. *Journal of environmental management*, *86*(3), 451-464.

Diwekar, U. M., & Cabezas, H. (2012). Sustainability : Multi-disciplinary Perspectives. Bentham Science Publishers.

Drury, J. (2010, July 29). Shanghai Expo 2010: The Chinese Pavilion. China Briefing News. Retrieved April 3, 2022, from https://www.china-briefing.com/news/shanghai-expo-2010-the-chinese-pavilion/.

Du Pisani, J. A. (2006). Sustainable development–historical roots of the concept. Environmental sciences, 3(2), 83-96.

Engel, H. (2013). *Tragsysteme - Structure Systems* (5th ed.). Hatje Cantz.

Expo 2000. MVRDV. n.d. Retrieved Apr. 5, 2021, from https://www.mvrdv.nl/projects/158/expo-2000.

Expo 2000: Hungarian pavilion. Projects. (n.d.). Retrieved May 9, 2021, from https://www.tensinet.com/index.php/projects-database/projects?view=project&id=4004.

EXPO 2015 S.p.A. (2018, February 20). *Expo Milano 2015 - Official Report*. EXPO 2015. Retrieved April 9, 2022, from http://www.expo2015.org/wp-content/uploads/2019/10/OFFICIAL%20REPORT%20EXPO%20MILANO%202015-PDF-ENG.pdf

Expo 2020 Dubai. (n.d.). *After Expo 2020*. EXPO 2020 Dubai UAE. Retrieved March 2, 2022, from https://www.expo2020dubai.com/en/understanding-expo/after-expo2020

Expo Pavilion 2.0. MVRDV. n.d. Retrieved Apr. 5, 2021, from https://www.mvrdv.com/projects/432/expo-pavilion-20.

Finland Pavilion Shanghai Expo 2010. JKMM. (2022, January 4). Retrieved April 5, 2022, from https://jkmm.fi/work/finland-pavilion-shanghai-expo-2010/

Follow-up uses assured for many exhibition facilities. (2000, October 29). EXPO 2000 Hannover GmbH Press Office, Germany. Retrieved November 26, 2020, from http://site.expo2000.de/expo2000/presse_bilanz/english/PM_Nachnutzung_Engl

Foy, G. (1990). Economic sustainability and the preservation of environmental assets. *Environmental Management*, *14*(6), 771-778.

Francescato, G. (1991). Housing quality: technical and non-technical aspects. In *EUROPEAN SYMPOSIUM ON MANAGEMENT, QUALITY AND ECONOMICS IN HOUSING AND OTHER BUILDING SECTORS* (p. 548).

Frearson, A. (2015a). *Anne Holtrop creates peaceful oasis in Bahrain's Expo Pavilion*. Dezeen. Retrieved April 11, 2022, from https://www.dezeen.com/2015/05/12/bahrain-pavilion-milan-expo-2015-anne-holtrop-interview/

Frearson, A. (2015b). *China Milan Expo 2015 pavilion has over 1,000 bamboo panels*. Dezeen. Retrieved April 17, 2022, from https://www.dezeen.com/2015/05/05/beijing-

skyline-mountain-range-roof-china-milan-expo-2015-pavilion-studio-link-arc-tsinghua-university-bamboo/

Frearson, A. (2015c). *XTU architects creates wooden lattice for French Expo Pavilion*. Dezeen. Retrieved April 16, 2022, from https://www.dezeen.com/2015/05/06/france-pavilion-xtu-architects-milan-expo-2015/

French Pavilion Expo Milano 2015: XTU Architects. (n.d.). Archello. Retrieved April 16, 2022, from https://archello.com/project/french-pavilion-expo-milano-2015#stories

Fricker, A. (1998). Measuring up to sustainability. *Futures*, *30*(4), 367-375.

Geissdoerfer, M., Vladimirova, D., & Evans, S. (2018). Sustainable business model innovation: A review. *Journal of cleaner production*, *198*, 401-416.

German pavilions over the years. CAMPUS GERMANY - German Pavilion Expo 2020 Dubai. (2020, April 17). Retrieved December 10, 2021, from https://www.expo2020germany.de/en/the-german-pavilion/german-pavilions-over-the-years/.

Gibson, R. B. (2010). Beyond the pillars: sustainability assessment as a framework for effective integration of social, economic and ecological considerations in significant decision-making. In *Tools, Techniques and Approaches for Sustainability: collected writings in environmental assessment policy and management* (pp. 389-410).

Giddings, B., Hopwood, B., & O'brien, G. (2002). Environment, economy and society: fitting them together into sustainable development. *Sustainable development*, *10*(4), 187-196.

Gidlund, A. (2020). The Diagrid: Adaptable housing with timber construction.

Golański, M., & Góra, Z. (2018). Digital tectonics and dynamics in designing of wooden architecture envelopes. In *11th Conference on Advanced Building Skins, Berna, Suíça*.

Goldsmith, E. (1972). Blueprint for survival (Vol. 7830). Houghton Mifflin.

Harris, R., Romer, J., Kelly, O., & Johnson, S. (2003). Design and construction of the Downland Gridshell. Building Research & Information, 31(6), 427-454.

Heatherwick Studio: UK Pavilion. (n.d.). Heatherwick Studio | Design & Architecture. Retrieved August 3, 2021, from http://www.heatherwick.com/projects/buildings/uk-pavilion/.

Hegger, M., Fuchs, M., Stark, T., & Zeumer, M. (2012). *Energy manual: sustainable architecture*. Walter de Gruyter.

Higgins, P. (2010, March 26). *Shanghai Expo 2010: The U.K. Pavilion*. China Briefing News. Retrieved April 3, 2022, from https://www.china-briefing.com/news/shanghai-expo-2010-the-uk-pavilion/

Hikosaka, Y. (2005). Eco-friendly technologies in the Japanese Pavilion at EXPO 2005 in Aichi, Japan. *Internationales Holzbau-Forum 2005*.

Hill, R. C., & Bowen, P. A. (1997). Sustainable construction: principles and a framework for attainment. *Construction Management & Economics*, *15*(3), 223-239.

Hiller, H. H. (1998). Assessing the impact of mega-events: A linkage model. *Current issues in tourism*, *1*(1), 47-57.

Hiller, H. H. (2000a). Mega-events, urban boosterism and growth strategies: an analysis of the objectives and legitimations of the Cape Town 2004 Olympic Bid. *International journal of urban and regional research*, *24*(2), 449-458.

Hiller, H. H. (2000b). Toward an Urban Sociology of Mega-Events. Constructions of Urban Space. Ed. Ray Hutchison.

Historic precedent Dutch Pavilion Hanover 2000. (n.d.). Retrieved April 25, 2021, from https://celloexpressions.com/wp-content/uploads/2013/11/Historic-Precedent-Dutch-Pavilion-Hanover-2000.pdf

Hounsgaard, L. (2010, January 11). *Shanghai Expo 2010: The Norwegian Pavilion*. China Briefing News. Retrieved April 3, 2022, from https://www.china-briefing.com/news/shanghai-expo-2010-the-norwegian-pavilion/

Hounter Douglas. (n.d.). *China Pavilion at Shanghai Expo.* Hounter Douglas Architectural. Retrieved April 4, 2022, from https://www.hunterdouglasarchitectural.eu/de-CH/projects/project.jsp?pId=8a43834927a88aca0128888cdffc0283

Hu, L. (2002). Expo 2000. The Fifth Column, 10-4, p. 58–63. Retrieved December 14, 2021, from https://fifthcolumn.library.mcgill.ca/issue/view/36.

Hurol, Y. (2016). *The tectonics of structural systems: an architectural approach*. Routledge.

Hwang, B. G., & Ng, W. J. (2013). Project management knowledge and skills for green construction: Overcoming challenges. *International journal of project management*, *31*(2), 272-284.

Inoue, M., Tanaka, K., Tagawa, Y., Nakahara, M., Goto, Y., Imabayashi, M., & Uchiyama, Y. (2008). Application of bamboo connector to timber structure—Introduction of construction and dismantlement of Japanese government pavilion Nagakute in Expo 2005 Aichi, Japan. In *Modern Bamboo Structures* (pp. 203-212). CRC Press.

Jacobson, C. (2010, January 21). *World Expo 2010 Shanghai: Republic of korea pavilion*. Architectural Record RSS. Retrieved April 7, 2022, from https://www.architecturalrecord.com/articles/6769-world-expo-2010-shanghai-republic-of-korea-pavilion

Japan Association for the 2005 World Exposition. (2005). *Results and evaluations of Expo 2005, Aichi, Japan - Appendix II*. The 2005 World Exposition, Aichi, Japan. Retrieved March 2, 2022, from http://www.expo2005.or.jp/en/results/pdf/r_e_2.pdf

Japan Pavilion Nagakute. EXPO 2005 AICHI, JAPAN. (2004). Retrieved November 23, 2021, from http://www.expo2005.or.jp/en/venue/jz_a.html.

Japan Pavillion Expo 2000 Hannover - Data, Photos & Plans. WikiArquitectura. (2020, September 10). Retrieved December 10, 2021, from https://en.wikiarquitectura.com/building/japan-pavillion-expo-2000-hannover/.

Jeska, S. (2014). Experimental and temporary structures. In Emergent Timber Technologies (pp. 76-94). Birkhäuser.

Juc, C. (2015). *Winners of expo milan 2015 announced*. Arch2O.com. Retrieved March 3, 2022, from https://www.arch2o.com/winners-of-expo-milan-2015-announced/

Kamara, J. M., Heidrich, O., Tafaro, V. E., Maltese, S., Dejaco, M. C., & Re Cecconi, F. (2020). Change factors and the adaptability of buildings. *Sustainability*, *12*(16), 6585.

Kanekar, A. (2014). Space of Sound and Music: Architecture as a Performative Instrument–Zumthor's Sound Box. In Architecture's Pretexts (pp. 100-124). Routledge.

Kefayati, Z., & Moztarzadeh, H. (2015). Developing effective social sustainability indicators in architecture. *Bulletin of Environment, Pharmacology and Life Sciences*, *4*(5), 40-56.

Khan, M. A. (1995). *Concepts, definitions and key issues in sustainable development: the outlook for the future*.

Kim, S., & Kwon, H. A. (2018). Urban sustainability through public architecture. *Sustainability*, *10*(4), 1249.

Korean Pavilion. (n.d.). World Expo 2010 Shanghai - Pavilions. Retrieved April 7, 2022, from http://www.expo2010china.hu/index.phtml?module=home&menu_id=koreanpavilion

Krupar, S. (2018). Sustainable World Expo? The governing function of spectacle in Shanghai and beyond. *Theory, Culture & Society*, 35(2), 91-113.

La Tegola, A., Longo, F., & Lanzilotti, A. (2019). The pavilions of Expo 2015 in Milan, as a privileged observatory about the concept of sustainable construction in all languages of the world. *Sustainable Buildings*, *4*, 1.

Lienhard, J., Abrahamsen, R., Schoene, S., Soto Rubio, M., & Knippers, J. (2010). The Norwegian Pavilion at the Expo Shanghai 2010.

Liu, Z. (2003). Sustainable tourism development: A critique. *Journal of sustainable tourism*, *11*(6), 459-475.

Loostrom, L., & Glaeser, J. (2018). *TIMBER TECTONICS CASE STUDY: A Comparison of Two Structures*. Timber Tectonics in the Digital Age. Retrieved April 13, 2022, from https://timbertech17.files.wordpress.com/2018/11/glaeserloostrom_expo_bldgs.pdf

López César, I. (2017). *World Expos: A history of structures*. Bureau International des Expositions.

López-César, I. (2019). World Expos and architectonic structures. An intimate relationship. *This article has been published online by Bureau International des Expositions (BIE), Paris.* Retrieved from: https://www.bie-paris.org/site/en/focus/entry/world-expos-and-architectonic-structures-an- intimate-relationship

Lutz, J. (2005). Thinking outside the (Music) box: collaborations between composers and architects. In Proceedings of the 93 rd ACSA Annual Meeting, The Art of Architecture/The Science of Architecture (pp. 69-74).

Macdonald, A. J. (1997). *Structural design for architecture*. Butterworth-Heinemann.

Macdonald, A. J. (2001). *Structure and architecture*. Routledge.

Macnaghten, P., & Jacobs, M. (1997). Public identification with sustainable development: investigating cultural barriers to participation. *Global Environmental Change*, *7*(1), 5-24.

Man, Nature, Technology. About JDP Econ. (n.d.). Retrieved February 15, 2022, from http://jdpecon.com/expo/wfhannover2000.html

Marsh, G. P. (1965). *Man and Nature.* Edited by David Lowenthal. Cambridge, Mass.

Martek, I., Hosseini, M. R., Shrestha, A., Zavadskas, E. K., & Seaton, S. (2018). The sustainability narrative in contemporary architecture: falling short of building a sustainable future. *Sustainability*, *10*(4), 981.

McDonough, W. (1992). The Hannover Principles. Design for Sustainability. Prepared for EXPO 2000, the World's Fair. Hannover Germany.

Meadows, D. H., Meadows, D. L., Randers, J., & Behrens, W. W. (1972). The limits to Growth. *102*, 27.

Mebratu, D. (1998). Sustainability and sustainable development: historical and conceptual review. *Environmental impact assessment review*, *18*(6), 493-520.

Memmott, P., & Keys, C. (2015). Redefining architecture to accommodate cultural difference: Designing for cultural sustainability. *Architectural Science Review*, *58*(4), 278-289.

Mensah, J. (2019). Sustainable development: Meaning, history, principles, pillars, and implications for human action: Literature review. *Cogent Social Sciences*, *5*(1), 1653531.

Mexico Pavilion at Expo 2005 Aichi. Second Wiki. (2019, September 1). Retrieved November 16, 2021, from https://second.wiki/wiki/pabellc3b3n_de_mc3a9xico_en_la_expo_2005_aichi.

Mexico Pavilion opens its doors in the Expo. EXPO 2005 AICHI, JAPAN. (2005). Retrieved November 16, 2021, from http://www.expo2005.or.jp/en/nations/release/pdf/050325_mexico.pdf.

Mexico Pavilion. EXPO 2005 AICHI, JAPAN. (2004). Retrieved November 16, 2021, from http://www.expo2005.or.jp/en/nations/2e.html.

Meyer Boake, T. (2013). Understanding Steel Design: A Handbook of Steel in Architecture. Berlin, Boston: Birkhäuser. https://doi.org/10.1515/9783034610483

Michael, A., & Phocas, M. C. (2012). Construction Design and Sustainability in Architecture: Integrating Environmental Education in the Architectural Studies. In *International Conference on Renewable Energies and Power Quality (ICREPQ'12) Santiago de Compostela (Spain), 28th to 30th March*.

Milbrath, L. W. (1989). *Envisioning a sustainable society: Learning our way out*. Suny Press.

Mill, J. S. (1871). *Principles of political economy: with some of their applications to social philosophy* (Vol. 1). Longmans, Green, Reader, and Dyer.

Ministry of Ecological Transition. (2015). *The Expo We Learned - EXPO Milano 2015*. Ministry of Ecological Transition. Retrieved March 13, 2022, from https://www.mite.gov.it/sites/default/files/archivio/allegati/impronta_ambientale/the_expo_we_learned_EN_web.pdf

Mitchell, G., May, A., & McDonald, A. (1995). PICABUE: a methodological framework for the development of indicators of sustainable development. *The international journal of sustainable development & World Ecology*, *2*(2), 104-123.

Mohamed, A. S. Y. (2017). Smart materials innovative technologies in architecture; towards innovative design paradigm. *Energy Procedia*, *115*, 139-154.

Müller, M. (2015). The mega-event syndrome: Why so much goes wrong in mega-event planning and what to do about it. *Journal of the American Planning Association*, *81*(1), 6-17.

Müller, M. (2016). What makes an event a mega-event? Definitions and sizes. *Leisure studies*, *34*(6), 627-642.

Nassauer, J. I. (1997). Cultural sustainability: aligning aesthetics and ecology. Island Press.

Norwegian pavilion in Expo Shanghai 2010. (n.d.). Archello. Retrieved April 8, 2022, from https://archello.com/project/norwegian-pavillion-in-expo-shanghai-2010

Økland, A., & Olsson, N. (2016). Flexibility as Enabler of Sustainability. *CFM Second Nordic Conference 2016.*

Pabellón Expo Milán 2015. (2019, December 15). Undurraga Deves Arquitectos. Retrieved April 13, 2022, from https://undurragadeves.cl/pabellon-expo-milan-2015-3/?lg=en

Palazzo Italia - Human Technopole Foundation. (n.d.). World Architecture. Retrieved April 10, 2022, from https://worldarchitecture.org/architecture-projects/hffzm/palazzo-italia--human-technopole-foundation-project-pages.html

Pavilion Design Prize disclosed in Shanghai World Expo. (2010). People's Daily Online. Retrieved March 3, 2022, from http://en.people.cn/90001/90776/90883/7185408.html

Pearson, C. A. (2010). *World Expo 2010 Shanghai: Finland pavilion*. Architectural Record RSS. Retrieved April 7, 2022, from https://www.architecturalrecord.com/articles/6770-world-expo-2010-shanghai-finland-pavilion

Performance of Mexico at the 2005 Aichi. EXPO 2005 AICHI, JAPAN. (2005). Retrieved November 16, 2021, from http://www.expo2005.or.jp/en/nations/release/pdf/050224_mexico.pdf.

Philippines Pavilion. EXPO 2005 AICHI, JAPAN. (2004). Retrieved November 14, 2021, from http://www.expo2005.or.jp/en/nations/6h.html.

Pietrogrande, E. (2016). Natural materials and basic construction techniques. Aspects of neo-brutalism in current architectural experience.

Pletcher, K. (2010, April 22). *Expo Shanghai 2010*. Encyclopædia Britannica. Retrieved May 10, 2022, from https://www.britannica.com/event/Expo-Shanghai-2010

Portugal Pavilion at the Expo Shanghai. Corticeira Amorim. n.d. Retrieved June 9, 2021, from https://www.amorim.com/en/media/news/portugal-pavilion-at-the-expo-shanghai-wins-design-award/963/.

Poveda, C. A. (2017). *Sustainability assessment: A rating system framework for best practices*. Emerald Group Publishing.

Poveda, C. A., & Lipsett, M. G. (2014). An integrated approach for sustainability assessment: the Wa-Pa-Su project sustainability rating system. *International Journal of Sustainable Development & World Ecology*, *21*(1), 85-98.

Purvis, B., Mao, Y., & Robinson, D. (2019). Three pillars of sustainability: in search of conceptual origins. *Sustainability science*, *14*(3), 681-695.

Reganold, J. P., Papendick, R. I., & Parr, J. F. (1990). Sustainable agriculture. *Scientific American*, *262*(6), 112-121.

Republic of Korea Pavilion. EXPO 2005 AICHI, JAPAN. (2004). Retrieved November 14, 2021, from http://www.expo2005.or.jp/en/nations/1j.html.

Rizzi, E. L. M. (2010). *Future scenarios for the Hannover Expo area* (Dissertation Thesis).

Roche, M. (1992). Mega-events and micro-modernization: on the sociology of the new urban tourism. *British Journal of Sociology*, 563-600.

Roche, M. (1994). Mega-events and urban policy. *Annals of Tourism research*, *21*(1), 1-19.

Roche, M. (2000). *Megaevents and modernity: Olympics and expos in the growth of global culture*. Routledge.

Roderick, Y., McEwan, D., Wheatley, C., & Alonso, C. (2009, July). Comparison of energy performance assessment between LEED, BREEAM and Green Star. In *Eleventh international IBPSA conference* (pp. 27-30).

Rosen, M. A. (2012). Engineering sustainability: A technical approach to sustainability. *Sustainability*, *4*(9), 2270-2292.

Rotmans, J. (2006). Tools for integrated sustainability assessment: a two-track approach. *Integrated Assessment*, *6*(4).

Rovers, R., & Klinckenberg, F. (2008). *Sustainable housing projects: implementing a conceptual approach*. Techne press.

RP Bags Top Prize in Japan Expo. Philstar. (2005, May 28). Retrieved November 14, 2021, from https://www.philstar.com/headlines/2005/05/28/279396/rp-bags-top-prize-japan-expo.

Sahu, A. (2021, September 19). *Unit weight of construction materials*. Civil Gyan. Retrieved March 28, 2022, from https://www.civilgyan.com/unit-weight-of-construction-materials-cement-steel-concrete-sand/

Sandaker, B. N., Eggen, A. P., & Cruvellier, M. R. (2011). *The structural basis of architecture* (Second Edition). Routledge.

Sassi, P. (2006). *Strategies for sustainable architecture*. Taylor & Francis.

Schrenk, L., & Jensen, M. (2014). Dystopia in the world of utopia: Unsustainable realities of sustainably themed expositions. In *ARCC Conference Repository*.

Scognamiglio, A., & Privato, C. (2008, September). Starting points for a new cultural vision of BIPV. In *Proceedings of the 23rd European Photovoltaic Solar Energy Conference* (pp. 3222-3233).

Shanghai Expo 2010 Finland Pavilion "Kirnu" JKMM Architects. World-Architects. (n.d.). Retrieved April 5, 2022, from https://www.world-architects.com/en/jkmm-architects-helsinki/project/shanghai-expo-2010-finland-pavilion-kirnu

Shanghai Portuguese Pavilion Expo. (n.d.). Corticeira Amorim, world's biggest cork processing group. Retrieved April 7, 2022, from https://www.amorim.com/en/projects/portuguese-pavilion-expo/440/

Shen, S. (2012). The environmental impact of expositions: a study of some contributing factors.

Shigeru Ban Architects. (n.d.). JAPAN PAVILLION, EXPO 2000 HANNOVER - Germany, 2000. Shigeru Ban Architects. Retrieved December 10, 2021, from http://www.shigerubanarchitects.com/works/2000_japan-pavilion-hannover-expo/index.html.

Silver, P., Evans, P., & McLean, W. (2014). *Structural engineering for architects: a handbook*. Laurence King Publishing.

Sirica, A. (2006). Spanis Pavilion Expo 2005 - Haiki. Foreign Office Architects. *Projects*, 98–109.

Smits, K., & Jansen, A. (2012). Staging the nation at expos and world's fairs. *National Identities*, *14*(2), 173-188.

Soini, K., & Birkeland, I. (2014). Exploring the scientific discourse on cultural sustainability. *Geoforum*, *51*, 213-223.

Spanish Pavilion at the 2005 World Expo, Aichi, Japan. (n.d.). FARSHID MOUSSAVI ARCHITECTURE. Retrieved November 16, 2021, from https://www.farshidmoussavi.com/node/27.

Spanish Pavilion Expo 2005. Arquitecturas Cerámicas. (2020, May 1). Retrieved November 16, 2021, from https://www.ceramicarchitectures.com/obras/spanish-pavilion-expo-2005/.

Spanish Pavilion, Aichi - FOA: Foreign Office Architects. (2020). Arquitectura Viva. Retrieved November 16, 2021, from https://arquitecturaviva.com/works/pabellon-de-espana-aichi-.

Stacey, M. (2016). Bees Are Sentinels of the Earth: The Hive–A Responsive Ecology. *WHITE PAPERS*, 300.

Sterling, S. (2001). *Sustainable Education: Re-Visioning Learning and Change. Schumacher Briefings*. Schumacher UK, CREATE Environment Centre, Seaton Road, Bristol, BS1 6XN, England (6 pounds).

Studio Anne Holtrop. (2015, May 17). *Bahrain Pavilion – Milan Expo 2015*. ArchDaily. Retrieved April 11, 2022, from https://www.archdaily.com/631908/bahrain-pavilion-expo-milano-2015-studio-anne-holtrop

Sverdrup, H., & Stjernquist, I. (Eds.). (2013). Developing principles and models for sustainable forestry in Sweden (Vol. 5). Springer Science & Business Media.

Swarup, L., Korkmaz, S., & Riley, D. (2011). Project delivery metrics for sustainable, high-performance buildings. *Journal of Construction Engineering and Management*, *137*(12), 1043-1051.

Światek, W. (2012). THREE POLISH PAVILIONS FOR WORLD EXPO- THREE LEVELS OF QUALITY. Technical Transactions, (26), 331–348.

Swiss Sound Pavilion - Data, Photos & Plans. WikiArquitectura. (2020, September 11). Retrieved December 9, 2021, from https://en.wikiarquitectura.com/building/swiss-sound-pavilion/.

Tam, V. W. (2011). Rate of reusable and recyclable waste in construction. *The open waste management journal*, *4*(1).

Tapia, D. (2018, April 10). *Chile Pavilion at Expo Milan 2015 / Undurraga Devés Arquitectos*. ArchDaily. Retrieved April 13, 2022, from https://www.archdaily.com/892070/chile-pavilion-at-expo-milan-2015-undurraga-deves-arquitectos

Technolog, J. M. L. C. (Ed.). (2014). *The Research Report on Application of Low-carbon Technology in Expo 2010 Shanghai*. Springer.

The Building [DAS GEBÄUDE]. Der Deutsche Pavillon - EXPO 2000. (n.d.). Retrieved December 10, 2021, from http://dp.expo2000.de/cont4.html.

The EXPO 2000 - Reuse. EXPOSEEUM - Das Expo-Museum an der Expo-Plaza. (n.d.). Retrieved May 7, 2021, from https://www.expo2000.de/index.php/expo-2000/gelaendenachnutzung.html.

The Japan Pavilions -The Host Country Welcomes Visitors with its National Pavilions. Ministry of Economy, Trade, and Industry, Japan Association for the 2005 World Exposition. (n.d.). Retrieved November 23, 2021, from https://www.jef.or.jp/journal/pdf/Expo%202_0503.pdf.

The Limits to Growth. (2021, August 11). The Club of Rome. Retrieved January 19, 2022, from https://www.clubofrome.org/publication/the-limits-to-growth/

The Spanish pavilion at Expo Aichi 2005 puts the hexagon ceramics and other materials up for sale. (2005). Retrieved November 16, 2021.

Tsunoda, M. C., Harada, S., Toriumi, M., & Yanagisawa, T. (2007, November). Design for re-use: case study of World Exposition 2005, Aichi, Japan. In *Proceedings of Building Stock Activation, International Conference of 21st Century COE* (pp. 5-8).

Turcu, C. (2013). Re-thinking sustainability indicators: local perspectives of urban sustainability. *Journal of Environmental Planning and Management*, *56*(5), 695-719.

Turkey Pavilion. EXPO 2005 AICHI, JAPAN. (2004). Retrieved November 14, 2021, from http://www.expo2005.or.jp/en/nations/3m.html.

United Nations Conference on Environment and Development (UNCED) - Earth Summit. United Nations. (n.d.). Retrieved February 12, 2022, from https://sustainabledevelopment.un.org/milestones/unced

United Nations Conference on Sustainable Development, Rio+20. United Nations. (n.d.). Retrieved February 12, 2022, from https://sustainabledevelopment.un.org/rio20

United Nations Conference on the Human Environment - Stockholm Conference. United Nations. (n.d.). Retrieved February 12, 2022, from https://sustainabledevelopment.un.org/milestones/humanenvironment

United Nations Department of Economic and Social Affairs (ed.). 2016. Transforming our world: The 2030 agenda for sustainable development.

Upham, P. (2000). An assessment of The Natural Step theory of sustainability. *Journal of Cleaner Production*, *8*(6), 445-454.

USGBC. (n.d.). *LEED Credit Library*. U.S. Green Building Council. Retrieved March 6, 2022, from https://www.usgbc.org/credits

Valentin, A., & Spangenberg, J. H. (2000). A guide to community sustainability indicators. *Environmental impact assessment review*, *20*(3), 381-392.

Vatansever, N. (2009). *Sergi binalarında, geniş açıklık geçen çelik taşıyıcı sistemlerin incelenmesi [The analysis of steel structures that pass wide span in exposition buildings]* (Doctoral dissertation, DEÜ Graduate School of Natural and Applied Sciences).

Vogt, W. (1948). Road to Survival. William Sloane Associates. *Inc., New York*, *335*.

Warmann, C. 2010a. *Installation for the UK Pavilion at Shanghai Expo 2010 by Troika*. Dezeen. Retrieved September 22, 2021, from https://www.dezeen.com/2010/05/20/installation-for-the-uk-pavilion-at-shanghai-expo-2010-by-troika/.

Warmann, C. 2010b. *UK Pavilion at Shanghai Expo 2010 by Thomas Heatherwick*. Dezeen. Retrieved September 22, 2021, from https://www.dezeen.com/2010/03/31/uk-pavilion-at-shanghai-expo-2010-by-thomas-heatherwick-2/.

Werner, F., Althaus, H. J., & Richter, K. (2002). Post-consumer wood in environmental decision-support tools. Schweizerische Zeitschrift für Forstwesen, (153 (3)), 97-106.

Wilson, M. I. (2011). Event engineering: Urban planning for Olympics and World's Fairs. In *Engineering Earth* (pp. 1045-1055). Springer, Dordrecht.

Winston, A. (2016, June 14). *What happened to the temporary pavilions from 2015?* Dezeen. Retrieved April 10, 2022, from https://www.dezeen.com/2016/06/14/2015-temporary-pavilions-fate-burnt-recycled-storage-sold-serpentine-gallery-milan-expo-moma-ps1/

World Summit on Sustainable Development (WSSD), Johannesburg Summit. United Nations. (n.d.). Retrieved January 22, 2022, from https://sustainabledevelopment.un.org/milesstones/wssd

Wu, M., Meng, L., & Mu, T. (2010, January). Temporary Structures in Shangai EXPO2010-Structural Design Specification and Example. In *Symposium of the International Association for Shell and Spatial Structures (50th. 2009. Valencia). Evolution and Trends in Design, Analysis and Construction of Shell and Spatial Structures: Proceedings*. Editorial Universitat Politècnica de València.

Wu, X., Sun, F., Lu, X., & Qian, J. (2014). Nonlinear time history analysis of China Pavilion for Expo 2010 Shanghai China. *The Structural Design of Tall and Special Buildings*, *23*(10), 721-739.

Yang, J., Chen, Y., Jiang, H., & Lu, X. (2012). Shaking table tests on China pavilion for Expo 2010 Shanghai China. *The Structural Design of Tall and Special Buildings*, *21*(4), 265-282.

Yunlong, C., & Smit, B. (1994). Sustainability in agriculture: a general review. *Agriculture, ecosystems & environment*, *49*(3), 299-307.

Zabihi, H., & Habib, F. (2012). Sustainability in building and construction: revising definitions and concepts. *International Journal of Emerging Sciences*, *2*(4), 570.

Zavadskas, E. K., Šaparauskas, J., & Antucheviciene, J. (2018). Sustainability in construction engineering. *Sustainability*, *10*(7), 2236.

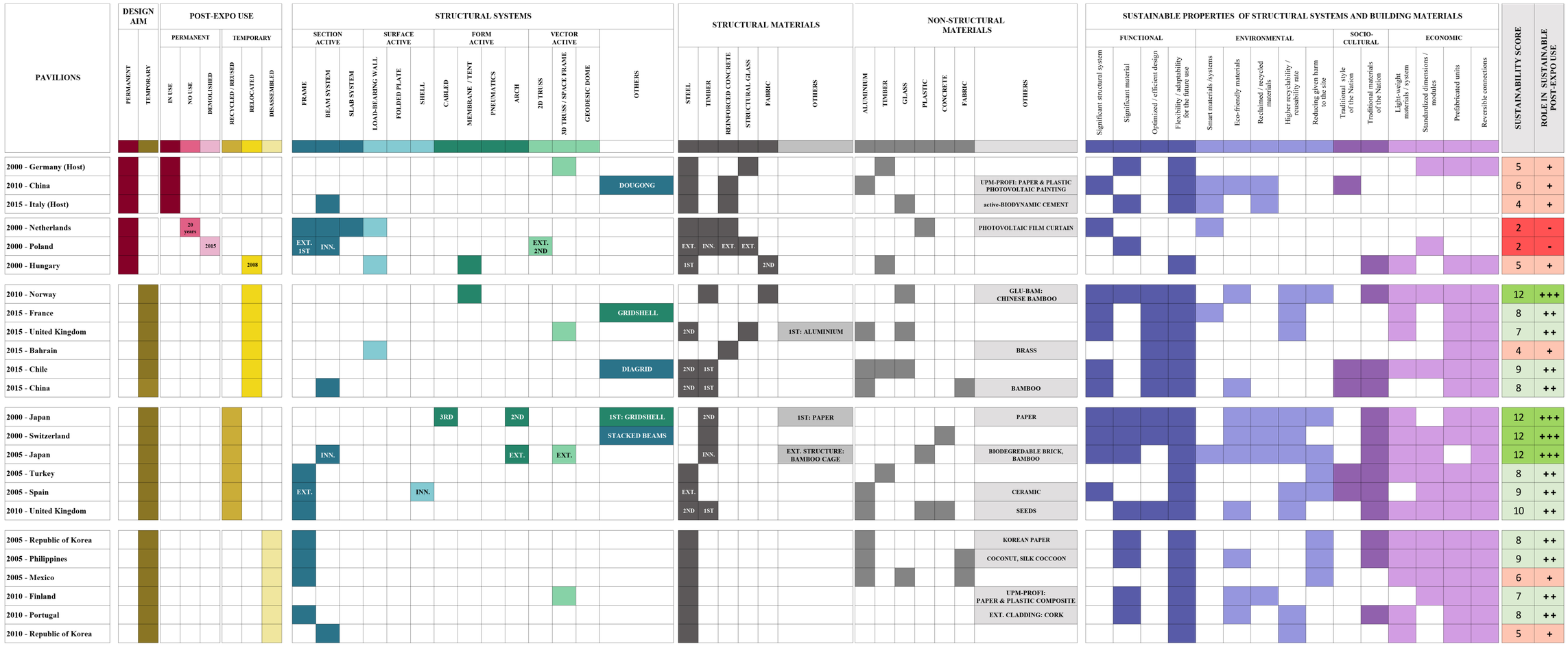
Zhang, X. (2013). Going green: initiatives and technologies in Shanghai World Expo. *Renewable and Sustainable Energy Reviews*, *25*, 78-88.

Zhe, W., Li, Z., & Jing, S. (2011). On the Beauty of Green Expo Architecture and Sustainable Development-Taking "China Pavilion" As An Example. *Procedia Engineering*, *21*, 163-167.

Zsolt, E. (2001). GEMS OF TIMBER ARCHITECTURE-PAVILIONS OF EXPOS Hungarian pavilion in Sevilla and Swiss pavilion in Hannover.

APPENDIX

Table 7: Comparison Table



1ST: Main Structural System
2ND: Secondary Structural System
3RD: Tertiary Structural System

EXT. : Exterior Structure
INN. : Inner Structure

Role of structural systems and materials in sustainable post-expo use process:
(-): No / Negative role
(+): Low-level role
(++): Mid-level role
(+++): High-level role