Feature Articles

Technologies that Support the Realization of Attractive Design

Summary

Results of technological development conducted at Takenaka Research and Development Institute are implemented in society mainly through the Takenaka Group. Among the Takenaka Group companies, Takenaka Corporation in particular applies its technologies mainly to buildings and landscapes, and develops technologies for planning, design, construction, maintenance, and operation of such buildings and landscapes. Many of these technologies help Takenaka realize its “attractive design,” which is one of our strengths and is recognized by society.

For example, the BCS Award, which is given by the Japan Federation of Construction Contractors, is selected "based on a comprehensive evaluation of architectural project planning, planning and design, construction, environment, and operation and maintenance of buildings. Takenaka Corporation has received a relatively large number of awards as a constructor compared to other general contractors, but the difference is more pronounced when compared Takenaka Corporation as a designer. Prize of Architectural Institute of Japan for Design is an award for "an original work that is recognized as being of an extremely high standard from social, cultural, and environmental perspectives, or an excellent work that suggests the possibility of new architecture and is considered to be a landmark of the times." In the 10 years from 2014 to 2023, only two awards were given to works by general contractor designers, both by Takenaka Corporation.

In order to continue to provide designs that are recognized by society, there are often technical challenges that is to realize those designs, and Takenaka R&D Institute is conducting these technical challenges day by day. In this special issue, entitled "Technologies that Support to Realize Attractive Designs," we pick up examples of technological developments that lead to attractive design and introduce them, including examples of their application to actual projects.

The term "attractive design" has a rather vague and broad meaning. For example, a design that incorporates technological development results mainly for the purpose of cost reduction is also attractive from a cost perspective and can therefore be referred as an attractive design. In this special issue, however, we will focus on technologies that contribute to the aesthetic design of the building. The aesthetic design is related to "beauty" among the universal three principles of architecture: "durability," "utility," and "beauty." However, it is extremely rare for technological development to focus solely on "beauty," and most technological development is conducted with "beauty" in mind while focusing on " durability " and " utility" as the main objectives.

"Durability" is mainly related to structural design. Buildings need to withstand external forces such as earthquakes and wind. However, from the viewpoint of "beauty," there are demands for slender members, free shapes, and beautiful surfaces when the frame is used without finishing materials. In order to meet these demands, materials, members, and their design methods with high strength and excellent workability are being developed. In this special issue, we focus on wooden structure technology from the viewpoint of structural system, technology to improve the aesthetics of concrete from the viewpoint of materials, and technology to increase the degree of freedom of design (3D printer) in terms of rational design, manufacturing, and construction methods.

"Utility" is mainly related to the environmental design. Environment here refers to indoor and outdoor environments, and aims to be comfortable and pleasant. As a function of a building, it is desirable to make air, temperature, brightness, sound, vibration, etc. comfortable indoors. While many of the factors that disturb these factors occur inside the building, many of them also occur outside the building, which is difficult to control the source of these factors. The design of exterior walls has become increasingly important in recent years because it has a significant impact on energy and CO2 reduction. In addition, from the viewpoint of "beauty," exterior walls have a direct meaning as façades. For this reason, this special issue focuses on the technologies that support façade design. Next, the outdoor environment is the outdoor space that includes both inside and outside of the construction site, which is continuous with the building. Since the outdoor space greatly affects the function (and thus the value) of a building, it is essential to design the building including (or considering) the outdoor space. The importance of landscape design has been widely recognized from the viewpoint of biodiversity in recent years. This special issue also discusses the technologies that support landscape design.

Keywords: attractive design, wooden structure, aesthetic concrete, 3D printer, facade design, landscape design

1 Introduction

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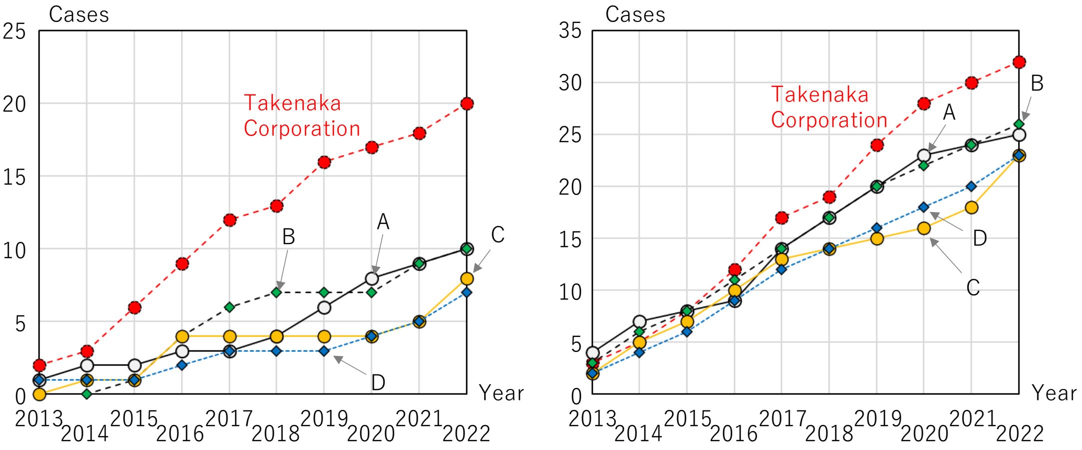
Many of the results of technological developments created at the Takenaka R&D Institute are implemented in society through the Takenaka Group. Within the Takenaka Group, the Takenaka Corporation in particular applies its technology primarily to buildings and landscapes, developing technologies that are related to their planning, design, construction, maintenance, management, and operation. I believe that one of the strengths of the Takenaka Corporation is “attractive design.”

For example, winners of the BCS Award1.1), which is awarded by the Japan Federation of Construction Contractors, are selected “based on a comprehensive evaluation of architectural business planning, planning/design, construction, environment, and building operation/maintenance management, etc.”; the cumulative number of awards received by the Takenaka Corporation over the 10 year period from 2013 to 2022 is shown in Fig. 1.1 (according to research by the author). Fig. 1.1(a) summarizes the number of awards received as a designer, and Fig. 1.1(b) summarizes the number of awards received as a builder, comparing the awards received by Takenaka Corporation with those received by four major construction companies (Companies A–D). Takenaka Corporation has received more awards as a builder than the other construction companies, but the difference is even more notable when comparing the companies as designers. Additionally, the Prize for Design given by the Architectural Institute of Japan (architectural design division)1.2) commends “original works that are recognized to be of an extremely high standard from social, cultural, and environmental standpoints, or outstanding works that suggest new architectural potential and are viewed as defining an era.” From FY2014 to FY2023, only two awards were given for projects by construction company designers (according to author research), with both being awarded to the Takenaka Corporation.



A–D denote four major construction companies in Japan.

(a) As a designer

(b) As a builder

Fig. 1.1 Cumulative number of BCS awards received

Continuing to provide designs that are recognized by society in this way often involves technical issues that must be overcome to make those designs a reality, and the Takenaka R&D Institute is working on these technical issues on a daily basis. In this special feature, “Technologies that Support the Realization of Attractive Design,” we will explore examples of technological developments that lead to attractive designs and introduce these along with examples of their application to actual projects.

The term “attractive design” has a rather vague and broad meaning. For example, a design that incorporates the results of technological development with the primary aim of reducing costs also can be considered an attractive design because it is attractive in terms of cost. However, this special feature focuses on technologies that contribute to aesthetic design. Aesthetic design pertains to the “beauty” aspect of the three architectural principles: “durability,” “utility,” and “beauty”. In this case, an attractive design is one that places a premium on beauty, invoking a sense of attachment and pride. However, technological advancements exclusively targeting the enhancement of “beauty” are exceedingly rare. Typically, these advancements aim to bolster 'durability' and 'utility,' while simultaneously considering “beauty.”

“Durability” primarily concerns structure. Buildings need to withstand external forces such as earthquakes and wind. However, there are now requests for buildings to also focus on "beauty," such as having slender members, free shapes, and aesthetically pleasing surfaces for exposed skeletons. Addressing these desires necessitates the development of materials and structural components that are both highly durable and workable, alongside their design methodologies. In this special feature, we discuss timber design technologies from the perspective of structural form [Chapter 2], technologies that support the aesthetic design of concrete from a material perspective [Chapter 3], and 3D printer utilization technologies that increase design freedom from the perspective of rational design, manufacturing, and construction methods [Chapter 4].

“Utility” primarily pertains to the building environment, encompassing both indoor and outdoor settings with the goal of achieving comfort and a pleasant ambiance. Desirable building functionalities include those that ensure indoor air quality, temperature, illumination, acoustics, and vibration levels are conducive to comfort. While many factors disrupting these conditions originate within buildings, numerous external sources also contribute, albeit they are more challenging to manage. Consequently, mitigation strategies are commonly applied to the building's exterior, including its roof, underscoring the growing importance of exterior wall design not only for energy efficiency and carbon dioxide reduction but also for its aesthetic value as a façade [Chapter 5].

Furthermore, buildings do not exist in isolation but are part of a broader outdoor space that encompasses the area both within and surrounding the premises. This outdoor space significantly influences the building's functionality and, by extension, its value, making the integration of this space into the overall design imperative. The recognition of landscape design's importance, especially in relation to biodiversity, has grown in recent years. Therefore, in this special feature, we also discuss technologies that support landscape design [Chapter 6].

In this special feature, we will introduce the following five technologies that support the realization of attractive design:

- Timber design technologies [Chapter 2],
- Technologies that support the aesthetic design of concrete [Chapter 3],
- 3D printer utilization technologies that enhance design flexibility [Chapter 4],
- Technologies that support façade design [Chapter 5],
- Technologies that support landscape design [Chapter 6].

Various other technologies that support the realization of attractive design exist in addition to the above-mentioned technologies. By appropriately applying these technologies, we anticipate that all stakeholders involved with the buildings and landscapes provided by Takenaka Corporation—including owners and users—will find these structures aesthetically pleasing, develop an attachment to them, and take pride in their ownership. The extended use of these buildings has the potential to make a significant impact on environmental issues and enhance the corporate value for a broad range of stakeholders.

References

1.1） Japan Federation of Construction Contractors website: https://www.nikkenren.com/kenchiku/bcs/, last accessed on August 1, 2023

1.2） Architectural Institute of Japan website: https://www.aij.or.jp/prize.html, last accessed August 1, 2023

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2 Timber Structure Design Technologies

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2.1 Design, Structure, and Environment of Timber Architecture

As a building material, wood is used as both a structural material and a finishing material. While wood has the advantage of being an effective structural material with properties such as high specific strength, it also has aesthetic appeal, such as in its appearance, texture, and material feel. Considering how to utilize these two features is an important aspect of timber architecture design.

Here, we consider why wood is aesthetically preferred. The first reason is that the gradations and patterns created by the wood's color, growth rings, and grain are visually pleasing; moreover, the heat transfer rate and hardness of wood are tactilely pleasing. Combined, these aspects are thought to generate the sensations of "warmth," "coziness," "softness," and "gentleness." Another possible reason is that people often come into contact with wood as a material in everyday tools such as furniture and tableware, and traditional architecture using exposed wood is burned into the memory of Japanese people as a representative example of timber architecture. Research on the psychological impact of wooden buildings2.1) has employed scientific methods to analyze these sensations and impressions, and the results indicate that wooden spaces can lower negative moods such as tension and anxiety.

The use of wood in architecture, particularly timber architecture, has attracted increasing attention in recent years, and wooden structures of unprecedented scale and height have been constructed. This is probably the result of the use of wood in buildings being promoted as a solution to social issues such as the realization of a decarbonized society and the revitalization of the domestic forestry industry, as well as advances in legal systems and technological innovation. Wood is created through the fixing of carbon dioxide from the atmosphere during photosynthesis in the growth process of trees. Given its storage of carbon dioxide in buildings and its ability to fix even more carbon dioxide by replanting trees on land after felling, the use of wood as a building material can contribute to the realization of a decarbonized society. Furthermore, the use of wood in construction has been promoted as a measure for encouraging the growth of domestic forestry in terms of preserving forests and revitalizing local economies. A representative example of this is the enactment of the Wood Utilization Promotion Act in 2010. Moreover, a 2020 amendment added a description of the use of wood in private construction, which is expected to further accelerate the use of wood.

As discussed above, timber architecture has aesthetic features not found in other structures and is expected to become more popular not only from an architectural perspective but also from a social perspective. Takenaka Corporation has named the sustainable virtuous cycle of forest resources and the local economy the "Forest Grand Cycle" (Fig. 2.1)2.2). We are increasing the demand for wood and promoting activities that revitalize Japan's forests, forestry industry, and local communities by increasing the number of buildings in urban areas made of wood.

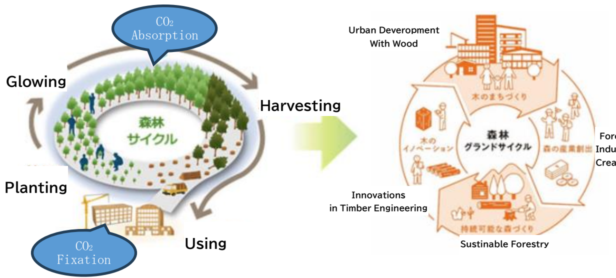

Fig.2.1　Forestry Grand Cycle

We believe that large-scale buildings, high-rise buildings, and mixed-structure buildings, which have previously not been made of wood, are important areas of focus for promoting the spread of timber construction. Popularizing timber architecture in these areas, which have previously been dominated by other structural materials, requires creating designs and structures that take advantage of the texture and characteristics of wood and appeal to the attractiveness of new architecture. At our company, we view improving the structural performance and attractiveness of timber architecture as major issues, and we have developed many structural technologies that enable "exposed" wood materials. In this chapter, we introduce these technologies. Section 2.2 describes the "Moen-Wood" timber construction technology that has achieved new designs and the "KiPLUS" series, which utilizes wood as an earthquake-resistant element in steel and RC buildings. Section 2.3 discusses the "T-FoRest" series as a seismic retrofitting technology that can be used in an exposed form. Finally, Section 2.4 highlights future timber construction technologies.

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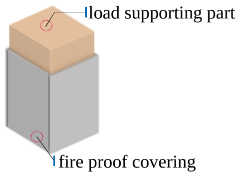
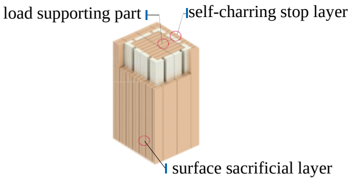
2.2 Timber Structure Technologies Developed for New Building Design

The biggest challenge in realizing the mid-to-high-rise timber architecture that has become popular in recent years is ensuring safety in the event of a fire. Large-scale buildings constructed in urban areas must be fire-resistant structures that will not collapse in the event of a fire. However, amendments to the Building Standards Act in 2000 enabled even wooden buildings to be treated as fire-resistant buildings if they met the required performance requirements. This paved the way for the realization of fire-resistant wooden buildings and the construction of large-scale timber architecture in urban areas. In response to this amendment, Takenaka Corporation developed the fire-resistant wooden member "Moen-Wood" (column/beam), which was applied to a project for the first time in 2013. As shown in Fig. 2.2, Moen-Wood uses a method called a self-charring stop type, which differs from the conventional fire-resistant timber construction that uses plasterboard, etc. Moen-Wood not only provides fire-resistant performance that prevents the building from collapsing in the event of a fire, but it also allows for the wood to be "exposed."



Conventional technology (covered type)



Moen-Wood (fire-retardant type)

Fig. 2.2 Types of fire-resistant wooden member

At the beginning of its development, Moen-Wood was applied to medium- and low-rise buildings of 3–4 stories, such as the Osaka Timber Association Building (Photo 2.1). However, improvements in its fire-resistant performance since 2018 have allowed its scope of application to expand to higher-rise buildings, including Park wood Takamori (2019, 10 floors), FLATS WOODS Kiba (Photo 2.2, 2020, 12 floors), and HULIC & New GINZA 8 (Photo 2.3, 2021, 12 floors). There are currently plans to extend this technology even to skyscrapers, such as the N project (scheduled for completion in 2025, 17 floors, Fig. 2.3).

The round-shaped Moen-Wood column was developed as a further extension of the original Moen-Wood column. This circular column is a Moen-Wood column that has a load-bearing section with a round cross-section wrapped around a fire-retardant layer and a burning substitute layer; thus, it can provide an architectural space with a different look than conventional columns with square cross-sections. FLATS WOODS Kiba uses these circular Moen-Wood columns (Photo 2.2), and the rounded columns create

Photo 2.1 Osaka Timber Association Building

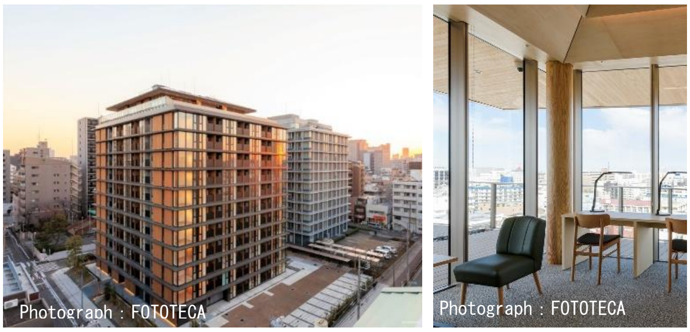


Photo 2.2 FLATS WOODS Kiba （Exterior and Round-shaped Moen-Wood column）

Fig 2.3 N project

Photo 2.3 HULIC & New GINZA 8 (Exterior and CLT composite slab)

a soft space.

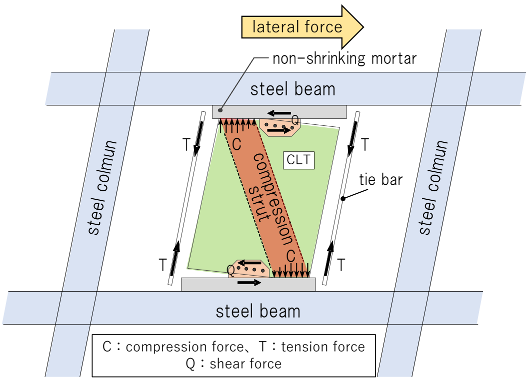


Fig 2.4 image of KiPLUS WALL for steel structure

The development of Moen-Wood columns and beams has enabled the realization of large-scale timber architecture. However, there is no established method for structurally evaluating the resistance performance against lateral forces caused by earthquakes or wind in Moen-Wood columns and beams that use standard joint methods; thus, they cannot be used as earthquake-resistant elements. As a result, the parts of buildings that can be constructed of wood are limited to columns and beams that do not resist horizontal forces, which may hinder the diversification of large-scale timber architecture designs. Widespread use of large-scale timber architecture requires further development of timber construction technologies to increase the number of building elements that can be made of wood and to achieve a variety of architectural designs.

In this context, the KiPLUS WALL was developed as an earthquake-resistant element made of wood. The KiPLUS WALL uses cross-laminated timber (CLT) in newly constructed RC and steel-framed buildings as an earthquake-resistant wall that can resist the horizontal forces caused by earthquakes and wind.

In RC buildings, CLT panels with uneven top and bottom sides (cotters) are integrated into the RC frame. Fitting the cotters on the upper and lower sides to the RC frame creates a mechanism that allows shear force to be transmitted without the use of metal joints. This increases the rigidity and yield strength of the RC frame without compromising its deformability.

In steel-framed buildings, the CLT panels and steel beams are joined using shear hardware, and tie bars are placed on both sides of the CLT. In the event of an earthquake, the shear force is transmitted by the shear hardware, and a truss is formed with the compression struts and tension-side tie bars of the CLT to handle the fluctuating axial force (Fig. 2.4).

Whether in RC or steel-framed structures, CLT can be used without a fire-resistant coating because it does not support the building weight, and thus it can be used to create a warm space with exposed wood. CLT has been employed in the Hyogo Prefectural Forestry Hall (Photo 2.4, 2019, five floors, steel-framed structure), Takuma New Building (Photo 2.5, 2020, six floors, steel-framed structure), Proud Kanda Surugadai (Photo 2.6, 2021, 14 floors, RC structure), and FOREST GATEWAY CHUO (2021, six floors, RC structure), among others.

The Moen-Wood CLT load-bearing wall (Fig. 2.5) was developed as an extension of the Moen-Wood lineup. The Moen-Wood CLT load-bearing wall is a fire-resistant member that contains a CLT load-bearing section, self-charring stop layer, and surface sacrificial layer, similar to the Moen-Wood columns and beams. It provides a two-hour fire-resistant performance and is capable of both resisting horizontal forces and supporting the weight of a building (certified in 2020 by the Minister of Land, Infrastructure, Transport and Tourism as a two-hour fire-resistant load-bearing wall). Thus, this element can be used to support buildings with CLT alone without using columns, and the CLT surface provides an exposed finish without requiring it to be covered with a fire-resistant coating. The Kego Chikuyuryo (Photo 2.7, 2023, five floors) uses this Moen-Wood CLT load-bearing wall, which was combined with RC flat slabs to create an open wooden space.

Photo 2.4　Hyogo prefectural forestry hall (exterior and interior)

Photo 2.5　Takuma new building (exterior and interior)

Timber construction technology has been applied not only for columns, beams, and walls but also for floors. The CLT Composite Floor, which is a technology that combines CLT and an RC slab, involves stacking an RC slab on top of the CLT. By placing a shear key at the interface between the CLT and RC, the integrity of the CLT and RC slab is improved, thereby increasing the stiffness of the RC slab. CLT also plays a role as a finishing material for RC slab formwork and ceilings, as it is a logical technology that considers workability and aesthetics while improving the structural performance of the floor. This technology has been adopted in the HULIC & New GINZA8 (Photo 2.3, 2021, 12 floors).

The timber construction technologies described here are not pure timber architecture methods but are rather intended to be used in conjunction with steel-framed or RC construction. This is partly due to reasons relating to economic efficiency and structurally reasonable design, but it is also because it is thought that increasing opportunities to come into contact with wooden structures by incorporating wooden structures into more buildings will contribute to the future development of timber construction technologies and timber construction design.

Photo 2.6 Proud Kandasurugadai (exterior and interior)

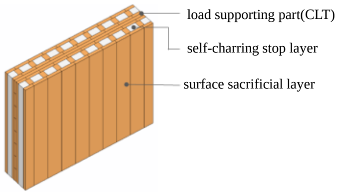


Fig. 2.5 Moenwood load bearing wall

Photo 2.7 Kego Chikuyuryo

2.3 Exposed Timber Technologies for Seismic Retrofitting

The use of wood is not limited to new buildings. We have developed the T-FoRest series of wood materials as a seismic retrofitting technology for existing RC buildings. Conventional construction methods generally involve constructing earthquake-resistant RC walls within existing buildings and installing steel braces; however, the T-FoRest technology enables an aesthetic design of the reinforcing members by using wood materials for the shear walls and braces.

The T-FoRest series includes three types of construction elements: the T-FoRest Wall, which is a wooden shear wall (Fig. 2.6); the T-FoRest Light, which uses laminated timber as a brace (Fig. 2.7); and T-FoRest ESTONE blocks, which are butterfly-shaped CLT blocks stacked in a wall shape (Photo 2.8).

The T-FoRest Wall construction method uses an epoxy resin adhesive to attach wooden panels to existing columns and beams, with the ability to use two types of wood materials: laminated veneer lumber (LVL) and CLT. LVL has the advantage of an expected improvement in yield strength owing to its high rigidity in the vertical direction, which generates a strong frictional force at the adhesive interface in the event of an earthquake. Meanwhile, CLT is often selected for aesthetic reasons because it provides a natural grain. The shear strength of the concrete base material in contact with the adhesive determines the upper limit of the yield strength of this construction method and is slightly inferior or comparable to the strength of conventional construction methods that construct RC walls of the same thickness; however, this construction method has low rigidity. Therefore, the maximum yield strength cannot be achieved at larger deformation angles compared with conventional RC earthquake-resistant elements. However, in cases where only a few locations need to be reinforced, the reinforcement can be provided while preventing increases in eccentricity. Because T-FoRest Light is a brace, it can be applied to locations with openings and foot traffic. As shown in Fig. 2.6, this construction has two methods: in the first method, construction is simplified by applying a pre-stress using springs installed at the ends of the braces and crimping them to the existing frame to serve as compression braces; the second method incorporates PC steel rods and is effective in both compression and tension. These methods can be selected according to the reinforcement plan and required performance. T-FoRest ESTONE blocks are a construction method for building shear walls by stacking butterfly-shaped blocks. Shear force is transmitted by the interlocking of the blocks, which not only contributes to improved structural performance but also serves as an aesthetic feature. Additionally, various treatments can be applied to the exposed surface of the block to create a three-dimensional effect. Each block is extremely lightweight (less than 10 kg), which greatly contributes to improved construction efficiency.

A common feature of the T-FoRest series is that it not only takes advantage of the aesthetic properties of wood but is also greatly advantageous during construction. All the T-FoRest construction methods eliminate the need for anchor work to the existing frame, can be completed with low noise and vibration, and can be completed in a short construction period, which makes these methods suitable for installing seismic reinforcement while the building is still in use. Additionally, wood has a low specific gravity, and thus the use of heavy machinery can be reduced during delivery and construction. The use of wood has enabled both improved construction and design in seismic retrofitting work, where construction conditions are highly restricted.

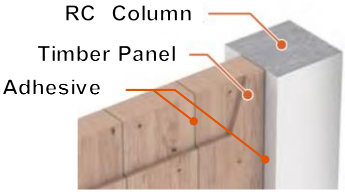


Fig. 2.6 T-FoRest Wallのディテール
Detail of T-FoRest Wall

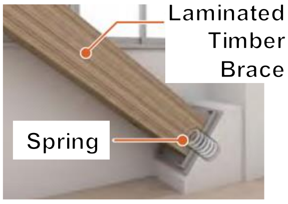


Fig. 2.7 Detail of T-FoRest Light

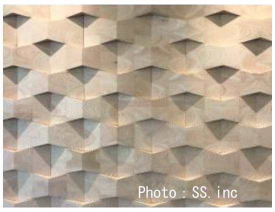


Photo 2.8 Stereoscopic expression by T-FoRest ESTONE blocks

2.4 Future Timber Technologies

As timber architecture becomes more widespread and its market share grows, we can expect the development of technologies that enable even more large-scale and high-rise buildings as well as more aesthetic designs in the future. In this section, we describe technologies currently being developed in anticipation of the future needs of the timber architecture market.

We are currently developing a new fire-resistant wooden structure system as a technology that will further promote larger-scale and higher-rise wooden buildings. The wooden columns and beams that have been used in large-scale timber architecture to date have only served to support the building’s own weight; in general, the resistance to horizontal forces caused by earthquakes and wind was not considered, and the design was such that the horizontal forces were borne by the RC or steel frame present alongside the wood. In contrast, with the new fire-resistant wooden structure system, the building’s own weight can be supported by the steel frame members, and laminated timber is actively used as an element for resisting horizontal forces. This system consists of steel columns and beams that support the building’s own weight and are covered with an outer shell made of laminated timber, and a horizontal force is applied to the wooden parts by placing braces at the column–beam joints of the outer-shell laminated timber frame. This outer shell also serves as a fireproof covering for the steel frame.

The new fire-resistant wooden structure system uses the steel frame to bear the building’s own weight. This allows for larger spans than are possible with conventional fire-resistant timber architecture, which allows for the design of large-scale and highly flexible architectural spaces. Additionally, in high-rise structures made of wood, the large creep deformation that occurs in laminated timber columns over time necessitates design considerations such as anticipating the stress state of the building frame after creep deformation and adjusting the fit of finishing materials in consideration of creep deformation. However, the new system has the advantage of no creep deformation because the building weight is supported by the steel frame, making such design considerations unnecessary. As a result, the new fire-resistant wooden structure system meets the needs of higher-rise and larger-scale timber architecture designs, and our goal is to apply it to actual medium- and high-rise building projects.

In terms of aesthetically excellent technologies, we are developing an shear glass wall for wood frames that utilizes embedding, which is a mechanical property unique to wood. Wood is an anisotropic material, and thus its strength and stiffness vary depending on the relationship between the direction of the applied force and the direction of the wood fibers. When a force is applied in a direction perpendicular to the fibers, the fibers exhibit a property called embedding, where the material exhibits high deformation performance despite low rigidity. Embedding is a property unique to wood that cannot be found in steel or concrete, and the shear glass wall technology for wood frames utilizes this property. This technology involves a wooden column–beam frame that incorporates transparent glass as an shear wall. In the event of an earthquake, this glass resists horizontal forces; however, the technology aims to ensure seismic performance while minimizing damage to the glass by embedding the glass into the wooden frame to utilize the embedding characteristics of the surrounding wooden members.

Conventional shear elements that can be incorporated into wooden frames include plywood, CLT, or braces, and improving the seismic performance of wooden buildings has been paired with creating enclosed spaces within the building. Meanwhile, transparent shear walls are a unique technology with shear elements that are transparent, enabling improved seismic performance without closing off the architectural space; thus, these elements expand the potential for new timber architecture designs.

As discussed above, we are currently engaging in technological development while considering the future needs of timber architecture design without being bound by existing technologies or ways of thinking. Therefore, we expect to contribute to the future development of timber architecture design.

2.5 Conclusion of This Section

Currently, timber architecture in the non-residential field is attracting unprecedented attention and is a rapidly growing field. Meanwhile, compared with the technologies for other structures, timber construction is still undergoing development, and many technical challenges remain, such as the need to increase the rigidity and yield strength of joints and establish countermeasures against creep deformation. Preventing the current situation from becoming a temporary fad and promoting the further development and spread of timber architecture in the future will require proposing a new architectural space that does not view wood materials as a substitute for steel or concrete building materials, but that utilizes both the aesthetic properties of wood and structurally reasonable designs that employ the material properties of wood to an advanced level; this new space will also require a sense of scale and order not seen in conventional architecture. Furthermore, increasing the value of wood as a building requires establishing a method that can quantitatively evaluate the psychological and physical effects that wooden spaces have on people and their contribution to a decarbonized society. Further advances in design, structural, and fire-resistant technologies are essential for achieving such timber architecture. We hope to foster diverse architectural designs and a rich architectural culture and to further contribute to the realization of a carbon-neutral society by refining the technology introduced here and developing new technology.

References

2.1) Miyazaki, K., Nishida, M., Mori, K., Seto, Y., Ishikawa, A., Sugahara, T., Yoshioka, Y., Ishimoto, A. : “Influence of the wooden indoor environment on patient’s psychological response in an urban clinic Part1 Psychological investigation for human mood under woody and non-woody indoor environment”, Annual Meeting of the Architectural Institute of Japan, July 2017

2.2) Creating a forest and town of the future with wood innovations, https://www.takenaka.co.jp/enviro/feature/02/

3 Technologies Supporting Aesthetic Design of Concrete

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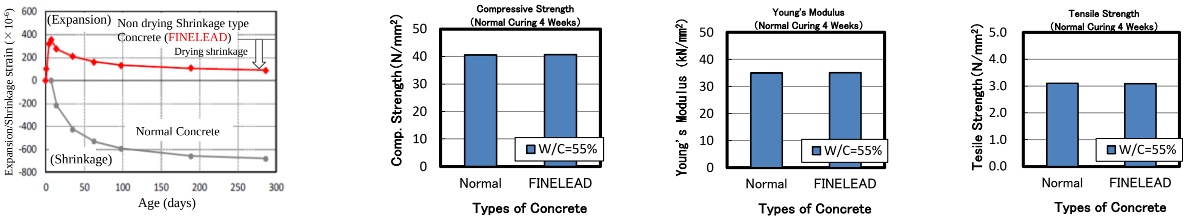
In recent years, the demands on concrete used in reinforced concrete (RC) buildings have expanded beyond traditional performance requirements as a structural material (e.g., strength, rigidity, and earthquake resistance) to include specifications for its quality as a finishing material or as a base for finishing materials, depending on the type of building. For instance, buildings intended to have a decorative exposed concrete finish are expected to be devoid of construction defects such as honeycombs, voids, and cold joints and to exhibit minimal cracking throughout their service life. Similarly, for buildings where finishes like paint, plaster, or diatomaceous earth are applied, a finished quality comparable to fair-faced concrete is necessary as a base for these finishing materials. In both scenarios, it is crucial to ensure that durability-related deterioration, such as corrosion of reinforcement due to carbonation, does not occur over the building's long service life. Additionally, the control of finish quality, color tone, and gloss of concrete surfaces are sometimes required from an aesthetic standpoint, applicable to both in-situ concrete constructions and factory-produced items like precast components. Achieving the desired finishing quality and performance demands necessitates reliable construction practices underpinned by comprehensive construction management methods that leverage the advanced technical skills of various finishing techniques. Fulfilling the designed performance criteria is contingent upon executing reliable construction practices.

Herein, we introduce two pivotal technologies – the non drying shrinkage type concrete (FINELEAD) [3.1)] and ECM-colored concrete. These innovative solutions are instrumental in our pursuit of more advanced and attractive building designs.

3.1 Non Drying Shrinkage Type Concrete (FINELEAD)

Various properties and added values are currently expected of concrete to address recent environmental concerns and satisfy increasingly stringent quality demands. In reinforced concrete (RC) buildings, heightened expectations extend to durability, enabling longer use periods, and aesthetics are crucial factors that influence durability. Achieving an attractive and aesthetically appealing design for an RC building, such as a fair-faced finish, necessitates ensuring fundamental performance like strength, rigidity, and durability against earthquakes and attaining a high-quality surface finish. Common defects on the surface of concrete include those that occur during construction, such as honeycombs, unfilled areas, and cold joints ①, cracking due to drying shrinkage, etc. ②, and rust staining from corroded reinforcing bars due to durability degradation like carbonation ③ that may occur during the long-term service. Our technologies aim to minimize these defects as much as possible to realize advanced designs. To support the creation of buildings with high design quality, we have developed and applied two types of non drying shrinkage type concrete, FINELEAD (high slump and high flow specifications), building upon previously developed low drying shrinkage type concrete [3.2)]. These advancements have facilitated the construction of high-quality and aesthetically pleasing buildings featuring curved walls and fair-faced finish walls made of natural cedar board [3.3), 3.4)]. FINELEAD has good workability due to its high slump or high flowability, extremely high crack resistance due to its apparent non-shrinkage performance, and high durability due to its improved carbonation resistance. Thus, it is expected to reduce and suppress the adverse effects of defect types ①-③ as much as possible.

As shown in Fig. 3.1, FINELEAD minimizes the drying shrinkage of concrete to around 300 μ or less through a new chemical admixture that considers the use of crushed limestone and economic efficiency. The chemical admixture is then combined with an expansive additive; the initial expansion rate of this concrete compensates for the drying shrinkage to yield apparent non-shrinkage behavior. To date, we have developed FINELEAD S with a high slump specification [3.1)] and FINELEAD F with a high flow



(1) Expansion/shrinkage strain characteristics (2) Compressive strength (3) Young's modulus (4) Splitting tensile strength

Fig.3.1 Properties of FINELEAD

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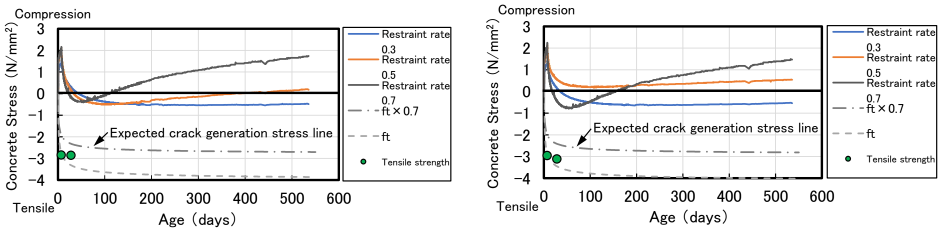
specification [3.5)] to provide slump flow performance. Both products have been put into practical use. Their compressive and tensile strengths and Young's modulus are equivalent to those of normal concrete with the same water–cement ratio; therefore, the FINELEAD can be used without redoing the structural design. Almost no tensile stress is generated owing to the apparent non-shrinkage behavior of these concrete, even in the case of walls restrained by thick members such as columns and beams. Even if tensile stress occurs, the magnitude will be minimal (approximately 0.5-0.7 N/mm^2), resulting in an allowance that is several times higher than the expected cracking stress line (which is 0.7×ft = 2.5 N/mm^2) (see Fig. 3.2). Therefore, the concrete is expected to be effective in reducing and suppressing shrinkage cracks not only in general areas such as unopened walls but also around openings where stress is concentrated.

Furthermore, as shown in Fig. 3.3, carbonation tends to progress much more slowly in FINELEAD S and FINELEAD F than in normal concrete of the same strength, which is an additional effect of the reduced permeability coefficient of carbon dioxide gas due to the apparent non-shrinkage of the FINLEAD concrete [3.4)]. Recent research has shown that the carbonation rate coefficient, which indicates the progress of carbonation, is generally less than approximately 0.7 times that of normal concrete (e.g., in Fig. 3.3 (1), the ratio 1.232 / 2.282 = 0.54; in (2), the ratio = 0.60; in (3), the ratio = 0.67). Therefore, when calculating the lifespan using the square root law for carbonation, the lifespan is expected to be more than twice. Therefore, these concrete are expected to significantly delay the progression of carbonation to the reinforcing bars and the beginning of rusting of the reinforcing bars. It not only suppresses cracks due to the non-shrinkage behavior of the concrete, but it also significantly delays the occurrence of stains on the concrete surface caused by the generation of rust during the corrosion of the reinforcing bars.

Furthermore, the various FINELEAD types possess properties that enhance workability and contribute to more dependable construction. FINELEAD S, characterized by a high slump specification, exhibits slightly lower viscosity than normal concrete with an equivalent slump. This property facilitates easier vibration compaction, thereby reducing labor efforts. Moreover, FINELEAD F, known for its high flow specification with a slump flow exceeding 45 cm, demonstrates high fluidity and self-filling capabilities. Its strong resistance against material and aggregate segregation ensures a significant reduction in construction defects, such as in the construction of honeycombs and unfilled areas. Thus, this technology not only markedly diminishes the need for vibration compaction work but also aids in enhancing construction quality through more reliable building processes.

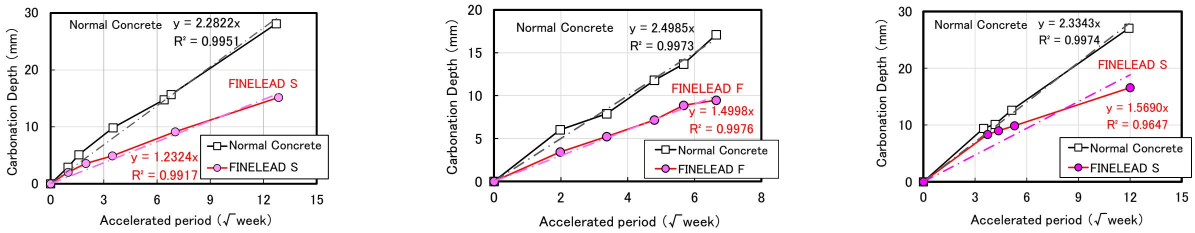
As shown in Photo 3.1 (1)-(4), the two FINELEAD types have been widely applied in projects designed and constructed by our company, and these projects have won various awards, such as awards given by the Japan Concrete Institute Best Work Award, the fib Best Work Award, and the Good Design Award. FINELEAD S, with a high slump specification, was applied to the dormitory T for singles to provide a fair-faced finish, as shown in Photo 3.1 (1). FINELEAD F [3.4), 3.5)], with a high flow specification, was applied to the entrance area of apartment complex Y, which has a fair-faced finish with natural cedar planks, as shown in Photo 3.1 (2). In both cases, buildings with high aesthetic quality RC members were achieved. Furthermore, FINELEAD S has been applied not only to buildings with a fair-faced finish but also to exhibition and guest facility A with a plaster/diatomaceous earth finish and office building R with a painted finish, as shown in Photo 3.1 (3)-(4); buildings of high aesthetic quality were also successfully achieved in these cases.



where
Restraint rate = (area of restrained material) / (area of restrained material + area of unrestrained material)

(1) FINELEAD S (SL=21 cm) test results (2) FINELEAD F (FL=50 cm) test results

Fig.3.2 Test results of generated stress under various restraint conditions with FINELEAD [3.5)]



(1)Test results for dormitory T for singles (2)Test results for apartment complex Y (3)Test results for office building R

Fig.3.3 Effect of improving the carbonation resistance of buildings to which various FINELEAD are applied [3.1),3.3),3.4)]


(1)Dormitory T for singles (2)Apartment complex Y (3)Exhibition and guest facility A (4)Office building R

Photo 3.1 Examples of buildings with FINELEAD applied [3.1),3.3),3.4)]

3.2 Colored Concrete with ECM Cement

Concrete used in construction often has finishing materials on its surface. However, in recent years, building owners and designers have increasingly demanded exposed concrete with a high degree of aesthetics. Colored concrete is a technology that can support the realization of attractive designs for exposed concrete structures. Concrete is colored by mixing finely powdered inorganic pigments into the concrete, and our company has a successful track record of applying this method to several projects we have designed and constructed. However, coloring concrete in various forms faces the challenge of faint color due to the gray color of the cement itself. White cement is sometimes used to address this issue but requires ministerial approval for application. Moreover, few plants are equipped to employ this method, which is less economically efficient, making it challenging.

Under these circumstances, we have developed and applied energy CO_2 minimum (ECM) colored concrete. This concrete uses ECM cement, which contains approximately 60%–70% ground granulated blast furnace slag powder, a byproduct of steel manufacturing, and approximately 30% ordinary Portland cement. The resulting ECM cement complies with the JIS standards for type C equivalent blast furnace slag cement. ECM cement was developed to achieve both environmental friendliness and essential performance (workability, strength, and durability). Additionally, by reducing the amount of ordinary Portland cement, which emits a large amount of CO_2, emissions can be reduced by around 60%-70% compared to using ordinary Portland cement alone. The ECM cement also contains an optimal amount of gypsum within JIS standards, showing advantageous material characteristics[3.6)], including low heat of hydration leading to suppressed temperature rise inside members (Fig. 3.4); improved strength development compared to blast furnace slag cement (Fig. 3.5); reduced shrinkage strain (Fig. 3.6); and high resistance against chlorides and acids. These performance characteristics have been utilized in applying such concrete to various underground structures, such as mat foundations, foundation beams, and cast-in-place piles, mainly in Tokyo and Osaka. In addition, we are also currently using ECM cement as the core material in the ongoing development of carbon-negative concrete[3.7)].

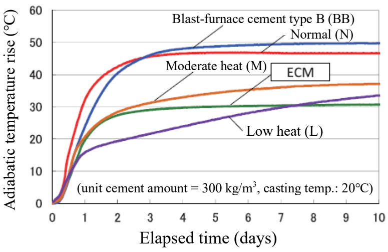


Fig.3.4 Adiabatic temperature rise amount [3.6)]

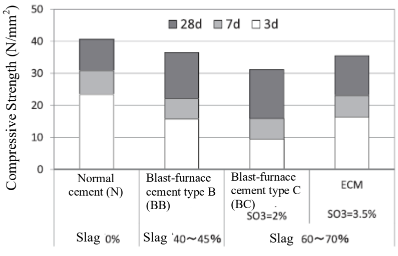


Fig.3.5 Property of compressive strength [3.6)]

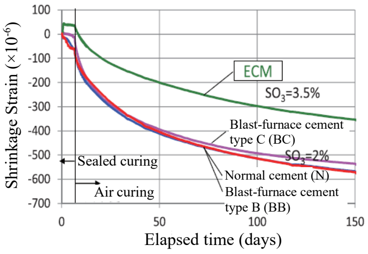


Fig.3.6 Shrinkage property [3.6)]

ECM cement has several advantages when applied to colored concrete, such as its inclusion of 60%–70% white blast furnace slag powder, which results in an improved color performance compared with ordinary Portland cement. The acquired ECM concrete technical certification, a large number of available ready-mixed concrete plants that can use the JIS-certified cement, and increased economic efficiency compared with white cement favor the employment of ECM cement. As shown in Fig. 3.7, the color performance of ECM cement tends to be higher than that of ordinary Portland cement but lower than that of white cement overall. However, some colors exhibit the same color level as white cement, making it possible to meet the various color needs of building owners and designers. Additionally, Fig. 3.8 shows the test results for the compressive strength and Young’s modulus when inorganic pigments are added to ECM cement. The results confirm that the strength characteristics are not changed.

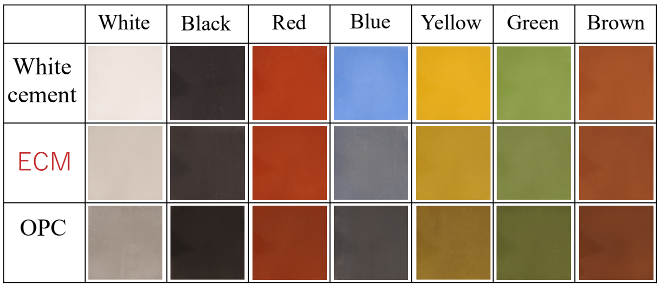


Fig.3.7 Color development performance of ECM cement (2% pigment added)

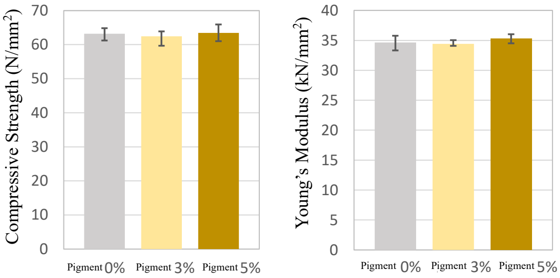


Fig.3.8 Property of compressive strength when pigment is added

Photo 3.2 Test mixing at ready-mixed concrete plant

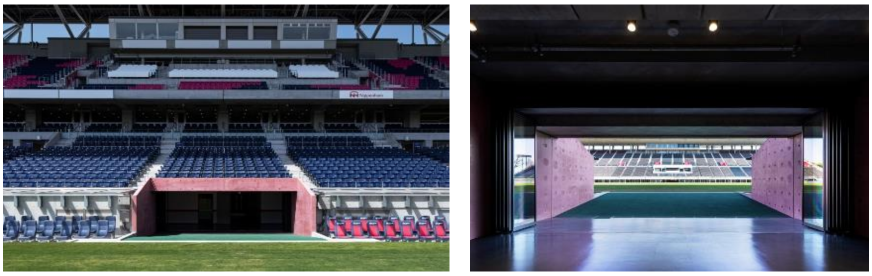


Photo 3.3 Application example of colored concrete with ECM cement (Photographer: Hiroyuki Tsuda, SS Osaka Branch)

Photo 3.2 shows test samples of ECM-colored concrete produced during the trial mixing at a ready-mixed concrete plant, and Photo 3.3 shows an example of the application of ECM-colored concrete. We have had a successful track record of applying this concrete to several projects. When using this method, we first evaluate the mixtures through the trial mixing at a plant; then, given the unique concrete construction, we conduct a trial construction to decide the optimal mix and construction method. Since inorganic pigments are added to the ECM concrete on-site, we consult with a designated confirmation and inspection body in advance, and we conduct acceptance testing when discharging concrete and after adding inorganic pigments.

3.3 Conclusion of This Section

We introduced a non drying shrinkage type concrete (FINELEAD) that significantly reduces and suppresses shrinkage cracks, contributing to the enhanced aesthetic appeal of buildings. Additionally, we introduced ECM-colored concrete, which offers precise color control in concrete, further enhancing aesthetics. These concrete technologies facilitate our company's realization of attractive designs. Moving forward, we aim to refine these technologies, increasing their sophistication to satisfy the growing demands of designers. Moreover, the criteria for concrete are continually evolving and becoming more complex, influenced by historical contexts. Hence, we will persist in fundamental research and development concerning various performance and quality aspects of these products to keep pace with the increasingly diverse demands of designers. Furthermore, we plan to advance technological development to facilitate the application and promotion of appealing concrete, aiming to elevate their aesthetic performance and quality further.

References

3.1) Inoue, K., Honma, D., Ogawa, A., et al.: Development and application of non drying-shrinkage type concrete using hybrid admixture and expansive additive, AIJ Journal of Technology and Design, Vol. 27, No. 65, pp. 30-35, February 2021

3.2) Inoue, K., Iwashimizu, T., Saito, K., et al.: Development of low drying-shrinkage concrete using hybrid admixture, and verification of reducing cracks by application to building structures, AIJ Journal of Technology and Design, Vol. 16, No. 34, pp. 849-854, October 2010

3.3) Sato, T., Inoue, K., Honma, D., et al.: Application of non drying-shrinkage type concrete to curved wall, Summaries of

Technical Papers of Annual Meeting of the Architectural Institute of Japan (Kanto), pp. 117-118, September 2020

3.4）Inoue, K., Honma, D., Ogawa, A., et al.: Development of high fluidity and low drying shrinkage concrete using new hybrid admixtures (Part 17: Application to fair-faced concrete walls in a collective housing building.), Summaries of Technical Papers of Annual Meeting of the Architectural Institute of Japan (Kinki), pp. 519-520, September 2023

3.5）Inoue, K., Ogawa, A., Sato, T., et al.: Development and application of high-fluidity and super-low drying shrinkage concrete for fair-faced concrete walls using a new hybrid admixture, AIJ Journal of Technology and Design, Vol. 29, No. 72, pp. 609-614, June 2023

3.6）Tsuji, D.: Low-carbon concrete “ECM Concrete”, Takenaka Technical Research Report, No. 73, pp. 5-6, 2017

3.7）Torichigai, T., Mori, T., and Kojima, M.: Development of innovative carbon-negative concrete materials, construction technology, and quality evaluation technology–CUCO (Carbon Utilized COncrete), Concrete Journal, Vo. 61, No. 6, pp. 520-527, June 2023

4 Technology Using 3D Printer that Enhance Design Flexibility

Yoshihiro Ota＊5

4.1 Overview

It can be said that the evolution of architecture has been characterized by the interplay between aesthetic and structural design, with new forms emerging as advances in materials and construction techniques are realized. In this dynamic, the design challenge of embodying novel forms has driven the evolution of materials and construction methods. Currently, 3D printing is emerging as a significant breakthrough in materials and construction technology, offering the ability to create forms without the molds that were once essential. This advancement is expected to bring new design challenges.

In the construction industry, 3D printing is often perceived as a new component manufacturing technology that will revolutionize traditional manufacturing processes. One example is the construction of low-cost, small-unit housing using mortar-based 3D printers4-1). At the same time, efforts are being made to improve the related computational design technology, such as realizing optimization for various conditions and complex shapes designed with this technology; the goal is to digitally combine time-consuming shapes with flexible and high-precision construction technologies using 3D printers. In addition, efforts are being made to create excellent architectural spaces and forms. In this chapter, we focus on the creation of new architectural spaces and forms using 3D printers. We have implemented two initiatives using 3D printing: one using topology optimization and the other using resin and metal 3D printers. Here, topology optimization refers to a method of calculating the arrangement of materials in a designed space to create an optimal structure. This method involves calculating the layout that maximizes the expected performance index under multiple constraints, such as the designed space, load conditions, and restraint conditions. Topology optimization itself has been used for many years, but it has not been widely used in the architectural field. The advent of 3D printers, which can embody designed shapes as they are, has expanded the potential for realizing shapes created by topology optimization. A review of specific examples is given below.

4.2 Steel Joint that Create a Large Roof with Timber

Timber structures have been in the spotlight in recent years as architectural structures that have the ability to decarbonize and provide improved comfort for occupants. The challenge with wood structures is to ensure the performance of joints that transfer forces from multiple directions, given the strength anisotropy of the material. Here, we consider the use of a metal 3D printer to fabricate the joints of wood members to solve this problem and achieve a large freeform roof. Figure 4.1 shows an illustration of the potential application results. The modeling methods for metal 3D printers are classified according to the energy/heat source (laser, electron beam, etc.), the state of the original material (powder, wire), and the material supply method (powder bed, wire supply, etc.)4.2). The 3D printing technology used in this study uses the arc welding method (wire and arc based additive manufacturing, WAAM). The arc welding method has a much lower material cost than the powder method and provides superior printing speed..

For the joints of these wooden members, we used this arc welding method to create a hollow space inside the joint, which was then filled with mortar. Our goal was to reduce the absolute amount of welding required by filling the cavity with mortar, thereby reducing the time and cost of the pressure. As the welding wire, we used a product used for welding duplex stainless steel, which has excellent strength and corrosion resistance.

Fig. 4.1 Application image

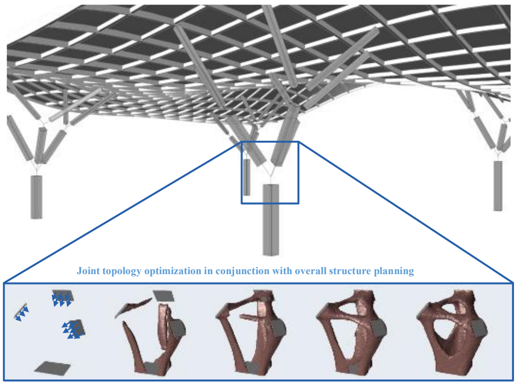


Fig. 4.2 Topology optimization

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In anticipation of accommodating multiple members with different cross-sections from different angles, the design process for the joint used topology optimization to automatically generate a joint shape that could be 3D printed while minimizing the amount of metal material used in the joint (Figure 4.2). This allowed us to derive a shape that met the required proof strength and used the least amount of material for the joint, taking into account the cross-sectional forces exerted on the joint by multiple timber members and the restraint conditions of the joint. Figure 4.1 shows a fabricated prototype joint with four members attached.

Photo 4.1 Joint by 3D printing

4.3 Sign at Shizuoka Office by Resin 3D Printer

The sign for our Shizuoka office was made using a resin 3D printer (photo 4.2). This sign was made using a technology that involves filling a three-dimensional grid of carbon-fiber-reinforced plastic (Photo 4.3) with foamed resin; the surface is then finished with glass-fiber-reinforced concrete or plaster.

The procedure is described below.

(1) Determining the rough shape

We used sketch diagrams provided by our company (Fig. 4.3) and discussed the designs with manufacturers who currently use 3D printers to make products to establish an image of the desired shape.

(2) Setting the shape to minimize the amount of material

We performed topology optimization while changing shape details and support conditions to ensure the strength of the sign while reducing the amount of material used in the three-dimensional carbon-fiber-reinforced plastic lattice (Fig. 4.4).

(3) Determining the final morphology through structural analysis

We used the data from the topology-optimized model to determine the strength of each material and examined the size and length of the three-dimensional lattice, the positions of the nodes, and the size of the structure to be embedded in the foundation to determine the detailed morphology (Fig. 4.5).

(4) Printing with a 3D printer

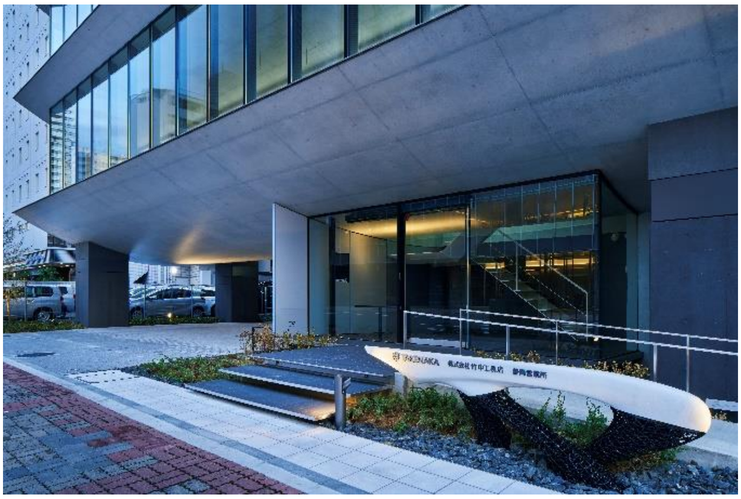

Photo 4.2 Sign at Shizuoka office

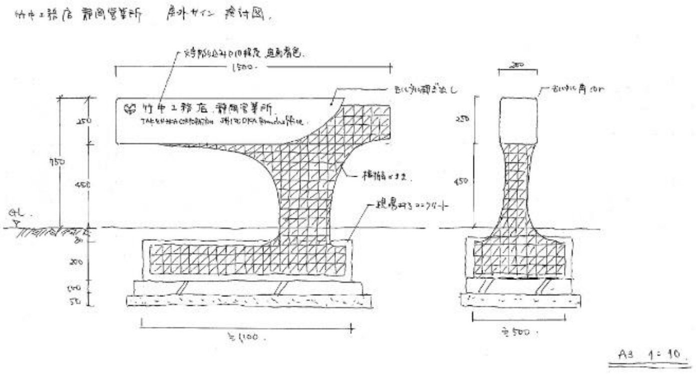

Fig. 4.3 Sketch of the sign

Printing was performed using a 3D printer (Photo 4.3). Product inspection was performed both on-site and online to check the thickness of the three-dimensional mesh and the node conditions.

(5) On-site installation

The product was shipped to Japan, and the bottom plate of the 3D grid was cast into the concrete foundation for installation (Photo 4.4).

In this new sign, the three-dimensional grid morphology that forms the basis of the design is more complex than that normally produced by manufacturers who use 3D printers. Therefore, completing the project required close communication between our company and the manufacturer when deciding on the final form and printing it using the 3D printer.

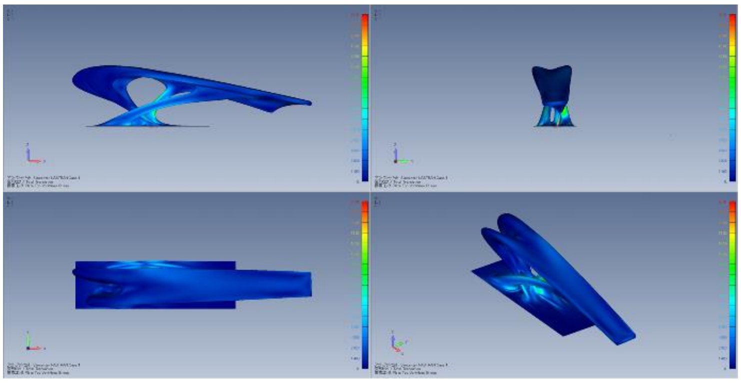

Fig. 4.4 Topology optimization

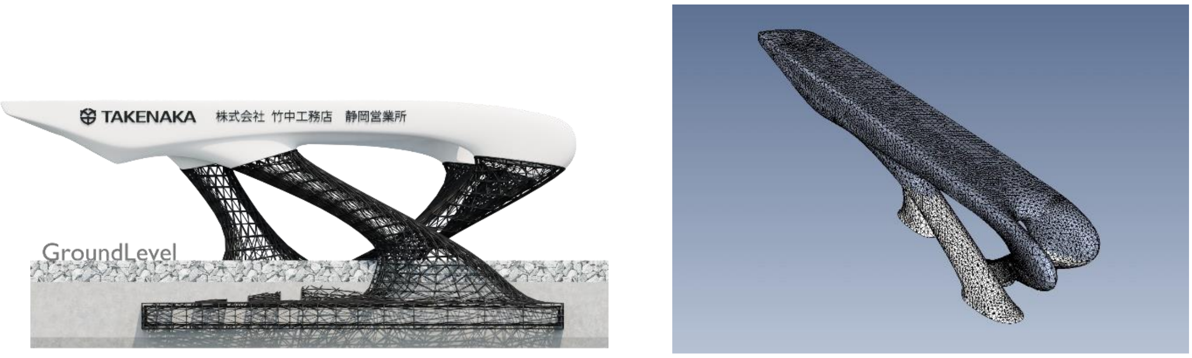

Fig. 4.5 Final configuration

Photo 4.3 Printing by 3D printer (USA)

Photo 4.4 Installation status on site

4.4 Conclusion of This Section

Through two case studies, we have demonstrated the potential of 3D printers to significantly advance materials and manufacturing technology, leading to new design challenges. The goal is to improve the efficiency of materials and design for freeform models using curved surfaces with a topology-optimized design. This novel method involves the use of a 3D printer with resin and metal as materials. The application of 3D technology to architecture is still in its infancy. As needs diversify in the future and mass customization occurs, we plan to consider the use of different 3D printers while overcoming issues such as cost and quality control. We are interested in architecture created through methods that combine the latest large-scale 3D printing technologies and handcrafting as a form of new space creation that is not limited to the production of building components. We are also working towards a future sustainable society, such as the Seeds Paper Pavilion4,3) where instead of dismantling and discarding components at the end of their useful life, they are decomposed and returned to the soil, eventually becoming a forest. Yoshifumi Kosugi of the Nagoya Branch Design Department, Shiro Osuga of the Osaka Head Office Design Department, and Takuya Kinoshita of the Takenaka R&D Institute assisted us in obtaining documents for this paper. We would like to express our sincere gratitude to them.

References

4.1）For example, Hattori, T., Kobayashi, N.: Designing temporary housing build by 3D printer–Providing a quick living space utilizing parametric design, Proceedings of the Conference of the Nihon University College of Science and Technology, 2021

4.2）For example, Kyogoku, H., Ikeshoji, T., Nikkan Kogyo Shimbun, Illustrated introduction to metal 3D additive manufacturing, October 2017

4.3）Yamazaki, A., Oishi, Y.: Seeds Paper Pavilion “What are temporary buildings that will become the seeds of future cities” GA JAPAN 175, March 2022

5 Technologies Supporting Facade Design

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5.1 Roles of the Facade

The façade is the face of an architectural structure and is thus an essential component of attractive design. Therefore, it is important to balance the highly aesthetically pleasing architectural envelope with the indoor environment it creates, as well as with the experiential value of comfort for the people in that environment. Façades are expected to function as a filter to block outside elements from entering the interior space, while also serving to bring the outdoor environment indoors. As a result, the façade reduces the operational energy of a building while also creating a comfortable indoor environment. To fulfill these roles, users demand façade designs that comprehensively consider functions such as heat insulation, solar shading, ventilation, daylighting, views, sound insulation, airtightness, and condensation prevention as a single system. To address comfort and energy conservation concerns, particular emphasis should be placed on functions related to the thermal environment, such as solar shading, insulation, and ventilation, as well as to functions related to the optical and visual environment, such as daylight utilization and visibility.

Glass is widely used to maintain the views and daylight performance of building, and multiple façade systems have been devised to prevent heat from entering through solar radiation and cross-flows. Eaves and outdoor louvers can provide significantly stronger solar shading than indoor blinds because they block solar radiation from entering the room and also create a cooling load on the outside of the glass[5.1)]. An airflow window double skin is a setup in which a blind is sandwiched between two panes of glass, and the air layer between the two panes serves to ventilate and dissipate heat. This setup provides a clean appearance, protects the blinds from wind and rain, and provides heat insulation performance that is similar to and may even exceed that of outdoor louvers[5.2)]. A closed cavity façade is a setup that improves the insulation performance of the glass on the indoor side compared to the double-skin façade but eliminates the ventilation mechanism. This closed cavity setup can provide improved insulation performance while maintaining the solar shading performance[5.3)].

We have researched and developed hardware technology that provides these façade functions[5.2)5.3)], software technology that predicts façade functions in advance and provides optimal designs[5.1)5.4)], and evaluation technology that quantifies the value of these façade functions[5.5)5.6)].

In recent years, as demands for a decarbonized society and interest in wellness have increased, users have demanded that façades fulfill new roles. Previously, typical non-residential buildings had a greater cooling load than heating load, and thus the solar shading performance of these buildings was emphasized. However, as buildings have become more energy efficient and the amount of heat generated inside buildings has decreased, the heating load has increased and the importance of insulation performance is being reconsidered[5.3)]. Furthermore, the ability for occupants to change their own environment has been shown to increase their self-efficacy and work engagement (state of being actively engaged in work and having vitality; WEn) and to allow them to work with enthusiasm[5.7)5.8)]. Efforts are ongoing to propose work styles that allow users to operate openable windows on façades themselves, create a variety of environments within the building without intentionally or excessively suppressing the unevenness of the environment in the window space, and select work locationa depending on their usage style. In the next section, we introduce technologies that support our façade designs based on examples of buildings that address these new trends (Fig. 5.1).

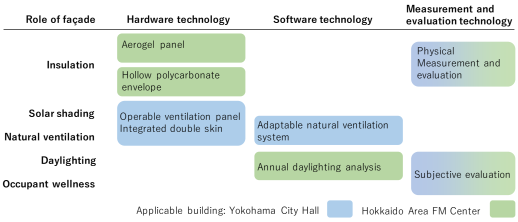

Fig. 5.1 Positioning of the technologies presented in the next section

Photo 5.1 Exterior view of the building
(Photographed by Shigeo Ogawa)

5.2 Examples of Our Technologies behind Facade Design

5.2.1 Case study: Yokohama City Hall

In this project, we pursued the ideal form of a landmark urban skyscraper that combined advanced

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＊7 Senior Researcher, Research & Development Institute, Dr. Eng.
＊8 Group Leader, Research & Development Institute

architecture, structure, and equipment technologies to establish a sustainable metropolitan model for the SDGs Future City Yokohama. Ultimately, we aimed to achieve a city hall that could serve as a flagship for the early realization of decarbonization, which is an emerging global issue (Photo 5.1). The building and equipment were planned to efficiently use the minimum amount of energy necessary. The space was then organized after reducing the load and creating a stable indoor environment through appropriate building layout and planning as well as a high-performance envelope. We planned a manual natural ventilation system in the skyscraper to improve energy efficiency and comfort on a daily basis, and we created ventilation equipment that could be operated manually as usual in emergencies. This manual natural ventilation system could also contribute to improving psychological satisfaction through self-efficacy, and we aimed for this function to be used effectively and efficiently in both emergency and non-emergency situations.

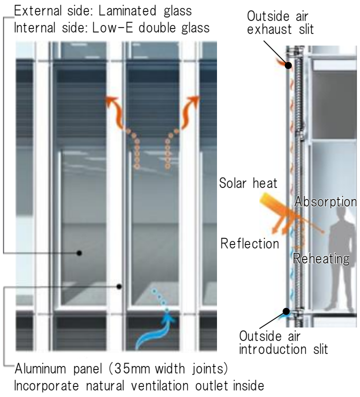


Fig. 5.2 Double skin with integrated operable natural ventilation panel

Therefore, we developed a double-skin curtain wall with an integrated operable natural ventilation panel that harmonized with the envelope design; in addition, an adaptable natural ventilation system encouraged participation by the office workers.

The double-skin curtain wall with an integrated operable natural ventilation panel blocks solar radiation through the electric blinds loccated inside the double-skin curtain wall; the air inside the cavity, which is warmed by the heat generated there, is discharged from the slit at the top of the panel (Fig. 5.2). The heat transmission coefficient, U, has a value of 2.3 W/(m^2・K), and the solar heat gain coefficient is 0.04–0.05; thus, the panel achieves high heat insulation and solar shading performance. Furthermore, we could achieve a clean exterior without any visible clutter by incorporating natural ventilation ports inside the aluminum panel to emphasize the vertical lines of the envelope design (Fig. 5.2). The curtain walls were placed in approximately 80 locations per floor, or approximately 2,000 locations throughout the building, to allow office workers to admit outside air and adjust their own environment without worrying about their surroundings.

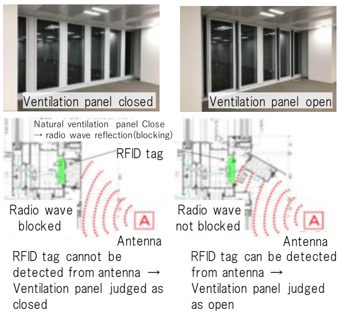


Fig. 5.3 RFID open/close detection

The adaptable natural ventilation system promotes the use of this operable natural ventilation panel and supports the ability of occupants to adapt to the environment. We measured the differential wall pressure at high density and calculated the ventilation airflow through central monitoring to understand the effects of natural ventilation in real-time. We developed and introduced a method to install RFID tags on all of the ventilation panels to monitor the open and closed status of the ventilation panels (Fig. 5.3). The data regarding the open and closed status was managed by cloud BEMS, converted into utilization rates for each floor and direction (open ventilation panels/all ventilation panels), and then imported into the central monitoring system. This information was then visualized in the central monitoring screen and used in the energy conservation effect calculations. A lamp (indicator light) was placed in a position where it could be easily seen by the occupants, and light and sound were used to notify the occupants when the outside air was suitable for natural ventilation. The open or closed status of the panel was also displayed to prevent users from forgetting to close the panels.

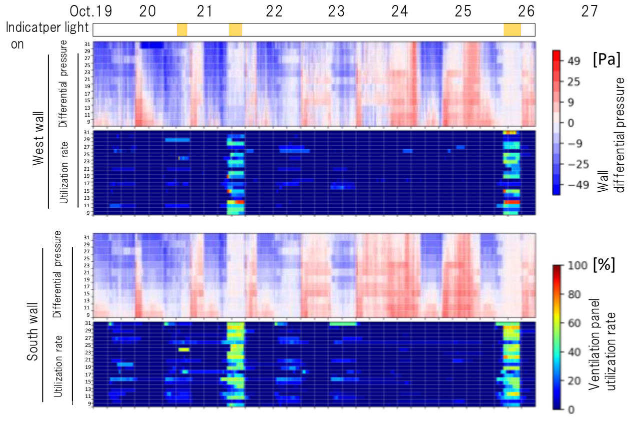


Fig. 5.4 Time series of ventilation panel usage and differential pressure at each floor and wall

Analysis of the cloud BEMS data shows that the occupants admitted outside air to feel more comfortable and participated in energy-conserving activities. Analyzing the changes in the differential pressure and ventilation panel utilization rate per minute in terms of the wall direction and floor (e.g., Fig. 5.4 showing data from 2020/10/19 to 10/26) shows that all of the ventilation panels

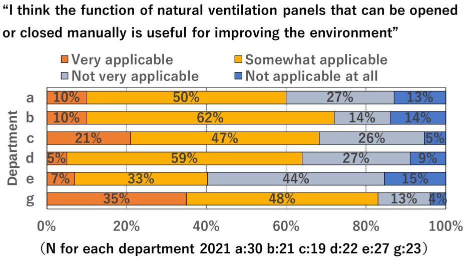


Fig. 5.5 Questionnaire results on ventilation panels

were used once the indicator lamps were turned on. It was also possible to observe which ventilation panels on which walls and floors were frequently used and at which times they were used. The variations in the ventilation panel utilization rate in the 1.5 years since completion of construction show that despite seasonal fluctuations that are mainly due to the direction of the monsoon wind, the average utilization rate remained at approximately 10%–35% (200–700 locations), and the ventilation panels appeared to be actively used by occupants. Furthermore, an average utilization rate of 2%–4% (40–80 locations) was observed even in the summer and winter when the indicator lamps were not illuminated, indicating that a small number of occupants sought to admit outside air for a short period of time under these conditions[5.8)]. Further research will be beneficial for the design of manual ventilation in skyscrapers.

We conducted a questionnaire evaluation to capture any changes in the self-efficacy of the occupants before and after moving to the new building. The percentage of respondents who answered that they were “satisfied with the functionality” of the ventilation panels varied between surveyed departments (departments a–e, g), ranging from 30% to 70%. However, the percentage of respondents who thought the ventilation panels were “useful for improving the environment” exceeded 60% in all departments except department e (Fig. 5.5). This result suggests that further improvements in satisfaction could be achieved by improving the method for operating the ventilation panels[5.9)]. Furthermore, a positive correlation between the thermal environment satisfaction and self-efficacy was observed in all seasons (summer, mid-seasons, winter) (data not shown). In addition, the self-efficacy scores were higher than those for the old city hall, which was occupied before the occupants moved to the current building (e.g., Fig. 5.6)[5.9)]. Further research is needed to determine the extent to which the developed façade and adaptable natural ventilation system contributed to this increase in self-efficacy.

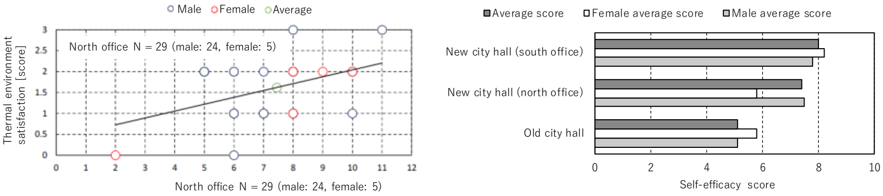


Fig. 5.6 Self-efficacy and thermal environment satisfaction (mid-seasons)

5.2.2 Case study: Takenaka Corporation Hokkaido Area FM Center

Photo 5.2 Building exterior (viewed from the southwest)

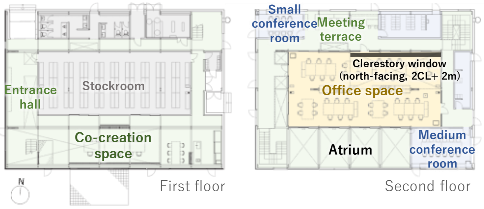


Fig. 5.7 Arrangement of office space and co-creation space, etc.

This small office building is located in a residential area in Sapporo City, Hokkaido, which has a humid subarctic climate. The building aims to be ZEB Ready. Office spaces for core work are located in the center of the building on the second floor and are surrounded by spaces such as a co-creation space and meeting terrace (Fig. 5.7). Furthermore, the layout has a thermal nesting structure that forms an intermediate area between the office space and outside environment. Various office spaces with different qualities are created, such as office spaces that are less susceptible to the arsh effects of nature, and co-creation spaces that are more susceptible to the effects of nature through the façade. The aim was to allow occupants to not only freely choose their work spaces depending on the work content and mood, but also to choose their heat and lighting environment. The intention for the façade was to create a calm look suitable for a residential area by diffusing natural light during the day similar to the effect with a shoji screen, thus bringing a pleasant soft light into the room. In addition, we aimed to allow the light from inside the rooms to bleed out to the outside at night, giving the building a slight glow like a *bonbori* (snow cave) (Photo 5.2). Meanwhile, given the humid subarctic climate and the low internal heat generation equipment specifications required to be ZEB Ready, we predicted a high heating demand in the building, and thus the façade required a high insulation performance. Therefore, we introduced two façade components using new materials.

The first façade component was an envelope panel using aerogel. Aerogel is a general term for a porous material that is obtained from a gel by removing the solvent contained in the gel using a supercritical drying method while maintaining the structure of the Their morphologies can be roughly divided into particle-like shapes ranging from several micrometers to several millimeters in size and plate-like shapes with a thickness of dozens of millimeters. The aerogel used here has a cluster structure called a pearl necklace, in which spherical silica particles of several to several dozen nanometers are bonded together, and the open voids formed by the clusters are approximately 50 nm in size; air accounts for over 90% of the volume. Air molecules (nitrogen, etc.) are trapped in this structure, which suppresses heat conduction by the gas, thus further complicating the heat conduction path and reducing the thermal conductivity[5.10] (Fig. 5.8). Furthermore, the cluster structure is smaller than the wavelength of visible light, and thus Rayleigh scattering occurs, which results in a slightly bluish, translucent appearance.

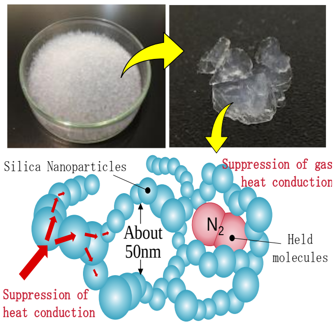


Fig. 5.8 Outline of Aerogel

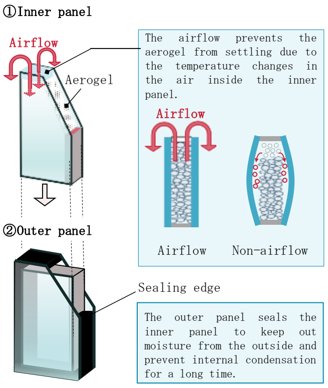


Fig. 5.9 Construction concept of Aerogel panel

The newly developed aerogel panel consists of an inner panel[5.11] that is fabricated by filling the space between two transparent plates (polycarbonate, glass, etc.) with powdered aerogel. This inner panel is then inserted between two sheets of glass that serve as the outer panels and are sealed at specific locations (Fig. 5.9). This configuration allows the aerogel layer to be held vertically without being affected by changes in the surrounding temperature[5.12] while ensuring durability equivalent to that of conventional multi-layered glass[5.13].

The heat transmission coefficient of the aerogel panel measured by a heat insulation test according to JIS A 4710 is 1.22 W/(m^2・K) (the calculated heat transmission coefficient value at center of the 900 mm × 900 mm × 40 mm thickness shown in Fig. 5.9 is 0.81 W/(m^2・K)). Meanwhile, the calculated value of the heat transmission coefficient of triple glass (900 mm × 900 mm × 36 mm thickness, with outermost layers of 4 mm Low-E glass, and an air layer of 12 mm × two layers) is 0.93 W/(m^2・K) at the center of the glass. Moreover, the heat transmission coefficient of the overall aerogel panel glass system including the sealing part of the panel is 1.39 W/(m^2・K), indicating that the aerogel panel has superior thermal insulation properties compared with those of triple glass. We installed a panel at the clerestory window with a visible light transmittance of approximately 10%–70% by mixing aerogel and white particles to change the diffuse transmitted light while maintaining the thermal insulation performance (Photo 5.3). We believe that this method will provide a technology that can add richness to architectural designs by acting as a “modern shoji screen.” This method provides the ability of traditional shoji screens to let in soft and natural light while endowing thermal insulation properties that traditional shoji screens lack.

Photo 5.3 Installation on Clerestory window

The second façade component is a hollow polycarbonate envelope (hollow PC envelope) (Fig. 5.10). The hollow PC envelope contains an insulating air layer while enabling the utilization of daylight and acquisition of solar heat in the winter (direct gain). This system has a heat transmission coefficient of 1.21 W/(m^2・K) and visible light (total light) transmittance of 40%. This system was introduced to the south and west exterior walls of the building (Photo 5.2), and solar heat storage was achieved by using flat PC plates with a high heat capacity for the flooring of the co-creation space and entrance hall adjacent to the exterior walls. This enabled stabilization of the indoor thermal environment. Owing to its frameless setup, this system exhibits none of the heat loss caused by a metal frame that occurs when glass is used. The thermal performance of the building was measured and evaluated[5.13]. The solar radiation, heat flux, and indoor temperature of the co-creation space measured inside the hollow PC envelope revealed that the indoor temperature of the co-creation space was maintained at around 20 °C during the day through solar radiation. Furthermore, nighttime measurement data showed that the heat transmission coefficient of the hollow PC envelope was 1.27 W/(m^2・K), confirming that high insulation performance equivalent to the design value was achieved.

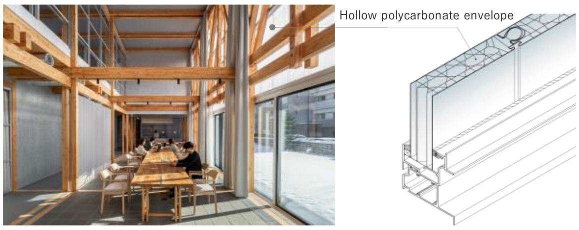


Fig. 5.10 Hollow PC envelope seen from the co-creation space and cross-sectional view of it

An optimum design is required to obtain an appropriate brightness with natural light. Therefore, when introducing these new

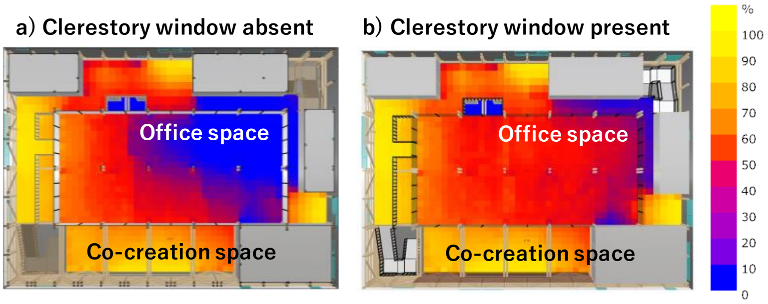
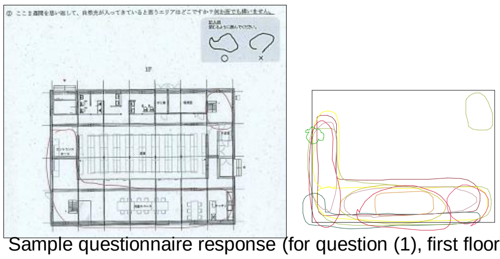


Fig. 5.11 Effectiveness of high sidelight predicted and evaluated with annual daylight index DA_{300lx}



Sample questionnaire response (for question (1), first floor)
Left figure: Example of entry by one respondent,
right figure: combination of all responses

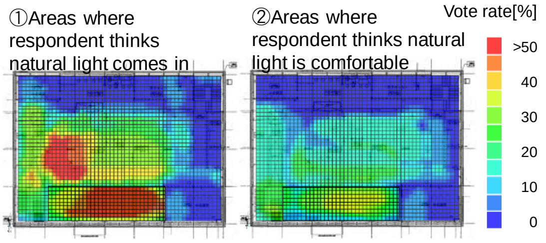


Fig. 5.12 Spatial distribution of vote rates of recognition and preference for daylight

façade components, we used predictive analysis technology during the design phase to incorporate these components into the design specifications. We also performed measurements and evaluations as well as post-occupancy evaluations after the completion of construction. An annual daylight analysis[5.13)] predicted that daylight could not be utilized on the northeast side of the office space (Fig. 5.11a)); therefore, we decided to install clerestory windows in the office space (Fig. 5.11b)) (the results for the first floor are shown in the atrium area on the second floor (Fig. 5.7) to display the overlapping results for the first and second floors). Furthermore, the glare index analysis predicted that unpleasant glare could occur in the co-creation space because the south and west faces are large-area daylight sources owing to the hollow PC envelope (Photo 5.2); however, no glare was predicted when looking to the south or west from the office space. The design concept allowed occupants to freely select their seats and avoid glare, and thus active use of daylight was prioritized; in addition, curtains were installed that could be adjusted by the occupants as needed. We conducted measurements and questionnaire evaluations after the completion of construction[5.13)]. We presented the floor plan to the occupants, had them recall the last two weeks, and then asked them to identify (1) “areas where you think natural light came in” and (2) “areas where you think natural light was comfortable” by drawing as many circles on the floor plan as needed (Fig. 5.12). The vote rate was calculated by counting the number of times points were circled in 500-mm grid intervals in the room and then dividing that number by the total number of respondents. This spatial distribution enabled us to visualize occupants’ awareness and preference for daylighting. High vote rates for comfort were obtained at the center of the co-creation space and the south side of the office space. This may have been due to not only the high daylight illumination, but also the use of the co-creation space by a larger number people, which thus increased their likeliness to vote for this space. However, factors other than daylight illumination and usage frequency may also have had an impact, such as the impression of the space, good views, and how the area was used. The vote rate showed a relatively high correlation with some daylight indicators calculated from actual illumination measurements (e.g., Fig. 5.13). These results suggest that façades can be designed optimally by predicting spaces where occupants can find comfortable natural light based on daylight indicators predicted at the time of design. We also conducted a questionnaire survey that focused on the relationship between WEn and the environmental satisfaction of various rooms such as co-creation spaces; the relationship between WEn and the frequency of use of various rooms was also analyzed[5.14)]. The Utrecht Work Engagement Scale[5.15)], which is a WEn scale, did not show any significant correlation with environmental satisfaction, but a positive correlation with the frequency of use of co-

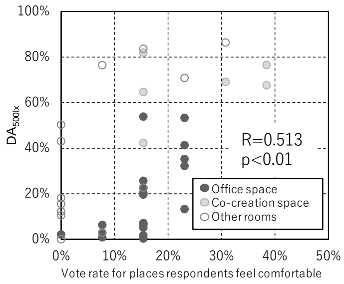


Fig. 5.13 Correlation between DA_{500lx} and daylight comfort vote at each measurement point

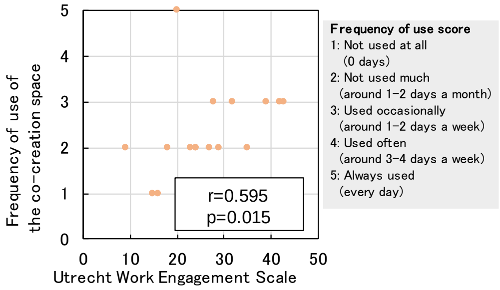


Fig. 5.14 Correlation between Utrecht Work Engagement Scale and frequency of use of co-creation spaces

creation spaces was observed (Fig. 5.14). Further research on the potential for increased frequency of use of co-creation spaces to contribute to improved WEn scores is expected in the future.

The above evaluations suggest means by which new façades can contribute to the formation of various indoor environments while providing a high energy conservation ability, as well as how design plans that include work styles that allow workers to choose their own environment can contribute to the comfort of the indoor environment and WEn.

5.3 Conclusion of This Section

In this section, we examined examples of façades designed to provide attractive exteriors that people living in the area can feel attached to and proud of, and we also introduced several research and development projects that not only ensure aesthetic appeal but also contribute to the realization of a decarbonized society and the occupant wellness. There is no single correct answer to creating an attractive façade, and a design that is adapted to the landscape and climate of the city is necessary. We plan to continue contributing to the development of hardware, software, and evaluation technologies that meet these design demands in the future.

References

5.1) For example, Kikuchi, T., Boda, H.: “Louver arrangement studies for huge light court using annual simulation of daylight and solar radiation”, Lux Pacifica 2013, 2013.3

5.2) For example, Hidari, K., Kikuchi, T., Wada, K., Tanaka, K., Hori, Y., and Naoi, K.: “Integrated planning and practice of solar shading and indoor natural ventilation with double skin façade (Parts 1 and 2)”, Technical Papers of the Annual Meeting of the Society of Heating, Air-conditioning and Sanitary Engineers of Japan, 2012

5.3) For example, Kikuchi, T., Wada, K., Kasai, K., Hori, Y., Sugano, Y., et al.: “Research on façade systems suitable for buildings with low internal heat generation (Parts 1–3)”, Summaries of Technical Papers of the Annual Meeting of the Architectural Institute of Japan, 2016.8

5.4) For example, Kikuchi, T. and Igawa, N.: “Validation of lighting simulation program with All Sky Model-L”, Journal of Environmental Engineering (Transactions of AIJ), Vol. 73, No. 629, 865-871, 2008

5.5) For example, Wada, K. and Higuchi, M.: “Annual thermal evaluation of the outer wall with the ventilated air layer”, Summaries of Technical Papers of the Annual Meeting of the Architectural Institute of Japan, 13-14, 2007.7

5.6) Hanazato, M., et al.: “How does the office environment affect work engagement, health, and behavior?: Part 13, Cross-sectional analysis of natural elements and work engagement at own desks”, Summaries of Technical Papers of the Annual Meeting of the Architectural Institute of Japan, 2019.9

5.7) Onga, A. and Nobe, T.: “Analysis of worker’s requirements for thermal environment”, Technical Papers of the Annual Meeting of the Society of Heating, Air-conditioning and Sanitary Engineers of Japan, 429-432, 2008

5.8) Takahashi, M., Tanabe, S., Nozaki, N., Takahashi, H., Wada, K., Nakagawa, J., et al.: “Research on influence of active design in office spaces on work styles (Parts 1–17)”, Summaries of Technical Papers of the Annual Meeting of the Architectural Institute of Japan, 2017-2023

5.9) Hidari, K., Takahashi, Y., Kikuchi, T., Nobe, T., Yamazaki, R., Ogino, K., et al.: “Study on the city hall in SDGs Future City for Zero Energy Building (Parts 1–17)”, Technical Papers of the Annual Meeting of the Society of Heating, Air-conditioning and Sanitary Engineers of Japan, 2019-2022

5.10) R. Baetens, B.P. Jelle, A. Gustavsen, Aerogel insulation for building applications: A state-of-the-art review, Energy and Buildings 43 (2011) 761–769.

5.11) E. Belloni, C. Buratti, F. Merli, E. Moretti, T. Ihara. Thermal-energy and lighting performance of aerogel glazings with hollow silica: Field experimental study and dynamic simulations. Energy & Buildings 243 (2021) 110999.

5.12) Oba, Y., Ihara, T., Sugita, K., Gibe, S., and Nakashima, N.: “Study on building envelope system using silica aerogel granules: Part 1: Sedimentation of gel layer”, Summaries of Technical Papers of the Annual Meeting of the Architectural Institute of Japan (Tokai), 2021.9

5.13) T. Ihara, B.P. Jelle, T. Gao, A. Gustavsen, Aerogel granule aging driven by moisture and solar radiation, Energy and Buildings 103 (2015) 238–248.

5.14) Kawahata, S., Kikuta, K., Tsuneoka, Y., Kikuchi, T., Miyakawa, Y., et al.: “Planning and evaluation of small offices with consideration for regional decarbonization under hot-summer humid continental climate (Parts 1–8)”, Technical Papers of the Annual Meeting of the Society of Heating, Air-conditioning and Sanitary Engineers of Japan, 2022-2023

5.15) Utrecht Work Engagement Scale (UWES), Shimazu Laboratory, Faculty of Policy Management, Keio University, https://hp3.jp/tool/uwes (accessed 2021.10.24)

6 Technologies Supporting Landscape Design

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6.1 Future Needs for Landscapes

Landscapes are often synonymous with scenery, yet their significance encompasses more than just aesthetic beauty. They encapsulate the essence of local society, embodying a multifaceted concept that intertwines social and cultural dynamics with the intricate relationship between nature and humanity. Within this realm lies landscape design, a practice that extends beyond the mere arrangement of natural elements. In a more specific sense, landscape design pertains to the crafting of public spaces within urban environments, such as open areas, plazas, and parks. However, it also encompasses the intricate coordination of both tangible and intangible aspects across varied scales, encompassing outdoor and indoor environments. This multidisciplinary endeavor draws upon a diverse array of disciplines, including environmental studies, architecture, civil engineering, sociology, and art. The technology underpinning landscape design spans a broad spectrum, facilitating innovation and creativity in the field. In recent times, the emergence of landscape urbanism has offered a novel approach to addressing the complexities of modern cities. Originating in the late 1990s, this urban theory integrates a holistic understanding of ecosystems, encompassing human activities within urban landscapes. This perspective has resulted in a remarkable increase in innovative solutions to urban challenges, as demonstrated by projects such as New York's High Line. Such endeavors have demonstrated remarkable efficacy in revitalizing disused urban spaces, while concurrently enhancing real estate values. As society increasingly recognizes the intrinsic value of well-designed landscapes, the potential for transformative impact also continues to increase.

Meanwhile, landscapes serve as the foundation that supports rich biodiversity and nature. Our societal and economic endeavors, in turn, rely heavily on the sustenance provided by nature and its biodiversity. These invaluable gifts from nature are commonly referred to as ecosystem services. However, if nature undergoes degradation, these ecosystem services are at risk, resulting in a decrease in the sustainability of both cities and businesses. International agreements underscore the urgency of preventing global nature degradation, emphasizing a substantial expansion of protected land areas in each country from current levels. This highlights the pivotal role of land use as a mechanism to combat nature degradation. Notably, these agreements reference the Kunming–Montreal Global Biodiversity Framework, a newly established global biodiversity goal announced during the 15th Conference of the Parties to the United Nations Convention on Biological Diversity in December 2022. Additionally, the adoption of the Kunming–Montreal 2030 Goals outlines 23 action targets aimed at achieving "nature positivity" by halting and reversing the loss of nature by 2030. Among these targets, at least six are related to land use, such as "Conserve 30% of Land, Waters, and Seas" (30 by 30) (Target 3) and "Restore, Maintain, and Enhance Nature's Contributions to People" (Target 11), underscoring the significance of a landscape-oriented approach in attaining nature positivity.

Another noteworthy aspect of the framework is its requirement for major companies and financial institutions to disclose nature-related information. Large companies and financial institutions are now mandated to regularly monitor and assess risks, dependencies, and impacts related to biodiversity, transparently disclosing them. International initiatives are progressing in establishing guidelines for disclosing biodiversity impacts, dependencies, and risks in corporate activities such as land use and procurement. The International Sustainability Standards Board, responsible for formulating international standards for corporate sustainability information disclosure, has resolved to include biodiversity as one of its forthcoming standards following climate change. In Japan, the disclosure of sustainability information in securities reports has been made mandatory since the fiscal year ending March 2023. This includes human capital information, as well as sustainability information, including climate change, biodiversity, and human rights, reflecting the increasing importance that companies attribute to these issues. Consequently, there is a growing interest in companies disclosing nature-related information in certifications such as natural symbiotic site certification and green space certification. These certifications objectively demonstrate the commitment of companies to land use practices that contribute to biodiversity conservation.

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Traditionally, companies have primarily promoted land use practices that contribute to biodiversity conservation with a focus on social contributions. However, given the aforementioned context, biodiversity conservation has now emerged as a management imperative on par with decarbonization. This paradigm shift has resulted in a rapid increase in momentum for the promotion of land use strategies that prioritize nature.

As previously mentioned, modern landscapes encompass diverse needs, yet a common aspect underscores the necessity to skillfully utilize the multifunctionality of nature to address intricate urban social challenges and generate integrated value. A design approach that seamlessly integrates diverse human activities with the natural environment and derives solutions through targeted land and spatial planning is imperative to meet these demands. Our company is actively engaged in developing technology to support such landscape designs. In this chapter, we categorize the technologies developed by our company to support landscape design into planning technologies (Section 6.2), environmental simulation technologies (Section 6.3), countermeasure technologies (Section 6.4), and operation support technologies (Section 6.5). Within each section, we elaborate on our endeavors. Table 6.1 in this chapter presents the individual technologies discussed, mapping them against a matrix that delineates the relationships between the four technology categories and the five effects landscapes should embody: environment, economy, society, disaster prevention/mitigation, and health. This matrix illustrates the positioning of each technology within the broader landscape design framework. We aim to complement existing design and construction methodologies such as architecture, civil engineering, and environmental engineering pertinent to realizing landscapes, as well as to address project-specific challenges and enhance the appeal of structures through our distinctive initiatives.

Table 6.1 Positioning of technologies supporting landscape design

Five effects that should be demonstrated by landscape	6.2. Planning technologies	6.3. Simulation technologies	.4. Countermeasure technologies	6.5. Operation support technologies
Environment	・6.2.1. GI Concept Book ・6.2.2. Green space planning support technologies using birds as indicators	･6.3.1. Wind / thermal environment analysis technologies ･6.3.2. Optimization of tree placement	･6.4.2. Honeycomb Green ・6.4.3 Vertical Forest ・6.4.4. Restoration of semi-natural grasslands	6.5.2. Sotocomi
Economy	・6.2.1. GI Concept Book			・6.5.1. Biophilic design ・6.5.2. Sotocomi
Society	・6.2.1. GI Concept Book		6.4.2. Honeycomb Green	・6.5.1. Biophilic design ・6.5.2. Sotocomi
Disaster prevention / mitigation	・6.2.1. GI Concept Book		・6.4.1 Rainscape ・6.4.2. Honeycomb Green	
Health	・6.2.1. GI Concept Book	・6.3.2. Optimization of tree placement		・6.5.1. Biophilic design ・6.5.2. Sotocomi

Note: Numbers such as 6.2 and 6.21 in this table correspond to the section numbers introduced in this chapter.

6.2 Planning Technologies

In Section 6.2, we introduce our innovative technologies designed to enhance future landscape planning. As highlighted in Section 6.1, landscapes serve as the foundation for nurturing rich biodiversity, sustaining our socioeconomic activities through the provision of ecosystem services. In response, our company has embraced the green infrastructure (GI) concept, integrating it into our landscape planning endeavors. We have compiled exemplary initiatives and strategies for judiciously leveraging nature to foster sustainability in our Green Infrastructure Concept Book. Furthermore, recognizing the crucial role of assessing the surrounding environment's impact on architectural plans, we introduce our innovative technology known as the "green-space planning support technology using birds as indicators." This technology serves as a valuable tool in the architectural planning process, facilitating a deeper understanding of the ecological dynamics and enhancing the integration of green spaces within our designs.

6.2.1 Green Infrastructure Concept Book

Green infrastructure (GI) represents a paradigm shift, emphasizing the multitude of services offered by nature. It embodies a holistic approach that harnesses nature's multifaceted functions to create diverse values and foster a sustainable society. This approach closely aligns with the landscape needs outlined in Section 6.1, refraining from viewing nature merely as a conservation target but rather as a dynamic resource to address societal challenges and enhance value creation. Consequently, these efforts are expected to contribute to the conservation of biodiversity, which is currently under threat.

In recent years, Japan has grappled with a myriad of social challenges, including population decline, frequent natural disasters, environmental degradation, aging infrastructure, fiscal constraints, and stagnating local economies. The Green Infrastructure Concept Book (Fig. 6.1) was issued with the aim of communicating to stakeholders our company's commitment and endeavors toward achieving a sustainable society through prudent utilization of nature to address these pressing issues.

This concept book delineates our company's history of coexistence with nature, our distinctive GI concept, the unique features of our solutions, the value we bring, and showcases examples of our initiatives. Our envisioned GI solutions are multipurpose, aiming to concurrently address at least two of the five facets of nature's impact: environment, economy, society, disaster prevention/mitigation, and health. Through GI, we endeavor to illustrate the value of our efforts in crafting vibrant cities that integrate and capitalize on the benefits of nature.

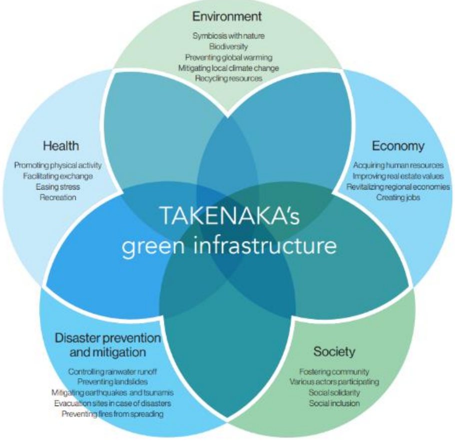

Fig.6.1 5 effects of TAKENAKA's GI described in the Green Infrastructure Concept Book

6.2.2 Green-space planning support technology using birds as indicators

The green space planning support technology, utilizing birds as indicators of urban biodiversity$^{6.1),6.2)}$, focuses on modeling the occurrence probability of each target species based on bird habitat data. This approach aids in the selection of appropriate target species and the creation of environments conducive to their preferences$^{6.3),6.4)}$. The workflow begins with the identification of the core green space, which is a large-scale green space that is a source of living organisms, sourced from multispectral satellite images to determine vegetation cover (Fig. 6.2). Subsequently, our company's database and literature are consulted to understand the local avifauna. The occurrence probability of each species is estimated using explanatory variables such as tree and shrub layer cover within the project area, as well as the surrounding vegetation. For example, Fig. 6.3 shows the relationship between the occurrence probability of the black-faced bunting and vegetation cover of the shrub layer. Subsequently, the target species is selected based on this analysis. Once the species are identified, landscapes are crafted, incorporating tree species favored by the target birds.

This method has been implemented successfully in various locations, including the Shinkashiwa Clinic, With Harajuku, Yoyogi Sangubashi Terrace, and Takenaka Ikueikai Student Dormitory. Furthermore, ongoing monitoring at the SHI-RA-BE forest within the Takenaka R&D Institute has revealed a remarkable success rate, with nearly 90% of the target species arriving after implementation.

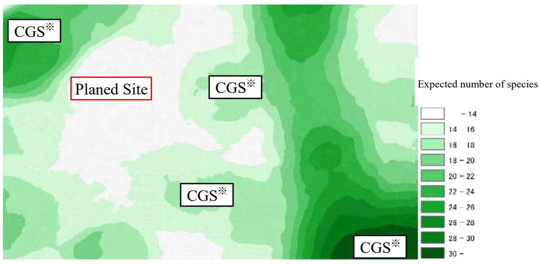

Fig.6.2 A potential map of bird habitat

※CGS:Core green space

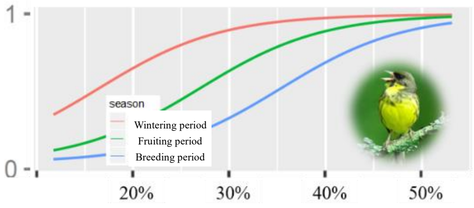

Fig.6.3 Relationship between probability of occurrence of Black-faced Bunting and shrub cover

6.3 Environmental Simulation Technologies

In Section 6.3, we unveil environmental simulation technologies tailored for landscape planning. Assessing the wind and thermal conditions of outdoor urban spaces is pivotal for designing safe and comfortable environments. Our suite includes highly precise wind and thermal environment analysis technologies capable of evaluating both urban and architectural scales, deployed across numerous projects. A new frontier in our environmental simulation endeavors is the development of a tree-placement optimization tool. This tool concurrently evaluates multiple environmental factors such as light, temperature, plant growth, and green shade effects in green-space planning, marking the inception of its application.

6.3.1 Wind / thermal environment analysis technology

Effective thermal environment design necessitates considerations across urban and architectural scales. This entails implementing measures to mitigate the atmospheric heat load, thus ameliorating the heat island effect and fostering spaces that offer comfort and safety. Leveraging Building Information Modeling (BIM) and Geographic Information System (GIS) data, our technology meticulously reproduces building shapes, constituent materials, and tree-placement details. It then conducts precise analyses of wind and thermal environments, spanning from individual buildings to city-block scales. This capability empowers us to verify the efficacy of building wind and heat island mitigation strategies and evaluate thermal comfort.[6.5] Fig. 6.4 illustrates an example of the enhancement of the thermal environment within a city block experiencing elevated temperatures during summer. Before the improvements the site (inside the red frame in the figure) experienced poor ventilation and heightened temperatures due to the densely packed buildings. Proposed interventions included refining building shapes, establishing plazas to enhance ventilation, introducing green shade with tall trees, and modifying ground surfaces with water-retaining pavement and grass. After the improvements, enhanced ventilation in the plaza and surrounding sidewalks, as indicated by arrows in the figure denoting wind direction and speed, mitigates temperature accumulation. The temperature distribution on both ground and building surfaces (lower right figure) illustrates how greening and ground surface modifications effectively mitigate temperature increases induced by solar radiation. The visualization of wind flow and temperature distribution provides quantitative insights into the efficacy of these interventions, demonstrating how greening and ground surface modifications curtail temperature escalations induced by solar radiation.

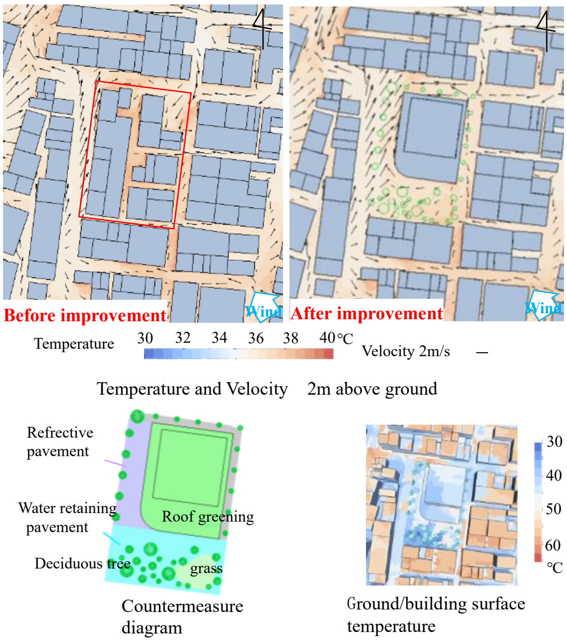

Fig. 6.4 Analysis of thermal environment around buildings

6.3.2 Optimization of tree placement

The integration of trees in green spaces is crucial owing to their multifaceted benefits, including heat, light, and wind regulation, as well as their aesthetic contributions to landscapes. However, the cost associated with planting and maintaining trees underscores the need to strategically arrange them to maximize their impact while minimizing their numbers. To address this challenge, our company has developed a tree-placement optimization tool for landscape design, as depicted in Fig. 6.5, which leverages environmental simulation and optimization algorithms. We are actively expanding its application across various projects.

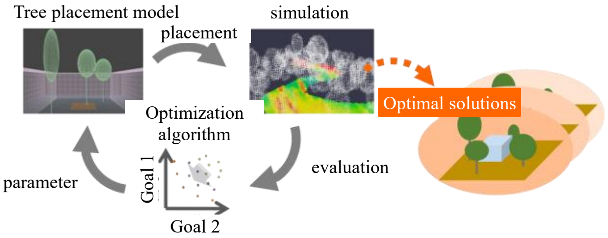

Fig. 6.5 Tree arrangement optimization flow

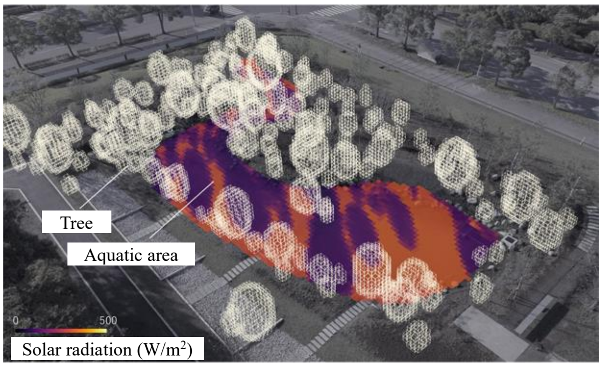

Fig. 6.6 Tree arrangement optimization based on solar radiation in SHI-RA-BE forest

This technology was employed as an environmental design support tool in the landscape planning of the SHI-RA-BE forest. This forest serves as a research hub for green infrastructure and natural coexistence at the Takenaka R&D Institute. During the renovation of the institute, particular emphasis was placed on maintaining an optimal growth environment, including water temperature and solar radiation, for aquatic organisms around ecological ponds. Our approach involved devising tree-placement strategies to regulate solar radiation into the ponds throughout the year. During the hot summer months, trees were strategically positioned to reduce solar radiation, preventing a rise in pond water temperature. Conversely, deciduous trees were strategically placed to increase solar radiation into the ponds during the cold winter months. Through meticulous optimization, exemplified in Fig. 6.6, we identified optimal tree-placement configurations to guide the final design plan. After the completion of construction, a comprehensive follow-up biodiversity survey of the aquatic area was conducted. The survey revealed thriving populations of rare aquatic plant species, demonstrating the efficacy of our design interventions in supporting biodiversity6.6).

6.4 Countermeasure Technologies

In Section 6.4, we introduce our company's innovative technology designed to address social issues by harnessing nature's diverse functions. With the frequency and intensity of torrential rains on the rise due to climate change, there is a pressing need to bolster rainwater management measures, particularly in urban settings. To meet this challenge, we have developed rainwater control and road-surface greening technologies, tapping into natural functionalities, and have commenced their implementation in various projects. Additionally, we have also developed a thin wall greening technology that addresses previous implementation challenges, thereby expanding the scope of urban greening initiatives. Moreover, we are actively engaged in developing technologies for regenerating grasslands using endemic species, responding to the rapid decline of these landscapes—iconic features of the Japanese satoyama—due to evolving land use practices since 1960.

6.4.1 Rainwater countermeasures (rainscape)

Given the rise in frequency of torrential rains, it is imperative for local governments to integrate rainwater storage and infiltration features into green areas and open spaces. For instance, the Setagaya Ward Heavy Rain Countermeasures Action Plan revised in 2020 aims to reduce runoff by at least 10 mm/h through watershed measures, including green infrastructure. There is also a concerted effort to implement rainwater storage and infiltration methods that not only serve as heavy rain facilities but also function as green spaces during normal conditions, exemplified by rain gardens that blend green belts with rainwater storage and infiltration functions.

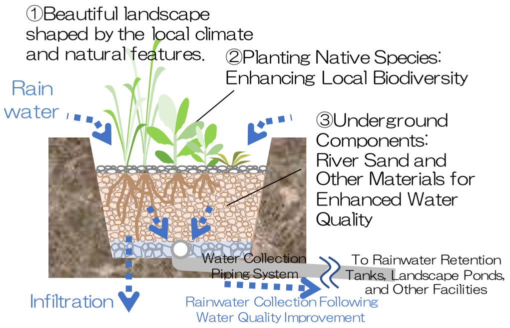

Fig.6.7 Cross-sectional composition of Rainscape

In response to these demands, our company embarked on the development of rainscapes in 2017 (Fig. 6.7, Photo 6.1). Rainscapes serve as green infrastructure, enhancing landscapes during regular periods while offering crucial benefits such as mitigating runoff into sewers and rivers during heavy rains and reducing pollution loads from combined sewer overflow. At the rainscape installed at the SHI-RA-BE forest within the Takenaka R&D Institute, ongoing monitoring of rainwater infiltration capacity is underway to establish effective maintenance and management protocols during its operation6.4). Notably, the maximum amount of rainfall till date occurred during the heavy rains in Chiba Prefecture caused by Typhoon No. 21 in October 2019, when there was 219 mm of rainfall over the course of 10 h, a quantity equivalent to the total amount that occurs during October in a normal year. During this event, the SHI-RA-BE forest demonstrated remarkable resilience by storing and infiltrating 236 m^3 of rainwater, which is equivalent to approximately 43% of the total rainfall in the catchment area during 10 h. Furthermore, this technology has been successfully implemented in projects such as the Shinkashiwa Clinic, Shinsuna Hydrogen Station, and the construction of the front gate of the Denso Headquarters, with its adoption increasing across Japan. Looking ahead, the application of this technology is poised to become an integral component of water resource conservation and rainwater management initiatives in projects pursuing certifications such as Leadership in Energy and Environmental Design (LEED) for environmentally friendly buildings developed and operated by the United States Green Building Council (USGBC)) and Sustainable SITES Initiative (SITES) for evaluating sustainable landscapes administered by Green Business Certification Inc., signaling a promising step towards sustainable landscapes.

6.4.2 Road-surface greening (Honeycomb Green)

Fig.6.8 Composition of developed products

Photo 6.2 Lawn, soil, and protection units

In recent years, the escalating risks associated with climate change have led to an increased demand for strategies to mitigate rainwater runoff and counteract the urban-heat-island effect. Our company has responded to this pressing need by focusing on road greening technologies[6.7], recognized as a potent remedy to these challenges. We have developed “Honeycomb Green,” a groundbreaking solution aimed at enabling the greening of grass in parking lots and roads, a task previously deemed formidable. This innovative technology employs a newly devised honeycomb-shaped lawn protection material (Fig. 6.8), meticulously safeguarding roots and stems against damage, even under considerable trampling pressure. Notably, it furnishes a verdant lawn surface that accommodates effortless mobility for wheelchair users, strollers, children, and those in high-heeled shoes. Furthermore, by seamlessly integrating the lawn, soil, and protective material into a unified structure (Photo 6.1) and implementing a unit-based construction approach, we have unlocked a myriad of advantages absent in conventional techniques. These include significantly reduced construction and delivery times, obviating the need for restricted entry periods during curing, and streamlining repair and replacement procedures, thereby driving down costs. Widely adopted across Japan, this technology garners favor for its user-friendly nature, aesthetic enhancement of landscapes, and promising long-term environmental benefits.

6.4.3 Wall greening (Vertical Forest)

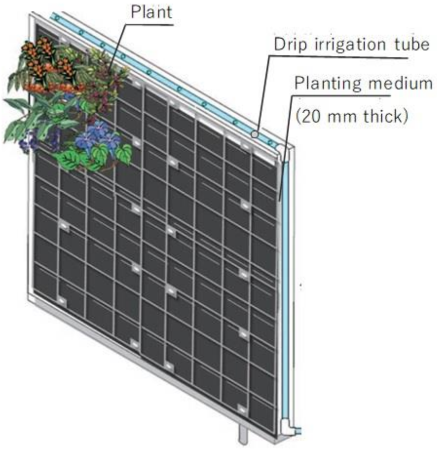

Fig. 6.9 Composition of the developed wall greening technology

A primary hurdle encountered in the development of greening technology is the amplified structural strain exerted on buildings by planting bases. Traditional greening methods necessitate an underground planting base commensurate with the size of the aboveground vegetation. Even for modestly sized trees spanning 1–2 meters, the requisite planting base thickness extends to 300 mm, resulting in a burdensome load of 240 kg/m^2, posing significant challenges to buildings. Consequently, achieving lush greenery with trees in building greening endeavors is a formidable task.

Addressing this challenge, the “Vertical Forest” emerges as a groundbreaking wall greening technology, featuring a thin layer of planting conducive to tree cultivation. This innovative approach entails installing a slender 20-mm planting base along the wall, supplemented by a drip irrigation system positioned atop the base to administer water as per the needs of plants. The result is a lightweight greening solution (50 kg/m^2) that fosters the healthy growth of trees, even with a thin foundation[6.8] (Fig. 6.9). Over the course of a decade, the Takenaka R&D Institute has rigorously tested specimens based on this configuration, affirming the sustainability of lush green landscapes achieved through this pioneering technology.

The incorporation of these trees in building greening initiatives has not only transformed landscapes into stunning green vistas but has also empowered us to offer building greening solutions that effectively demonstrate the multifaceted benefits of greening. This includes considerations for biodiversity and the facilitation of gardening activities.

6.4.4 Restoration of semi-natural grassland


Photo 6.3 Test area


Photo 6.4 Grassland plants identified in the test area （Left: *Dianthus superbus var. longicalycinus*, Right：*Patrinia scabiosifolia*）

Grasslands, which are one of the representative landscapes of satoyama, have faced significant decline since the 1960s due to shifts in land use, emerging as a pressing social concern regarding conservation and restoration. Our company has directed its attention toward a method known as hay transfer, a longstanding practice in Europe aimed at expanding pastures. This technique involves utilizing grass clippings generated during grassland maintenance to enrich areas earmarked for afforestation, with the objective of augmenting grasslands with similar species compositions[6.9)]. To this end, we conducted a demonstration test at the Takenaka R&D Institute (Photo 6.3), employing grass clippings sourced from a nearby pristine grassland as a greening material. Through varied construction methods and soil conditions, coupled with diverse approaches to grass clipping input, we scrutinized their impact on species composition within established grassland landscapes and the rate of green cover expansion. Vegetation surveys across all 10 test conditions revealed the presence of grassland flora such as *Dianthus superbus* var. *longicalycinus*, *Patrinia scabiosifolia*, *Sanguisorba officinalis*, and *Geranium krameria* (Photo 6.4). Subsequently, we identified the most effective method for restoring highly natural grasslands based on the diversity and abundance of grassland plant species, as well as the balance between exotic and native species. These findings have since been integrated into various nationwide projects, advocating for green space creation that prioritizes biodiversity through the establishment of grassland landscapes and the proliferation of grassland plant species[6.4)].

6.5 Operation Support Technologies

In Section 6.5, we explore initiatives aimed at incorporating natural elements into office spaces both indoors and outdoors, fostering their utilization by office workers while cultivating a sense of rejuvenation and connection with nature. This endeavor is geared toward enhancing work productivity and fostering serendipitous interactions. We introduce biophilic design and Sotocomi as integral technologies supporting our operational efforts.

6.5.1 Biophilic design


Photo 6.5 Example of indoor green space

Biophilic design revolves around the premise that humans possess an inherent inclination to connect with nature, known as biophilia[6.10)], and endeavors to fashion spaces that offer a sense of comfort by integrating natural elements. This approach encompasses elements such as light, wind, water, as well as natural building materials such as wood, and architectural designs inspired by nature’s motifs. Notably, the incorporation of plants both indoors and outdoors has garnered considerable attention within biophilic design. Recent advancements in greening technologies have facilitated the creation of meticulously crafted indoor green havens utilizing plants tolerant to low light conditions (Photo 6.5), along with the establishment of lush green landscapes on exterior building surfaces through cutting-edge greening techniques. When implementing biophilic design spaces, meticulous planning is vital, involving considerations such as plant selection and greening methodologies to ensure robust plant growth, utilization plans that optimize green space usage, and comprehensive operational strategies for effective implementation and ongoing enhancement.

The provision of such green spaces to users has been shown to elevate user satisfaction and subjective efficacy, including productivity[6.11)]. Furthermore, indoor and outdoor green spaces serve as aesthetically pleasing landscapes as well as platforms for horticultural therapy. Active involvement in activities such as gardening, encompassing planting, tending, and utilizing plants within green spaces, fosters not just physical and mental well-being but also enriches social health.

To explore the potential of biophilic design further, we engaged employees in gardening activities, such as creating swags, over a three-month period using plants cultivated in the green space of the Takenaka R&D Institute. This initiative sought to assess the impact of proactive involvement in biophilic design on enhancing value. The results demonstrated the potential of gardening activities to enhance physical and mental well-being, as well as social health, by fostering interactions among participants (Fig. 6.10) 6.12).

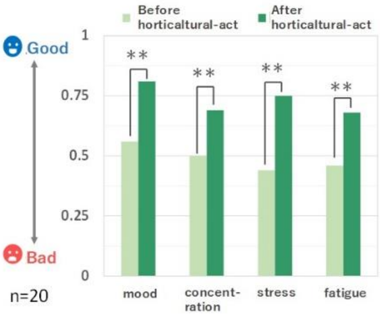

Fig.6.10 Effects of horticultural activity experience on wellness condition improvement

6.5.2 Sotocomi

Promoting the utilization of outdoor spaces necessitates not only concrete developments in planning and upkeep, as exemplified by biophilic design, but also intangible factors, such as fostering a culture that encourages people to incorporate outdoor activities into their daily lives, whether for work or leisure. Termed "Sotocomi" by our company, this intangible solution broadens the spectrum of outdoor space utilization. We equip users with our proprietary "Sotowork index" (Fig. 6.11), accessible through smartphones and other devices, to gauge the comfort level of outdoor spaces, thereby supporting work-lifestyles that incorporate outdoor environments. This index spans six levels, derived from real-time data sourced from composite weather sensors, encompassing variables such as temperature, humidity, solar radiation, and wind speed.

In a Sotocomi demonstration test, we established an outdoor workplace (Photo 6.6) equipped with heat environment mitigation measures at the Crystal Tower office building within the Osaka Business Park. Here, we assessed the practicality of employing the Sotowork index and explored the advantages of outdoor space utilization6.13). By informing users of the outdoor workplace's Sotowork index, seat availability, and ambient liveliness level via smartphones, we monitored shifts in usage frequency and gathered subjective evaluations. Additionally, through human trials, we verified that outdoor workplaces bolstered the intellectual productivity of users.

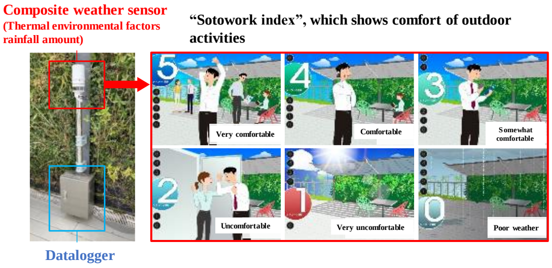

Fig. 6.11 Sotowork-index calculation and display examples

Photo 6.6 Example of Sotocomi implementation in Osaka Business Park

6.6 Examples of Application

Each of the aforementioned technologies can be seamlessly integrated into various project phases—from planning and design to construction, management, and operation—tailored to the unique characteristics of each endeavor, thereby enriching the allure of designs. Below, we present two illustrative examples.

6.6.1 With Harajuku[6.14]

With Harajuku is a commercial complex situated in front of Harajuku Station on the JR Yamanote Line, overlooking the Meiji Shrine Forest, and was finalized in 2020. The project’s vision was to craft a fresh thoroughfare featuring an outdoor terrace recessed alongside a pathway, resonant with the distinct “street culture” characterizing Omotesando, Takeshita Dori, and Ura-Harajuku, while leveraging the varied elevations of the site. Additionally, it aimed to revive the historic name of the vicinity surrounding the planned area, Mt. Genji, as depicted on ancient maps. To achieve this, we implemented planting strategies mindful of the local ecosystem spanning the Meiji Shrine Forest, Omotesando, and Ura-Harajuku regions, employed green-space planning technology utilizing avian indicators, evaluated wind conditions for passages traversing the facility, and integrated wall greening featuring indigenous species, including woody plants (Vertical Forest), to realize a terrace and low-rise rooftop adorned with greenery mimicking natural topography (Photo 6.7).

Photo 6.7 Bird’s eye view of Genji-Yama

The prominent Mt. Genji will serve as a landmark bridging the Harajuku skyline and the Meiji Shrine Forest. Simultaneously, the public pedestrian space linking the station front with Ura-Harajuku will enhance walkability in the area, fostering a new influx of visitors and contributing to the sustainable enhancement of the city’s value in the long run (Photo 6.8).

Photo 6.8 Outdoor terrace with city view

6.6.2 Shinkashiwa Clinic[6.15]

Shinkashiwa Clinic, a 120-bed dialysis facility and its adjacent amenities, is situated on the outskirts of Kashiwa City, Chiba Prefecture. The overarching concept revolves around creating a “clinic where patients can immerse in a forest bath” during their routine dialysis sessions to cleanse both the body and mind. Comprising a clinic housing a wooden dialysis unit and a spacious, open-framed structure affording panoramic views of the surroundings (Phase 1, 2016), a garden designed for exercise therapy in renal rehabilitation (Phase 2, 2017), and a diabetes treatment center addressing one of the leading causes of kidney disease (Phase 3, 2020) near the station, it forms a “medical care town fostering forest-bathing experiences” (Photo 6.9).

Photo 6.9 Aerial photograph

The medical care town development initiative, realized over three phases spanning 6 years, integrated various strategies such as green-space planning utilizing avian indicators, rainscape technology (rainwater storage and infiltration, Photo 6.10), establishment of a health promenade, and attainment of green-space certification (Social and Environmental Green Evaluation System [SEGES] Raising Green). These efforts transformed the urban landscape into a verdant enclave, contributed to talent retention for clinics and enhanced the quality of life for patients, thereby delivering value to stakeholders, including business proprietors, clinic personnel, patients, and local residents.

Photo 6.10 Rainscape and Garden

6.7 Conclusion of this Section

As highlighted earlier, the focus of companies promoting land use that fosters biodiversity conservation has evolved from merely a social endeavor to a critical management concern, alongside decarbonization. There has been a growing societal demand for emphasizing nature-centric land use practices. This chapter outlines our advancements in various technological fronts, such as planning, environmental simulation, countermeasures, and operational support, that support landscape design. We also illustrate how these technologies have been applied in architectural projects. Moving forward, we are committed to further developing and implementing technologies that support such landscape designs. Our goal is to harness the multifaceted benefits of nature within urban and built environments to address complex urban challenges comprehensively, contributing to the realization of a sustainable society.

References

6.1) Savard, J. P. L., Clergeau, P., & Mennechez, G. Biodiversity concepts and urban ecosystems. Landscape and Urban Planning:48(3-4), 131-142, 2000.

6.2) Simberloff. Flagships, umbrellas, and keystones is single-species management passe in the landscape era? Biological Conservation 83: 247-257, 1998.

6.3) Kitano, M., Fukaya, K.: “Green space planning technologies based on urban bird habitat model”, Journal of JCMA, Vol. 68(2), 89–94, 2016.

6.4) Kitano, M., Mukai, K., Tsuchio, T., Nishida, M., Suzuki, K., Hayashi, N., and Shimono, A.: “Creation and research utilization of SHI-RA-BE forest as green infrastructure”, Takenaka Technical Research Report, No. 79, 2023

6.5) Tsuchiya, N., and Ando, K.: “Thermal environment simulation for designing comfortable outdoor space around buildings”, Proceedings of the Conference on Computational Engineering and Science, No. 19, 2014.

6.6) Fujiwara, K., Miwa, T., Miyata, H., Suzuki, K., and Asawa, T.: “Research on optimizing tree placement for landscape design, Part 3: Examples of use in improving growing environment for aquatic organisms in biotopes”, Summaries of Technical Papers of the Annual Meeting of the Architectural Institute of Japan, pp. 2441–2442, September 2020.

6.7) Sakuma, M., Kojima, M., and Misaka, I.: “A study on green wall surface planting”, Summaries of Technical Papers of the Annual Meeting of the Architectural Institute of Japan, pp. 1029–1030, 2008.

6.8) Ito, K., and Ito, M. (2020). Utilizing the Power of Lawns to Restore Town Health: Science of Grass Parking, Osaka: Osaka Metropolitan University Press

6.9) Valko, O., Radai, Z., and Deak, B.: Hay transfer is a nature-based and sustainable solution for restoring grassland biodiversity. Journal of Environmental Management 311, 114816, 2022.

6.10) Kojima, M., Hanazato, M., Ishikawa, A., and Iwasaki, Y.: “Actual usage and the key factors influencing attitudes toward the use of common space incorporating biophilic design in an office”, Journal of the Japanese Society of Revegetation Technology, 47(1), pp. 129–134, 2021.

6.11) Edward O. Wilson. Biophilia. Harvard University Press. (1984.)

6.12) Kojima, M., Hanazato, M., and Iwasaki, Y.: Verification of improvements in work engagement, well-being, and social health of employees through gardening activities using office plants. Journal of Japan Revegetation Engineering Society 48(1), pp. 80–85, 2022.

6.13) Ando, K., Sakamoto, Y., Kawai, T., and nine others: “Divergent community space utilizing the ICT”, Summaries of Technical Papers of the Annual Meeting of the Architectural Institute of Japan, pp. 14–15, September 2015.

6.14) Second Green Infrastructure Award Excellence Award (2022), Good Design Award (2021), 20th Rooftop/Wall Greening Contest Minister of the Environment Award (2021), etc.

6.15) Good Design Award (2017, 2022), Medical Welfare Architecture Award 2017 (2017), etc.

7 Conclusion

Masashi Yamamoto*1

In this special feature, we highlight timber structure design technologies, methods that enhance the aesthetic appeal of concrete, 3D printing technologies that broaden design versatility, and technologies aimed at supporting façade and landscape design as examples of innovations fostering the creation of attractive designs. Many technologies developed by the Takenaka R&D Institute are intended to aid in bringing captivating designs to fruition. Through these advancements, it is our aspiration that the structures and landscapes offered by Takenaka Corporation are perceived as appealing by a diverse array of stakeholders, including owners and users, fostering a sense of attachment and pride in their possession.

With the spread of the COVID-19 pandemic in recent years, there has been a significant shift from physical to virtual spaces. Concurrently, the value of physical spaces has been reassessed, sparking a debate on the judicious use of both physical and virtual spaces. Furthermore, it is essential to address changes in work styles and the workforce, influenced by declining birth rates and an aging population, alongside concepts of work-life balance. Environmental concerns, such as reducing greenhouse gas emissions and preserving biodiversity, also demand attention. As the external environment evolves rapidly, the criteria for compelling design adapt accordingly. Moreover, given the long lifespan of buildings—and the desire to extend it further—future-focused strategies are essential..

The construction industry significantly influences society and the environment, and the endeavors mentioned above carry great expectations and responsibilities. At the Takenaka R&D Institute, we are committed to advancing technological development to sustain the delivery of appealing designs amidst societal shifts, leveraging state-of-the-art technologies such as robotics, artificial intelligence, and the metaverse, which have seen rapid advancement in recent years.

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