Subjects and Future Development to Realize the Place where Everyone Can Live Flexibly by 2050

Mineko Imanishi*1

Summary

This article presents an ideal form of architecture in the future and technical issues against its realization from the report for a new Moonshot goal, on which the authors worked the last year. As a current issue, buildings have a long change cycle discrepant with the updates of society, individual needs, and advanced technologies. Meanwhile, buildings would become more flexible and variable to meet individual needs by incorporating information technology. It can hence be proposed as the vision to aim for technological development. The realization will require investment in various domains; such as technologies for physical variability and human-building interface design.

Keywords: future building, digital twin, agile building, Common Ground

1 Introduction

1.1 Foreseeing architecture in 2050

When engaging in technological development that supports the future of manufacturing, it is imperative to have a long-term vision that focuses on a society in parallel with the more immediate development that confronts the challenges we face today. Promoting technologies beneficial to society requires the developer to envision an ideal future actively, share that vision with stakeholders, and lead society toward that goal.

In 2021, we proposed a new goal to be included in the "Moonshot Research and Development Program," led by the Cabinet Office[1)]. As part of the program, "the national government sets ambitious targets that attract people to address important social issues and promotes challenging research and development"[2)]. This includes drawing and sharing an ideal vision to drive technological development. Proposals for these new goals were made through an open tender and ranged from engineering issues—such as the decentralization of energy resources and weather control—to social issues, such as marine resources and diversity. Our proposal was on the ideal form of social infrastructure that integrates towns, buildings, and information infrastructure[3)]. Despite not being adopted, our proposal was among the final plans and ranked fourth among 129 proposals.

In this paper, we will reconstruct and introduce the form of architecture preferred in the future from among the towns and architecture of 2050 that we considered and proposed as our new Moonshot goal.

1.2 Social background surrounding architecture

As beings with mass, we live in a physical space (real space). The building space in which we live today has been constructed with meticulous planning. Physical architecture, which involves large buildings, is not easy to change and is generally used for decades after completion. Meanwhile, in the wake of the rapid evolution of information technology in recent years, the latest software continues to be available through the Internet. Even in the case of hardware, equipment utilizing information technology such as IoT is expected to become obsolete within a few years. Additionally, economic activities and the space required by individuals are inherently subject to change according to social conditions and individual life stages, and fixed physical spaces cannot cope with these changes, making them inconvenient for use over time. Furthermore, the risk of potential disaster that drives a sudden change in our current lifestyle, such as the COVID-19 pandemic, has also been identified as an issue for fixed physical spaces.

The manner in which we use and choose our space is also expected to change. By 2050, the population of approximately half of all residential areas in Japan is expected to decline by over 50%[4)], except in some urban areas where the population is increasing. Additionally, the issue of vacant houses is becoming increasingly grave[5)]. Meanwhile, changes in values regarding work–life balance, which have been symbolized by work-style reform[6)], the full-scale implementation of which began in 2019, as well as the expansion of remote work in light of COVID-19, have driven people away from expensive and cramped spaces in city centers to

*1 Senior Researcher, Research & Development Institute, Doctor in Human Sciences

rural areas. It can be said that remote work from home or shared space, online shopping, and games have renewed the distance and meaning of conventional spaces.

Our lives are at a turning point both socially and technologically, and it is time to reconsider our future lives. In a rapidly-changing society, realizing a life where everyone can meet their needs requires flexible spaces that consider the needs and emotions of a diverse range of people.

2 Proposal of flex-infrastructure

2.1 Moonshot millennia

As of 2020, seven research programs have been set and implemented for Moonshot research and development, with the Cabinet Office planning to add one or two new programs in response to changes in the social situation triggered by the pandemic. This new Moonshot program, implemented in 2021, was called the Millennia Program. As the name “Millennia” suggests, the program differs from the existing seven research programs—it encourages young researchers to devise with their ideas, adopting an open-call format. As of the end of 2020, an open call for participation in the program received 129 proposals from various institutions, including research institutions and private companies. Among these proposals, 21 were selected, and the teams were given an initial period of six months, starting from January 2021, to analyze and plan their programs. In these sessions, the teams were required to envision a society they wanted to realize in 2050, organize current technologies, use this as a basis for back-casting the technologies that will require research and development in the future, and discuss those technologies. The brainstorming content is submitted as presentations and reports at a symposium; based on this, two new programs to be added were decided after evaluation by experts.

2.2 Flex-Infrastructure

Our team set the vision of a city in 2050 that enjoys diversity, is resilient to disasters, and can flexibly respond to technological innovation and social change. We characterized it as “Flex-Infrastructure”—an autonomous evolutionary platform that links the hardware necessary for its realization (e.g., buildings) and the software and sensors that control it. Among the 21 teams, only our team is led by a researcher from a private company. The team comprises members who encompass the two areas of architecture/cities and information—the Takenaka Corporation, which includes the author (the team leader), and the University of Electro-Communications, Avanti R&D Inc., TIS Inc., KDDI Research Institute, Inc., and MT-Planning, Ltd. As part of the initiative, we examined technical issues from the professional perspective of each member through questionnaire surveys to obtain a broad overview of diverse values, advanced case surveys in Japan and overseas, and discussions at online symposiums.

The 2050 we envisioned was a society in which people could live in places they liked, owing to spaces where the environment could be changed flexibly and promptly to meet individual and societal needs. This is achieved through highly flexible, easy-to-change building spaces, whose environment can be adjusted according to the situation and where even the shape can be changed dynamically. It is realized by an open information infrastructure that can grasp the “current” needs of people and society. We aim for this type of human-centric, highly flexible space and information infrastructure (Fig. 1).

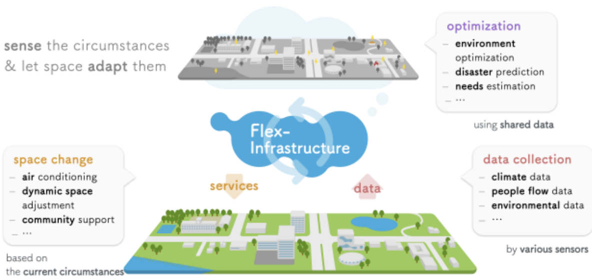

Fig.1 Concept diagram of Flex-Infrastructure

2.3 Four contributing perspectives

Flex-Infrastructure aims to enrich people’s lives from the following four perspectives.

- Diverse: people in diverse situations can be happy
- Selectable: people can select their lifestyle
- Customizable: people can change a space according to their liking
- Stable: lifestyles are not threatened by disasters

This can be said to be a state in which diversity is recognized as is, and autonomy is given to users. The mass production of modern industry and the development of mass communication have enriched our lives. However, concurrently, it has deprived people of their independence and fit them into given frames. Human beings are more diverse, and rather than fitting ourselves into a frame (such as architecture), the frame should conform to us. Meanwhile, this requires users' independence. "I want to do that" is a desire that arises from the user itself, and individual needs can be obtained by asking for them. Modifying one's own place independently generates a sense of self-efficacy, and attachment is born between such a place and its user. Nevertheless, a life in which we actively select everything is difficult and exhausting. Is it possible to use the power of technology to realize a friendly space that meets such needs in an autonomous and flexible manner? Additionally, the joy of daily life can only be obtained with a sense of security that life is not threatened by disasters and threats.

Essentially, these four perspectives are what we should pursue in society, and we defined that technological development should contribute to these four elements. We also believe that achieving this would require flexibility in building infrastructure.

2.4 Social significance

The purpose of this proposal is to improve the "place" of work and life in which everyone is involved. A society that allows diversity and accepts lifestyle changes will be universally desired in the future as well. In a disaster-prone country like Japan, everyone wishes for a society resilient to disasters and where people can live peacefully.

Innovative evolution of the physical space of buildings and towns closely related to our lives improves the convenience of life. Being able to find a "place you want to live" and customize it "to your liking" creates attachment toward that place and fosters a sense of happiness and well-being. Enhancing functionality with advanced technological investment rather than mere nostalgia can achieve a human-centric "place" that contributes to people's happiness.

3 Scene to aim for in 2050

In the Moonshot Millennia initiative, in parallel with the technical survey, we aimed to share a vision that draws a specific "scene" when the technological evolution we are aiming for is realized. What will our lives in flexible spaces look like in 2050, approximately 30 years from now?

3.1 Building composed of variable spaces to meet diverse lifestyle needs

A society where flexible buildings are widespread will have spaces that adapt to the situation and optimize the environment for people.

Buildings and rooms will be managed by software, and personal data, such as users' vital data, behavior, and preferences, will be combined with external data, such as weather and fashion, which will prepare an environment for users' "current" needs. For example, when the weather is pleasant, and the occupants appear to be in good physical condition, the windows will automatically open to let in outside light and breeze to wake them up. It would also be nice to have the indoor table automatically move to the terrace so that they can have coffee there. At this time, behind the scenes, the software performs advanced simulations that match the location of the user, shape and materials of the room, climate, etc., obtained by sensing, derives the optimal room environment, and controls the air conditioning environment (Fig. 2).

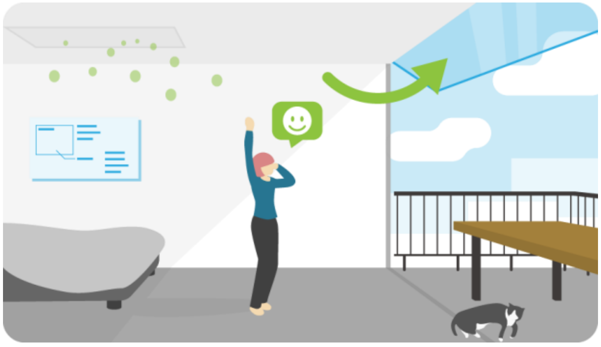

Fig.2 Space that transforms itself according to the circumstances

If the software has abundant information about space and people, and the variability of the physical space is significant, it will be easy to provide places that match people's abilities. For a wheelchair user, the provision of a flat and sufficient movement area, and to people with visual impairment, the provision of "current" spatial information to the device that the user usually has, enables them to move comfortably even in a place where they have never been before.

The highly variable room space can also provide different environments depending on usage. During meetings at a restaurant or office, the volume of each private room can be changed by moving the partition according to the number of users, allowing privacy to be maintained. The flexibility to change the space according to use makes it easier to share the building and enables changes in the use of the same space depending on the time, such as using it as an office during the day and social space at night.

This space responds flexibly to lifestyle changes and work styles that alter with time. The interiors of town squares and buildings can be easily changed in a short period. This can be largely attributed to the unitization of construction, a building design that considers future changes in advance, on-demand production, and an information infrastructure that manages space and environment with 3D data. Accordingly, it becomes easy to convert the space developed as a store into a residence, change the interiors, or replace IoT equipment.

Furthermore, rather than merely revamping a building for a change in application, it is possible to use a single building for a long period utilizing cutting-edge technology while meeting users' needs. Such flexible building spaces are not limited to brand new architecture. Utilizing the building stock in each area and considering the age of newly-constructed buildings will allow for the future to have a texture that has weathered the times and expand options for design styles. For example, renovating an old Japanese-style house with excellent design and installing information equipment will enable living in a physical space fused with cyberspace, where one can enjoy the convenience of the latest technology while inheriting past history.

Individuals can have diverse lifestyles and tastes while actively choosing and working on the space considered their living space, making it possible to create an optimal space for each person. Moreover, the relationship between the space and user, which can be called a dialog, allows people to feel attachment to their living space and achieve a sense of spiritual fulfillment in their lives.

3.2 Wide variety of services through open information infrastructure and high modularity

Flexible space optimization using software requires advanced predictions and various sensing data that capture the "current" situation as a basis for making decisions. Meanwhile, a wide range of data cannot be acquired by a single company, and a form of circulation that allows the free use of numerous data acquired by multiple institutions is essential. In such a society, individuals can view and manage their data without entrusting personal data to a single company or service. Additionally, people can easily enter new businesses, such as selling new prediction and optimization data by highly integrating primary sensor data, and proposing services and software using such data (Fig. 3). Closed data/API sharing by one company or an alliance of several companies will not produce services that exceed the technologies and domains within the company. The existence of various data that can be used easily is expected to drive the development of new services considered unimaginable previously and the emergence of regional services that meet residents' needs in specific areas.

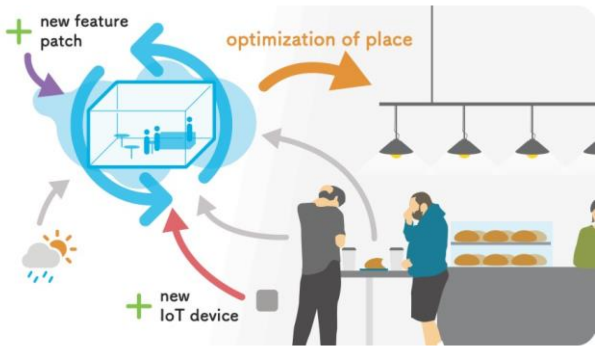

Fig.3 Autonomous evolution of services through open data use

Similarly, in the building space, preparing the connection module, which can be considered the API of the physical space, will facilitate the creation of suitable fittings and fixtures, even at an individual level, as well as the replacement of equipment across manufacturers. For example, it is currently not easy to change the key of the building entrance to a smart lock or change the light switch to one linked to IoT lighting. Even if we manage to do so after considerable effort, another electronic lock with a different concept may appear from another manufacturer within three years. Expanding the concept of modules in architecture and software to equipment and fixtures installed later in the space and with a face change cycle will increase the competitiveness between manufacturers of facilities, buildings, and IoT devices. Meanwhile, for users, it eliminates complaints such as "that newly released product cannot be used in my room," encouraging updating equipment in a physical space. With open data, people will understand the 3D specifications of the building space and the standards for expandable areas. Therefore, occurrences such as individuals selling fixture design data, adding individual customizations according to the room to which that fixture will be installed, and ordering it from an on-demand manufacturer and that person installing it in their space will become a routine occurrence.

4 Technological trends leading to flexible physical spaces

In line with our vision for 2050, we have depicted the flexibility of architecture, the physical space in which we live, and the convenience and diversity that will be achieved. This flexible physical space is achieved by transforming the building elements that constitute the space and controlling the spatial environment based on various sensing information and human needs. Additionally, there are multiple methods for transformation and control, such as fully automatic autonomous transformation using information technology and automatic transformation by human operation, as well as human modification of the environment.

Transformation of the physical space requires facilitating the construction of the space itself and moving or changing partitions or furniture and elements such as technology that transform the indoor environment by changing equipment such as video projection and electrical materials. Another method to increase flexibility is by using cyberspace. If the physical space and cyberspace can be combined to create a space where the boundaries between them cannot be experienced, cyberspace can also be integrated into our living space.

In that case, will it be possible to achieve that kind of universalization of society envisioned in the next 30 years? Or is this an absurd concept? We intend to list some of the current technologies that will lead to the future that will be the bases of the society we envision.

4.1 Customization of flexible space

Buildings are not easy to produce, as it is difficult to construct or refurbish them in a short period to meet unpredictable changes in social conditions and needs.

Unitization and modularization are being developed to simplify the production process. In recent years, there have been examples of unitized construction using containers used for transportation and the construction of high-rise buildings in an extremely short period by stacking unitized parts (e.g., a 10-story apartment built in 29 hours[7)] or a large-scale COVID-19 hospital built in 10 days[8)]).

The building frame can also be used as is, making it easier to refurbish the interiors, which must be more adaptable to changing needs. In Japan, a building that considered future unit replacement, called Metabolist architecture, was a pioneering development in the previous century but did not lead to actual unit replacement. Moreover, skeleton-infill architecture[9)] has also been devised, in which separate consideration is given to the structural framework, which emphasizes durability, and the floor plan, which requires flexibility. However, this has not become widespread since its introduction. Although it existed as a concept, the times had not caught up to it on a technical level.

A recent innovation in production is the 3D printer, which is being developed for small industrial products that use plastic material and technologies that use inorganic materials and metals that can be applied to large buildings. For example, with inorganic materials, a 3D printer has been used to fabricate a building that can be lived in by laminating mortar[10)]. For metal, there have been cases where free joints were created by 3D printing technology using metal welding and those where a movable shelter could be assembled manually by forming joint parts with a powder metal 3D printer[11)].

As an example of transformation of architectural space according to needs, in the 2000s, a countermeasure against the hollowing out of cities was introduced. Existing office buildings in urban areas with low profitability were converted into condominiums that attracted permanent residents, and related technologies were developed. In recent years, cultural resources have been used to create shared office spaces that promote innovation while preserving the decorations and fittings that remain throughout the building; the Hori Building[12)] is a representative example of this (Fig. 4).

Fig.4 A case of renovation of an office building featuring its history (Hori Building)

4.2 Dynamic transformation of physical space

Technology that dynamically changes the space can be considered a short-term space transformation, such as the change in the use of space during the day. Furthermore, achieving software control suitable to the environment requires automating the transformation.

Even in current buildings, many aspects are already variable and movable. For example, there are escalators and elevators, as well as revolving restaurants, movable bridges, and dome stadium roofs that open and close. Airplanes and passenger ships of the same scale as buildings are moving structures, and the docks that maintain them incorporate a mechanism that allows maintenance scaffolding to move and connect. Such examples show that changing massive structures is already being followed in certain areas and that it is not technically impossible. Meanwhile, there are many technical issues in terms of whether this can be carried out easily.

When turning around and looking inside the building, many fixtures can be seen. Self-propelled robots have been used in logistics warehouses, etc., in recent years, and it is technically possible to use them to move fixtures. Some international venture companies are already selling a system that transforms living spaces by automatically moving large fixtures[13] (Fig. 5).

Fig.5 Apartment with movable furniture by Ori, Inc.

4.3 Transformation of spatial environment

The use of projection mapping and high-definition monitors can be considered a qualitative transformation of the environment inside the building. E-Ink, which requires a power supply only when updating the screen and otherwise, like paper, remains without fading, has increased in scale[14]. If E-Ink is used in wallpapers, it is possible to change the pattern according to the mood of the day and issue appropriate evacuation orders in the event of a disaster. Demonstration experiments are already underway overseas to directly display information on pedestrian crossings and road signs and change them according to the traffic volume at the time of day[15].

A pioneering example of dynamic transformations of the indoor environment is EQ House[16] (Fig. 6)—an experimental building designed and constructed by Takenaka Corporation in 2019. This building senses the interior environment so that, for example, glass that used to be transparent becomes frosted upon people entering the building, or the presence of a function where the building learns that a situation is comfortable for humans when people "like" the comfortable environment using a smart watch. This can be considered an example of a concept in which a building takes care of its users and is close to them while communicating and creating mutual relationships.

Fig.6 Interior of EQ House

4.4 Connection between cyberspace and physical space

When controlling or intervening in the physical space with software, it is desirable to have a synchronized cyberspace that is a twin of the physical space to interpret the physical space as information. This concept is called a "digital twin" and has been developed in recent years. Society 5.0—the future society that Japan is aiming for[17]—also proposes "transformation to a sustainable and resilient society by integrating cyberspace and physical space." Efforts are underway to analyze sensing information collected and accumulated in cyberspace by IoT and feed it back to physical space.

In the construction field, for example, the concept of "Common Ground"[18] (Fig. 7) has been announced to promote the use of both spaces within the digital twin. The Common Ground is an area that mediates between the digital and physical spaces and bidirectionally connects these two spaces in high resolution and real time. We aim to share physical space geometry and environmental data among humans and digital agents. In 2021, the Common Ground Living Lab[19]—a demonstration experiment space—was also established.

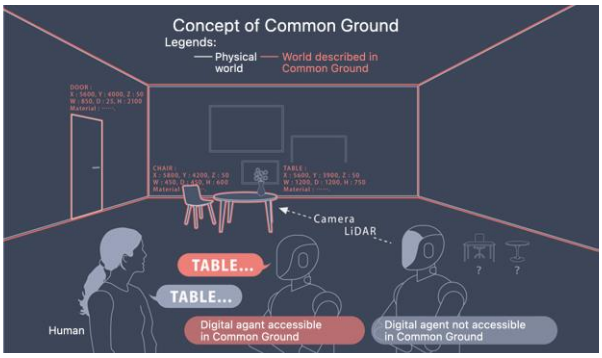

Fig.7 Concept of the Common Ground (translated) [19]

As a general technology for connecting physical space to cyberspace, virtual reality (VR) technology, which uses head-mounted displays, etc., to experience visual images immersively in cyberspace, has already begun to spread. There is also augmented reality technology that provides a visual experience in which information such as CG is superimposed on the physical space and mixed reality that reflects into cyberspace the camera images and sensing information in the physical space developed thus far. The xR technology—a generic term for these technologies—connects cyberspace and physical space and eliminates the boundary between the two spaces.

5 Technological development required for realizing flexible physical space

In Chapter 4, we listed current technologies believed to contribute to the realization of flexible physical spaces. Initially, it seems that a flexible physical space has "already been realized." Therefore, is it merely a question of waiting for cost reduction and popularization of the new technology? In fact, those that have been shown are only elemental technologies, and it cannot be said that these are the realization of the social vision raised at the beginning of this paper. What is needed from society is the integration of this technology into our daily lives and the ability for everybody to enjoy the diverse, selectable, customizable, and stable features mentioned in Section 2.3 by using them without stress to enrich their lives. Nevertheless, some technical issues must be overcome before it can be realized.

Technological challenges for widespread dissemination include cost reduction, simplification of introduction, and further developments of elemental technology for practical use in construction. However, in this section, we will describe the areas necessary for the new realm of flexible physical spaces, which is a higher-order challenge.

5.1 Realization of technology-integrated experiences

The aim is to improve experience. Integrating emerging or newly-developed elemental technologies mentioned in Section 4 and realizing the depicted social vision require designing a system that integrates elemental technologies. A satisfying experience cannot be created by connecting elemental technologies like pieces of a puzzle. For a user to transform and control the space to their liking, it is necessary to establish a system or service that facilitates customization by users if the transformation and control are manual. Further, it is imperative to select a change target and control algorithm if the transformation and control are automatic.

Consider, as an example of automatic control that uses human needs as a control trigger, the solution to the situation of "hot and uncomfortable" by transforming the space. First, how do you determine if a person is feeling hot and uncomfortable? Do you use vital data, sense the space the person is in, or determine the person's preferred settings? In another method, the person communicates through gestures or utterances. Moreover, there are several ways to address this problem: opening windows to let the breeze in or blocking the sun's rays and creating shade; operating the air conditioning equipment; suggesting a move to another place where it is not too hot. Such methods can also be combined. There are various sensing technologies, estimation algorithms from data, spatial transformation technologies for optimization, algorithms that combine them, and coordination with IoT devices and software that connects them. There may also be someone next to that person who feels cold easily. This kind of technological development requires designing the system from a broad perspective while providing feedback on the development of elemental technologies.

5.2 Building environment control user interface

Even if the space becomes flexible and can be controlled by the user, if its operability is poor and cannot be changed according to needs, it cannot be considered to have enriched people's lives. Furthermore, "comfort" during operation is essential. The interface between the user and the target of manipulation, such as an application, is mainly called a user interface (UI) in the software engineering world. Although properly designing this UI is the cornerstone of software operability, it will be necessary to consider user and building operation UIs even in buildings with high variability.

Equipment is generally operated in conjunction with a dedicated controller or smartphone app. However, today, gesture-based operations using sensing technologies and interactive operations using natural language have also been achieved. Starting from 2020, programming education became mandatory in compulsory education in Japan[20]. It is expected that future generations can give even more complicated instructions to machines in a simple manner.

At the 2021 Worldwide Developers Conference (WWDC), iPhone manufacturer Apple announced the enhancement of smart home collaboration in the next OS and the evolution of integrated experience and control that involves the integration of multiple IoT devices. The company has also established its UI guidelines and summarized design concepts for operating these facilities through Apple devices[21]. We can see the importance of securing the variability of each space and equipment and the experience design seen from the user's perspective when integrating them. Nevertheless, the current smart home led by the IT industry and equipment manufacturers is mainly limited to the operation of retrofitted IoT devices, and the discussion has not yet reached the level of the dynamic variability of the space itself.

It is difficult to present the three-dimensional space of a building on a two-dimensional screen, even regarding presenting control systems and providing feedback. For example, if information is displayed on personal devices such as smartphones and walls or in real space, multiple people can receive information in a form that can be shared intuitively. Although it can be considered a new form of interaction between buildings and users, many items are to be designed, such as the granularity of options that can be controlled and the timing of presentation. In architecture, there has been research and discussion on aspects associated with buildings, such as the ease of use of fittings, visibility of signage, and even aesthetics. Nonetheless, there is limited discussion on the operability and implementation of software and cyberspace.

New research and development are required to control the unprecedented phenomenon of the "dynamic control of space" using these rapidly advancing new technologies. The architectural field—the main subject of such research and development—must also participate.

5.3 Physical space exuded by cyberspace

As mentioned in Section 4.4, cyberspace will be an integral part of our lives in the future. Replacing some interactions in physical space with cyberspace will reduce the restrictions on individual and corporate bases and contribute to expanding the potential of base selection. However, although there has been progress in the development of devices that connect to cyberspace, communication technology by the five senses, and technology that handles physical space from cyberspace, such as the aforementioned Common Ground, there has been insufficient consideration and development of the physical space itself, which is optimal for interacting in cyberspace. Even when we interact in cyberspace, we continue to exist in the physical space. At that time, will a dedicated space like a VR game room be physically necessary for immersion, or will cyberspace be superimposed on the physical space where we live? Safety must also be considered when dealing with operations that involve vision combined with virtual images. A higher sense of immersion may be obtained by having physical space dynamically follow the state of cyberspace. It is necessary to research and demonstrate the physical preparations and equipment for conducting cyber exchanges in actual residences, offices, or large spaces such as stadiums.

6 Conclusion

In the 2021 initiative, we proposed the "realization of flexible and safe places with diverse happiness through Flex-Infrastructure driven by human, artificial, and natural intelligence" as a moonshot goal. This proposal seeks to improve the convenience of the physical space of buildings and towns where we live, redress disparities owing to the location and situation of people living in Japan, and enrich their lives.

In this paper, we introduced and discussed the technological developments from this proposal for developing flexible physical spaces. Technologies necessary to realize this vision of society are listed below based on current issues and domestic and international technological trends. First, realizing a flexible "place" requires research and development to increase the variability of building spaces, and increasing the flexibility of base selection requires developing a physical space that incorporates the convenience of cyberspace. Additionally, providing a “place” that parallels each situation requires an algorithm and UI that sense the situation and reflect it in the “place.” As diverse users, including elderly and people with disabilities, are expected, development from the perspective of universal and inclusive design is necessary.

Additionally, engineering fields such as building and communication technology and the perspectives of psychology and sociology, which connect these technologies and people, will become essential in development, such as when considering how people should choose bases, how communities should cooperate, how services should be provided that contribute to residents’ happiness and are accepted by them when such a society is realized. Furthermore, such technologies are currently not covered by the legal system, and consultation with relevant ministries and agencies on compliance with laws and regulations is necessary.

Numerous fields require research and development to realize this social vision. Each industry must work together to advance technological development toward their respective goals and foster an environment in which open data sharing and mutual use of technologies are possible without running into short-term business conservatism to create unprecedented services and achieve technologies that contribute to residents’ satisfaction.

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