Moonshot R&D MILLENNIA* Program

*Multifaceted investigation challenge for new normal initiatives program

「Research and study for Flex-Infrastructure realizing flexible and safe places with diverse happiness」

Initiative Report

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I. Concept

1. Proposed MS Goal

1.1. Proposed MS Goal title

"Realize a society where everyone can live safely and happily in flexible places by 2050"

1.2. Vision for 2050 society

We picture the year 2050 as a society in which each person can live the life they like in the place they like, thanks to spaces in which the environment can be changed to meet the needs of individuals and society in a timely and flexible manner. This is realized through highly flexible building space that is easy to modify on occasion, allowing the environment to be adjusted according to circumstances; sometimes it can even be dynamically changed in shape, and may have an open information infrastructure that can grasp the current needs of the occupants. Our aim is a human-centered, highly-flexible space and information infrastructure (hereinafter, "Flex-Infrastructure"). The objective is to enrich people's living places in four ways:

・Diverse: Can be enjoyed by people from diverse walks of life

・Selectable: Allows one to select a lifestyle

・Customizable: Can be changed into the space one desires

・Stable: No disaster-related threats to life

In this society, data can be used interchangeably without boundaries defined by corporations. This allows high-level situational inferences and applications that combine multifaceted sensing data and forecast data, and facilitates the emergence of new services, thereby enabling autonomous evolution of the information infrastructure. Advanced physical space (real space) information also increases the amount of corresponding information in cyberspace, making it easier for people to move between the two.

Flexible variability in real space combined with cyberspace interactions also allows individuals to make short-term changes their location. In a life in which you can be "where you want to be at any time," the places people choose as their location reflects not only their rational needs but also their lifestyle and preferences. This will lead to a re-examination of the distinctive regional cultures and characteristics, and increased decentralization from present urban centers to outlying towns.

Furthermore, a flexible society is resilient in the face of disaster. It can prepare spaces for damage in advance of predictable disasters, so that it is possible to reestablish life within a short period of time during emergencies.

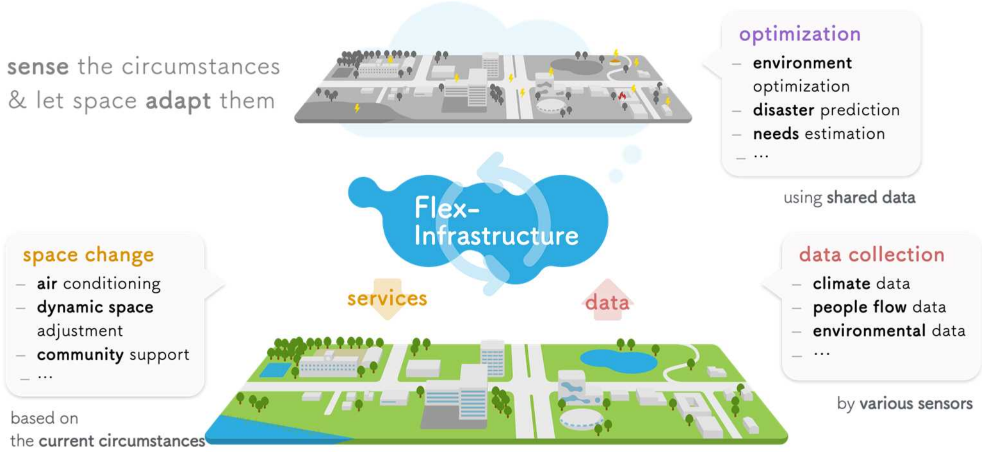

Fig. I.1 Conceptual diagram of Flex-Infrastructure

2. Targets

The following are typical examples of the scenes realized in the vision of society shown in 1.2.

2.1. Cities made up of versatile spaces that meet diverse lifestyle needs

In societies with Flex-Infrastructures, space is optimized to fit the circumstances.

By having buildings and rooms managed by software, it is possible to match personal data on users, such as vital data, behavior, and preferences, with external data on the weather and trends, to create the environment that users need “in the moment.” For example, on good weather days, windows open automatically to let in outside light and awaken the occupant of a home if they seem to be in a good mood. In the background, advanced simulations are carried out according to the occupant’s location, as well as the shape, fixtures, and climate of the room—all obtained by sensors. The optimum room environmental conditions are derived from this in order to run the air conditioner (Fig. II.2).

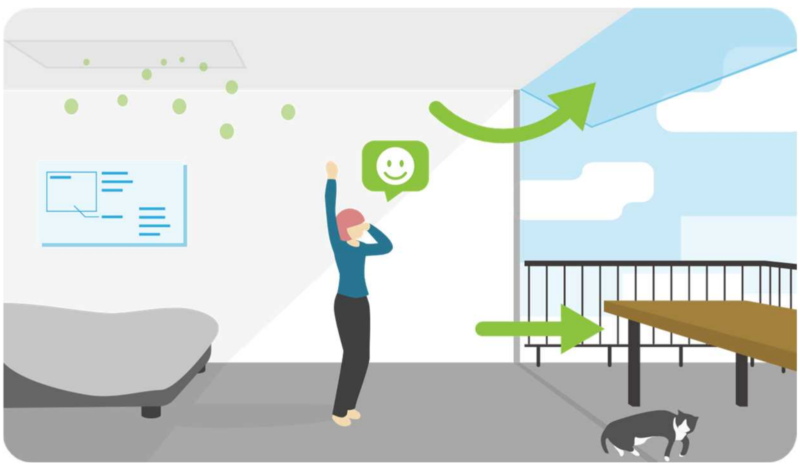
Fig. I.2 Space that transforms according to the circumstances

Versatile room spaces can also provide different environmental conditions, depending on usage. During meetings at restaurants and offices, the size of individual rooms changes according to the movement of partitions based on the number of users, allowing for privacy to be maintained. Being able to flexibly modify spaces according to their use at a given time makes sharing a building easier, and allows the repurposing of the same space at different times, such as using one as a workplace during the day and a social space at night.

If the software has plenty of space information and the range of motion in the room is wide, it is easy to provide a space that matches people's capabilities. By providing wheelchair users with sufficiently flat and maneuverable areas, and delivering "in the moment" space information to their devices if they are visually impaired, they can comfortably move around places they have never visited before all by themselves.

Such spaces also flexibly respond to lifestyles and work habits as they change with the times. Town square and building interiors can be easily altered within a short period of time. In addition to building design anticipating construction unitization and future changes, this is greatly enhanced by information infrastructure managed with 3D data, bringing together developments and spaces for on-demand production with environments. This makes it easy to repurpose spaces built for retail into dwellings, modify indoor installations, and replace IoT devices. Individuals will be able to easily upgrade their equipment and furniture parts according to their own environments.

Instead of simply renovating a building due to changes in use, long-term use of a single building satisfying user needs by fully utilizing the latest technologies will be possible. This is not just some new-fangled idea for building spaces. Capitalizing on regional inventories of historical buildings, as well as considering the aging of newly built ones, occasionally widens the options for design preferences. Individual locations satisfying diverse lifestyles and tastes, such as old private homes remolded into cyberspace-integrated spaces enjoying the latest technological benefits while maintaining their old charm, can be customized to meet any need at the individual level. Individuals are be able to proactively select and personalize their living spaces allowing optimal individualization—a relationship that may be considered a dialogue between person and space that may lead to a sense of attachment to the living space, and a sense of spiritual fulfilment in life.

Presently, smart home and smart city concepts depict some urban life involving the use of advanced information technology—something that is now starting to be realized. Although past building space dynamic variability is not mentioned in these concepts, examples of large moving structures are found in retractable stadium domes, as is the germ of simplified interior upgrades in metabolism architecture. Furthermore, it is felt that these concepts may be disseminated via commercialization, and the cost of elemental technology can be reduced through technical development. We aim to realize "spaces" like these throughout Japan by 2050, though they may be available as of 2030, appearing in the form of facilities using more diverse data than today, or highly versatile indoors implemented in advanced buildings. Thus, it may be possible to realize, at an early stage, the prediction of environments needed by users, and the preparation of indoor thermal environments using weather and personal vital data and behavior history.

2.2. Cities capable of diverse lifestyle realization—Societies easily sharing local multi-base space

In societies with highly flexible real spaces made available through Flex-Infrastructure, there are wider options for activity spaces, it is easier to modify living centers, and people have increased freedom and fluidity in choosing locations. For example, a person's preferences can be transferred and adapted to different places so they can continue their lives uninterrupted, not sacrificing any convenience while changing location. In a highly fluid society, "where you want to be" will transform with changes in an individual's life stage, job, or mood. Thus, a rich, fulfilling life can be realized if one can easily change their location or go to and from multiple locations—cyberspace included (Fig. II.3).

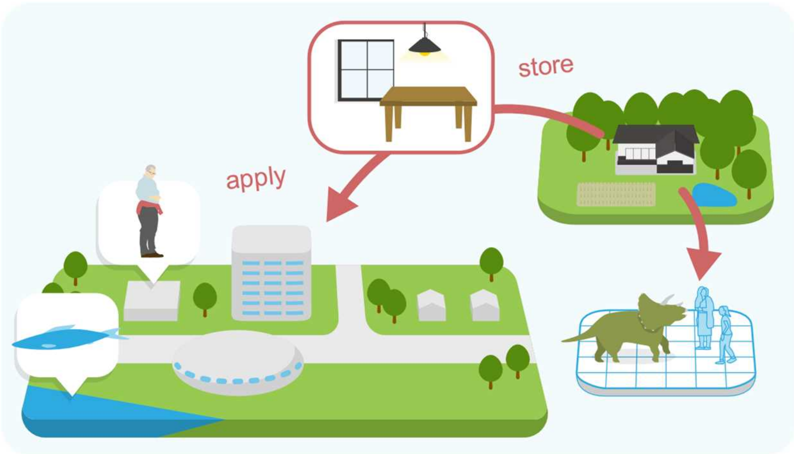

Fig. II.3 Life going around multiple bases

In this society, location options will change in meaning from today in 2021. Further developments in information and logistics will enable people at different locations in real space to interact through cyberspace to meet their needs, and may allow them to enjoy the benefits of public services, medical care, and shopping wherever they are in Japan. Real space locations will be chosen based on people one wants to see, local geographical and cultural characteristics, and "the appeal of real space locations, that is, actual towns and buildings. Despite such needs existing in 2021, linked as they are to the well-being of individuals, they have been lowered in priority due to other physical and social constraints. There may also be new ways of looking at the regions of Japan, summarizing each region's abundant individuality, which will be helpful when choosing locations.

The fact that you can now spend your time where you want to be, as you like, when you want to be there, rather than concentrated wholly within a major city, will bring more diversity into our lives, and bring diversity and vitality into our communities. Our first aim is to establish bases in 2030 where such lives may be tucked away in the corners of urban areas and in provincial towns. In addition, a new form of base selection, including cyberspace, may be starting up. The proposed 2050 Flex-Infrastructure will realize the use of such information infrastructures and the construction of highly versatile spaces, not only in certain buildings and special zones but anywhere in Japan. Capitalizing upon local characteristics of each region will lead to a society in which not only large cities benefit, but all citizens may find happiness.

2.3. Cities where people can live in peace of mind despite natural disasters

Unexpected social changes, such as intensified natural disasters and the coronavirus pandemic, can force people to live differently in an instant. Developing a highly flexible spaces will enable people to rebuild their lives in a short period of time even during disasters and unprecedented situations. When initially responding to disasters by converting everyday spaces into temporary evacuation sites or disaster response centers, it is possible to maintain one's manner of living by changing locations to a safe place in advance of predictable disasters (Fig. I.4). By changing spaces used in other ways into living spaces through social flexibility, long-term evacuation in narrow spaces lacking privacy and adequate amenities will no longer be the case.

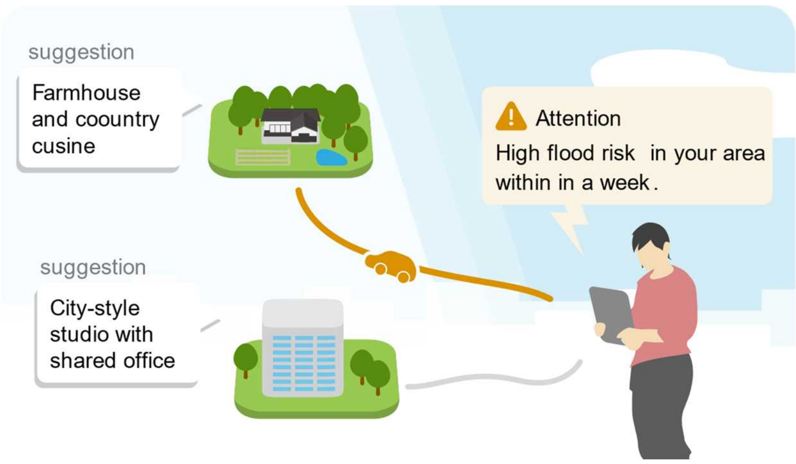

Fig. I.4 Moving base to prepare for disaster risk

Furthermore, in this society, data on the climate, atmospheric environment, and the flow of people is successively being compiled in an open information infrastructure by a wide variety of sophisticated sensing technologies such as satellite imaging built into things such as buildings, cars, and wearable terminals. Personal information can thus be collected while also being protected. This data can then be used to publicize the latest disaster information and conduct people-flow analysis for the whole of

Japan, and be employed to mitigate congestion and optimize evacuation during disasters. By raising the accuracy in predicting natural disasters, and increasing the volume of personal data information, it is possible to make detailed evacuation proposals tailored to the conditions of each individual and region. This is accomplished not only through technological advances in prediction accuracy, but also the wide use of multiple datasets, including diverse sensing and highly precise spatial information on towns and buildings from the open information infrastructure. If such advancements in data-sharing are reached by 2030, their use in advanced disaster forecasting and countermeasures will be fully possible.

Dynamic building transformation is also effective in the face of disaster. Altering building exteriors and shapes to ensure safety in response to disaster predictions is being realized. For example, by around 2050, forecasting wind force against individual buildings from predictions of storm direction and strength, plus the 3D shape and component information of towns, dynamically adjusting the angle of exterior building elements to avoid wind, and in towns with torrential rains, building roofs with automatically deployed water shutters on the "live activity lines" of towns, and may allow towns to successfully maintain their way of life even if severe disasters are predicted.

2.4. Wide range of services thanks to open information infrastructure and high modularity

The system undergirding the realization of a flexible "place" as described above is an autonomously evolving into an open information infrastructure as described in the proposal. This information system can widely share data acquired by individual players such as corporations and people without depending on specific companies or government entities while maintaining privacy, and utilize it through common application programming interfaces (APIs). As with the Internet today, while there is no single entity controlling everything; it is still oriented toward complete integration of all its parts.

A single entity is incapable of acquiring the various sensing data for capturing advanced predictions and whatever is "in the now," so an economic infrastructure that can freely use a wide variety of data obtained by multiple entities is essential. In this society, individual data is not entrusted to a single company or service, but individuals themselves can view and manage all data about them from the cloud. On the other hand, data shared by society as a whole, such as data on land and buildings, is managed in the manner of a business model as it is bought and sold with high versatility through the sharing of APIs. This also makes it easier to freely launch new businesses: highly integrating sensed primary data and selling new forecast data and optimization data, and proposing service software using this data (Fig. I.5). Closed data and API sharing by a single company or a consortium does not allow for services to appear beyond the technologies and domains within those companies. Freely usable data is expected to result in the development of previously unimagined services from new concepts, or the emergence of localized services meeting the needs of specific regional inhabitants.

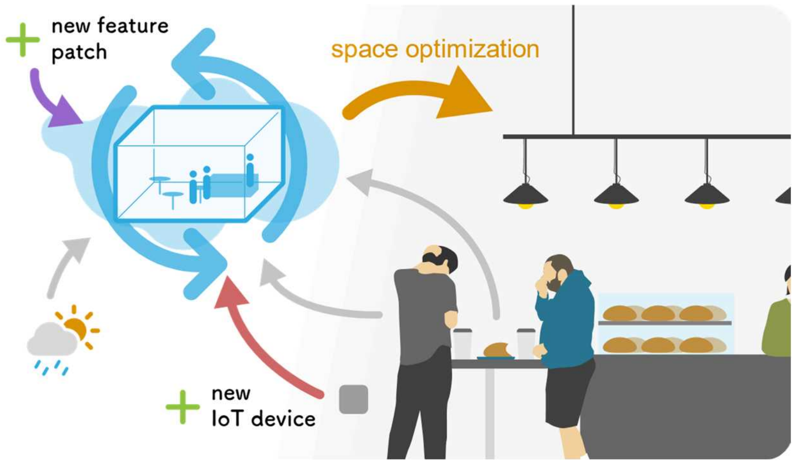

Fig. I.5 Autonomous evolution of services through open data provision and use

In addition, the development of modules for connecting parts, which may be considered "space APIs" for flexibility in building spaces, makes it easier to create suitable parts even at the individual level, and makes it easier to replace equipment by different manufacturers. This means that as competition rises between manufacturers of equipment, buildings, and IoT devices, users will no longer be frustrated because the product they just purchased does not fit in their room, forcing them to upgrade their real-space appliances, furniture, or fixtures. This sort of thing is happening every day. With space APIs, individuals can design furniture or other items that can be manufactured on a 3D printer, and can sell that printer data to customers. Customers can tailor that data to their own rooms, then place orders with manufacturers of 3D printed furniture and fixtures that have been self-customized to fit their personal spaces. Lifestyles involving multiple core businesses may appear, such as 3D furniture designer, in addition to one's main livelihood, while helping refine the analysis technology, thus contributing to improved prediction accuracy.

When this is done, personal data and location-specific data will not be obtainable without ensuring privacy and identifying data ownership. Personal and building data will not be entrusted to a single company, but will be managed on the edge side, by individuals and buildings. Privacy over shared API will remain secure for each service, and mechanisms will be put in place so that the minimum processing data required by services is delivered.

While the opening of data will lower barriers to individual volunteer activities and launch new business startups, and healthy and explosive technology promotion while maintaining high public awareness and transparency can be expected, an initial igniting spark is required to achieve a cycle that stands as a business model maintaining diversity. Under the Moonshot Research and Development Program, prototype mechanisms will be built by 2030—and it is expected that autonomous evolution will be brought about through the free participation of companies and individuals. By 2050, the freedom of participation will promote further evolution, which is currently being carried out through open-source software development; this will be realized in the diversity of the technology of the "place" in which we live.

3. Background

3.1. Why now?

Building spaces have, until now, been built with tight planning at time of construction or large-scale renovations. However, it is not easy to modify real spaces realized within large structures, so normally they are used for several decades after they have been completed. On the other hand, recent years have seen remarkable advancements in information technology, and even facilities utilizing information technology such as IoT devices will become obsolete in a few years. In addition, the spaces required for personal and economic activities are bound to change in nature due to changes in social situation and one's stage in life, which may impair their use, as fixed real spaces cannot cope with such changes. The risk of being suddenly forced to make changes to one's previous life as a result of disasters, such as natural disasters intensified by climate change, Japan's inevitable earthquakes, or the current coronavirus pandemic, poses problems for fixed real spaces.

Japan's population is projected to decline by more than 50% in about half of all residential areas by 2050 [1], and excluding a few urban areas with rising populations, many regions and communities will face the challenges of population decline. Along with it, the issue about vacant houses is becoming serious [2]. However, the changing value of the work–life balance, symbolized by the Work System Reform [3], which came into force in 2019, and the spread of remote work, has begun to be seen in outlying areas where people are seeking new ways of living, leaving behind the expensive, narrow spaces in urban centers. Now that we have experienced the coronavirus pandemic, the diversification of work and living locations—including the meaning of risk avoidance—and the promotion of remote work are social postures that ought to be promoted further. To provide such an environment to many citizens, it is necessary to establish a foundation that connects current places of residence with other locations, including virtual spaces, and it is necessary to develop flexible spaces that account for the needs and feelings of diverse individuals.

The Super City Initiative [4] set forth by the Cabinet Office in 2020 will use advanced information technology with regional revitalization as the basis for building city and town developments that will serve as special national strategic zones. Although this is a state-of-the-art effort to improve people's livelihoods using AI and big data, it mainly involves improving social systems, and there is no innovative technological concept of physical space such as buildings that will serve as actual living spaces.

Promoting the development of spaces, including social infrastructure, is subject to regulations under the law, including the current Building Standards Act; it also requires system designs based upon demonstration trials conducted over time. Although AI can even control building air conditioning or natural ventilation, there has been little discussion of versatile spaces suited to its application. In addition, control is performed on a building-by-building basis, and not at the town or block level. Since it is felt that various data can be used in Flex-Infrastructures, the technical development of IoT and AI based on shared APIs is also required. Specifically, the realization of versatile spaces is bound by current rules, including the Building Standards Act, and thus further rules must be created for versatile spaces together with their research and development. Therefore, to implement versatile spatial technology in society by 2050, technological goals should set by 2030.

3.2. Social significance

The purpose of this proposal is to improve the "place" of work and life for all people. Societies that allow diversity and accept future changes in life will be universally sought in future. In natural-disaster-prone Japan, everyone wants a society that is resilient in the face of disasters and is safe and secure.

The innovative evolution of the physical building and town spaces that are closely intertwined with our lives does not only improve life conveniences. The ability to be "where you want to be" and customize it "to your liking" creates an attachment between one's life and a place, and fosters a sense of happiness and well-being. In regional revitalization as well, societies that utilize local individuality and inventory encourage community development and revitalization. By enhancing functionality through advanced technological investment rather than nostalgic longing, a human-centered "place" can be realized that contributes to people's happiness.

As mentioned in section 3.1, our living places face a turning point, and despite being an issue concerning the lives of many stakeholders and all citizens, Moonshot's existing Goals 1 to 7 do not include the towns and buildings where people live, or safety and peace of mind regarding disasters [5]. Buildings and lives are closely tied to the land. Japan needs to make investments in its own particular natural science and technology, not some universal technology, to fully utilize the unique material of Japan's climate and buildings. The addition of goals explored in this study is strongly urged.

3.3. Action outline

To realize the scenes described in Sections 2.1 to 2.4, a wide range of industrial engineers and researchers in related technical fields, including construction and communications infrastructure, IoT devices, AIs, and UI[1]/UX[2], as well as psychological, physiological, and social researchers required for discussion from the perspective of happiness and well-being, must work together to solve the relevant problems in each field, and address the need for common rules and standardization, international

[1] Abbreviation for "user interface," that is, an interface (or contact medium) between a user and a product or service.
[2] Abbreviation for "user eXperience." that is, the "experience" that a user gains through a product or service. The UI and its usability are elements of UX.

cooperation, and legal action. These efforts are divided into four areas which are the components required for the realization of Flex-Infrastructures: flexible physical spaces; living where bases are freely chosen; "Places" optimization by sensing data; and true open data sharing.

3.3.1. Flexible physical space

To make flexible physical space a reality, technology involving the transformation of building members constituting spaces and technology in which spatial environments are controlled by various sensing information and human needs are required. The elements for boldly changing physical spaces are movable furniture and partitions, followed by buildings easily remodeled through a combination of skeleton–infill structures—buildings that can combine free space through unitization, and technology to construct buildings that integrate mobility vehicles, for example. Further ways to increase flexibility include the use of cyberspace. Cyberspace can be merged into living spaces if physical spaces and cyberspace can be fused together to form spaces in which the boundary is not sensed.

According to the user-centric principle, UI/UX design that considers the psychology and circumstances of users is a critical technical element for individuals to be able to transform and control these various spaces as desired. Development that envisions a variety of users, including the elderly and handicapped, is required, with universal and inclusive designs. Thus, technology for transferring user preferences as information and reproducing them in a different space requires the elements of the user preferences to be recorded, as well as research about what to reproduce so it feels like "the same thing was reproduced."

The above technologies assume that predetermined space uses will change from moment to moment according to need. Needless to say, this is not covered by the current legal system, and thus the relevant ministries and agencies must be consulted on the legal response.

3.3.2. Living where bases are freely chosen

In a society where Flex-Infrastructures are realized, individual people and companies freely choose their home base, and they can easily move to meet their needs, and sometimes have more than one home base in their daily lives. However, current laws and regulations assume that people have a certificate of residence in one municipality and receive administrative services by paying taxes there, and do not make frequent short-term changes in their home base or have multiple home bases. How the local government can facilitate fluid changes in home bases and the attendant legalities should be explored.

In addition, although actually practicing a multi-base lifestyle requires information for selecting locations, and while current information on a particular place's history, culture, and geography is required, not much is available in the form of data. The conversion of missing "human geography" information into data, and testing services for using it, remains a critical challenge.

In addition, psychological and sociological research is also required to investigate an ideal society in which “people from different walks of life can find happiness” as stated in the goals, and feed it back into technical development. These include research into the lives of people pursuing new lifestyles and the relationship between “places” and individuals.

3.3.3. “Places” optimization by sensing data

Optimization of the places aimed at by Flex-Infrastructures requires the sensing of situations to predict future needs. Integrating various sensing and spatial data and ways to optimize it requires information technology such as AI, and research and development is needed into what must be controlled to create the optimum environment. Typical places using sensing data that are to be optimized need to be incorporated into disaster response services and environmental control systems, with function verification.

Collected data is reflected in services for users after some processing, but the quality of services changes entirely depending on how the data is fed back to users. The technical elements of UI/UX designs are thus crucial to how such sensing data is used.

3.3.4. True open data sharing

In the smart cities and “super cities” currently being promoted in Japan, data infrastructures are being constructed with some restrictions from the viewpoint of protecting personal information. Information infrastructures for realizing Flex-Infrastructures, by treating all the information handled as open data, can facilitate the launch of application development by individuals or newly formed startups, and aim for the successive emergence of new services. However, it is necessary to construct and verify the operation of information infrastructure prototypes based on standardized APIs while safely protecting the privacy and consistency of the information handled. Since various types of open data are to be connected, mechanisms are required to improve the function through autonomous evolution, rather than constantly designing information infrastructures from scratch. Since data protection functions against illegal access are also needed, functions using blockchain must also be verified by incorporating functions into this autonomously evolving information infrastructure system.

There are also challenges for data holders. There is a wide range of data to be handled when providing any service to users visiting a building space, such as environmental data on the building space, security camera data, and user wearable device and smartphone data, each of which involves different data owners, such as building managers, security companies, wearable devices, and smartphone service providers. Cross-sectional use of this data is very cumbersome, requiring users to obtain licenses from each data holder or for each data type. Another challenge is to construct mechanisms so that information that should be retained by buildings is collected and held for building managers, and information that should be retained by users is collected and held for them, thereby eliminating the complicated situation described above.

4. Benefits for industry and society

4.1. Selection of location by people and corporations

Lifestyles in a society where people can easily customize their lives, workplaces, and spaces, as well as have multiple locations, would differ greatly from those of the past. Some people, for example, work at a company office on weekdays, then relocate to rural areas on weekends to take care of crops, or remodel old homes if they have an interest in construction. With the widespread use of remote work and online shopping, remote travel for commuting and functional needs is decreasing, while travel to places for leisure, to meet new people, and experience new things, is increasing.

Previously, companies would establish satellite offices in rural cities and temporarily relocate corporate activities there for fixed periods of time. However, in the society described above, changing location becomes a routine way of life. Especially when locations are close together, it becomes possible to carry out business activities while changing location on a daily or even hourly basis.

In multi-base societies, people are no longer tied to a single municipality. Some will have certificates of residence for multiple locations or something similar, or may continue to work from another location. Relationships between people who do not live in a place and the land will arise, such as remotely supporting events via cyberspace, or regularly purchasing foods from familiar producers at remote locations through cyberspace.

Diversification is occurring in a variety of industries to facilitate these lifestyle changes and make travel between locations more comfortable. These include services related to eating, drinking, and housing; cloud services based on the assumption that operations will be performed at multiple locations; and transportation that includes personal mobility for convenient travel. The emergence of new related industries may thus be expected.

4.2. Revitalization of industry through open data sharing

Since a variety of open data is connected and combined in autonomously evolving communications infrastructures, there are increased opportunities for launching any industry that handles data, such as communications, application development, or equipment and facilities. This takes the form not only of new corporate ventures, but new startups as well, and encourages individual volunteerism. If collaboration through open innovation is also expanding, and API standardization is progressing in turn, it will be easier to introduce overseas equipment manufacturers. Services combining superior products will be provided both domestically and internationally, and business will be revitalized in many industries, such as telecom carriers, application developers (including freelancers), and related equipment manufacturers and trading companies.

II. Analysis

1. Essential scientific/social components

The issue for achieving the Moonshot goal are categorized into scientific and technical issues, issues requiring international collaboration, issues requiring collaboration between fields and sectors, and ELSI (ethical, legal, and social issues); and organized according to the components of social efforts described, section 3.3 in Chapter I, as shown in Fig. II.1.

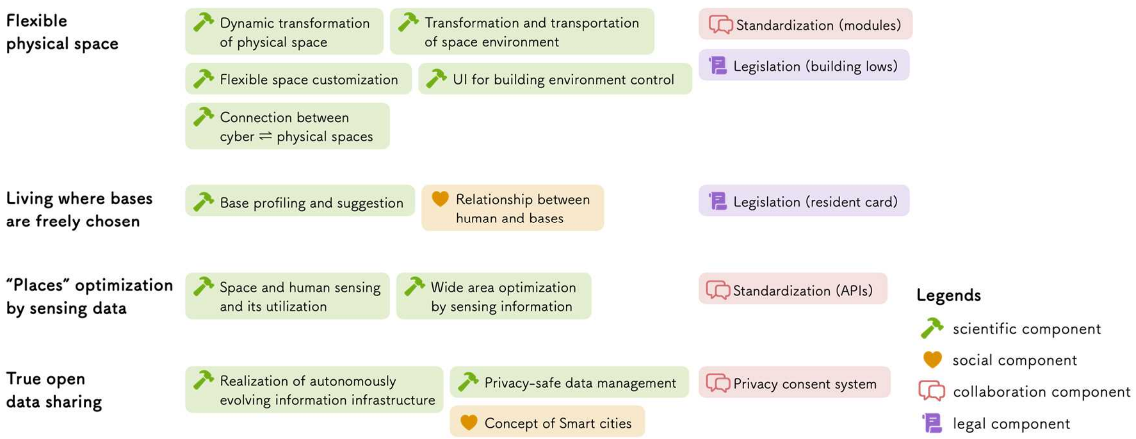

Fig. II.1 Components to realize the MS goal

Scientific and technical issues consist of the transformation mechanism of the non-structural and structural components needed to create flexible spaces, mechanisms for flexible customization, the design of UI control for building environments, as well as physical spaces for cyber exchanges. As for living where bases are freely chosen, social issues are major, but for scientific issues, there is a development for utilization of data on human geography, land, and climate. For "places" optimization, environmental control and disaster measures utilizing sensing data can be components to develop. In addition, there is a need to overcome the issues of prototyping autonomously evolving information infrastructure and safe data management in terms of privacy for true open data sharing. Furthermore, although technologies that are extensions of existing construction, and various AI IoT and communication-related technologies have also been discussed in our course of study, those being developed or evolving independently of Flex-Infrastructure have been omitted.

Issues requiring international collaboration consist of the collection of information on successful smart cities overseas, revealing practices that should be adopted in Japan, and the overseas deployment of superior domestically-produced technologies.

Issues requiring collaboration between fields and sectors consist of the standardization of specifications for the movable parts and joints of transformable buildings, and the sharing of APIs for building control.

ELSI issues for transformable buildings are the improvement and amendment of the compliance system for the current Building Standards Act and Fire Service Act, the ideal protection of personal information to overcome barriers to the open data sharing, and problems with certificates of residence and public services when choosing a multi-base lifestyle.

2. Science and technology map

Figure II.2 shows the relationship between the scientific and technological components from Figure II.1 and the fields related to each component. Fields include architecture, city planning, facilities, production, information, sensing, AI, UX, psychology, mobility, geography, sociology, social systems, and economics.

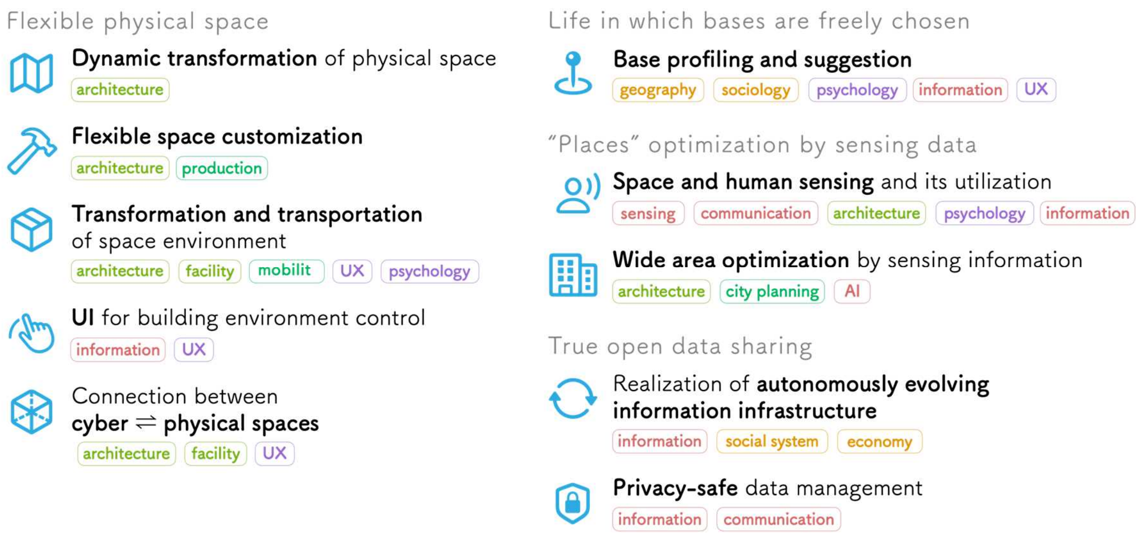

Fig. II.2 Sciences and technologies related to the components

Table II.1 summarizes breakthrough points for research and development issues to be implemented by 2030.

Table II.1 Issues to be overcome through science and technology

Major items	Technical items	Breakthrough points
Flexible physical space	Dynamic transformation of physical space	Although a building transformation function is partly realized by "observation restaurants" and retractable baseball stadium domes, space volume-changing mechanisms and structures have still not been realized. Although studies into deployable structure corresponding to basic research are advancing, they have not been practically applied in residential space applications. R&D on the durability of moving parts, and safety and quietness in operation, is needed. R&D is also required for the mechanism of equipment and piping during building transformation.

Major items	Technical items	Breakthrough points
	Flexible space customization	The unitization and modularization of architecture are essential for ease of change and production efficiency. For small single materials, services that allow individuals to submit CAD data for 3D printers and wood cutting are beginning to appear. As for customization, the use of existing construction stock is also an issue. To realize flexible customization of space, it is required to construct in a short construction period and produce individual fixtures to meet the needs of users. Development is also needed to put to practical use technologies such as modularized spatial data, simple model creation systems linked to advanced UI, model data sharing, and processing of complex parts and more diverse materials.
	Transformation and transportation of space environment	As for the transformation and transportation of the environment, both soft transformation and transportation and physical transportation can be considered. As for the latter, there are now some examples of MaaS proposals in which a car is incorporated into a building as one of the units to create a movable space. However, it does not yet include the aspect of transporting a space that suits a person's preference, and it is necessary to study the form that can be realized, including conceptual work.
	UI for building environment control	Although mobile applications for integrated control of IoT home appliances exist, none of them go into the dynamic transformation of space that has yet to be realized. UI/UX design needs to be done so that each person can control the building environment comfortably and as they wish.
	Connection between cyber ⇌ physical spaces	While the opportunities for people to interact through networks have been rapidly increasing in the wake of recent advances in information technology and the coronavirus pandemic, there has been insufficient study of physical spaces for such cybercommunication. Studies and demonstrations are needed on such topics as equipment and facilities to conduct cyber exchanges in actual residences and offices.
Living where bases are freely chosen	Base profiling and suggestion	When a person chooses a location, it is good to have a mechanism to convert land characteristics into data and properly present it as information to find a person’s “favorite” place. R&D is needed not only into climate and topographical data but also the conversion of human geography information such as history, cultural heritage, and food culture into data, and also what attracts people to a region.

Major items	Technical items	Breakthrough points
“Places” optimization by sensing data	Space and human sensing and its utilization	To optimize place automatically based on human needs, it is required to gather sensing data, recognize the needs from the data, and control the place based on the needs. AI control of air conditioners, lighting, and liquid crystal glass transmission characteristics has already been realized. There is already a lot of sensing of space and people, but obtaining an integrated space-person relationship from them is still a technical challenge. Moreover, Flex-Infrastructure considers human needs, emotions, etc., which have not yet been applied as control triggers, it is, therefore, necessary to verify a series of functions through PoC applying the targeted sensing technology.
	Wide area optimization by sensing information	Recently, position and height accuracy in satellite data has greatly improved, and the utilization of various outdoor environmental data has begun. For example, it is possible to obtain urban thermal imaging data, provide a risk map of heat island phenomenon in a real-time thermal environment simulation, and utilize it for heat stroke countermeasure services.
True open data sharing	Realization of autonomously evolving information infrastructure	Although the concept and some functions of autonomously evolving information infrastructures are being tested, full-scale function demonstration is yet to be accomplished. These infrastructures include functions for incorporating natural intelligence, the use of which is being considered for Flex-Infrastructures. These have still not been verified as information infrastructure for various controls and services related to buildings and spaces. Detailed functions need to have the same values, which will lead to them spreading to advanced areas and across the country. This may be accomplished by first verifying them with small-scale cases as they are being created.
	Privacy-safe data management	In Flex-Infrastructures, it is assumed that a variety of data will be opened, including location information and camera image data collected as a result of mobility, human flow, and individual personal data, and environmental data collected by equipment. These will then be used in a variety of applications. At present, although control signals are standardized by MQTT (Message Queuing Telemetry Transport) protocol, there are problems in licensing the use of personal information and data security, which are hurdles to data opening. Technologies need to be developed and verified, such as improved API, to broaden the use of open data, separating public data from private data so that the convenience of open data can be quickly recognized, individual data retained, and data mutually exchanged.

3. Japan’s position in overseas trends

We report on the related fields and technology groups summarized in Fig. II.2.1, and the research and development trends and current issues from their individual viewpoints.

3.1. Flexible physical space

3.1.1. Dynamic transformation of physical space

Japanese architecture, conventionally, does not limit internal space, and has been used to demarcate living rooms, bedrooms, and guest rooms according to the given needs at the time. The concept here is one of "universal space," one that consists of sliding panels and paper screens which are quite different from ordinary walls and doors, allowing one to use a space sometimes as a large single room, and sometimes are several partitioned rooms. As for furniture, instead of beds, freely moveable futons, low tables, and cushions are used. The original culture and lifestyle of the Japanese people itself was one of a living space that could be transformed according to one's needs.

Many current buildings are already changeable and movable in both large and small ways. Escalators and elevators, for example, are this way, as are rotating restaurants, moving bridges, and large buildings. Stadium domes can retract their roofs, and some domes have movable indoor turf (Sapporo Dome: Fig. II.3). Overseas, an ultra-high-rise building in which each floor rotates, is also planned in Dubai. Aircraft and passenger ships equal in size to buildings are really moving structures, and their maintenance docks also incorporate mechanisms for freely moving and connecting maintenance scaffolds. As described above, giant changeable structures can already be found around the world, and thus are not technically impossible. On the other hand, there are still many technical issues in terms of whether they are truly feasible.

Fig. II.3 Sapporo Dome [6]

Physical space transformation in building space can be divided into changeability in structural frames supporting building structures, changeability in other non-structural frame portions, and changeability in non-building furniture. In general, the former, dynamic transformation is technically the more difficult.

A notable issue is the technology behind deployable structures. Major advancements have been made in folding membrane structure technology for orbital satellites. These were developed because membranes need to be tightly folded on earth, and then expand to a large size when used in space. This technology was developed in Japan. It was first furthered by innovative technology in which membranes folded with the application of a unidirectional force according to the so-called Miura map-folding method [7] suddenly unfold two-dimensionally. Thereafter, a three-dimensional deployment structure called a Sogame Fold [8] was developed, and a variety of applications have already been attempted by venture companies. A recent further development is that it has been shown that this deployment structure, which was previously only a thin film, is mathematically deployable even when thick, and has actually been built on an experimental basis. As a result, it may be applied to thick buildings or repurposed for non-structural members in the future. In addition, R&D has been conducted in folding deployment film surfaces on top of one another, for so-called folding paper architecture systems, which have exhibited a certain degree of strength. It is expected that this system will be utilized to dynamically transform spaces in buildings.

Buildings often hold a great deal of furniture. In recent years, self-propelled robots have been used to move shelves in distribution warehouses, and it is considered technically possible to also use them to move office furniture and fixtures. In addition, chairs that operate by incorporating this function [9] are already available. Furthermore, some companies are involved in overseas ventures to develop systems [10] to freely transform living spaces by moving furniture around.

3.1.2. Flexible space customization

Buildings are difficult to construct and remodel according to need within a short time, as the process is not easy. To solve this problem, unitization and modularization will simplify the manufacturing process, and skeleton infill architecture in which different structural building forms with different durability will be considered separately.

Unitization involves prefabricated architecture in which a technology is used to enable high-quality buildings to be constructed in a short period by assembling rooms produced in factories on site. In recent years, we have begun seeing unitized buildings using containers that are generally used for transport, as well as overseas examples of constructing high-rise buildings in a short period of time by stacking unitized parts (cases include building a 10-story building in 29 hours [11] and building a large-scale corona hospital in 10 days [12], both in China). Japan has seen advancements in buildings that account for future unit exchanges, called Metabolism Architecture. In recent years, the relationship between cars and houses has changed due to the rise of electric vehicles and MaaS, and cases have arisen in which cars themselves have been incorporated into buildings as a single unit [13] [11] [12] [13].

Skeleton infill was devised in the Netherlands in the 1960s. It is a means by which a building is separated in into its structural frame (skeleton) and its interior floor space (infill), combining the former's emphasis on durability with the latter's ability to be flexibly changed or replaced according to need. Although this concept was developed to the point of a PoC [14]; it has not been widely used since then and has not been used to customize infills flexibility.

A further recent innovation in manufacturing is 3D printers. Such 3D printers are not only for small-sized industrial products, but are advancing toward ones that can handle larger metal products for buildings. For example, attempts are being made to create mortar-laid human dwellings with 3D printers [15]. In the materials field, there are examples of making metal-welded free joints with 3D printing technology, and free-forming joint parts with a metal 3D printer using powders, whereby moveable shelters using triangular, 3D-printed panels can be assembled by hand [16].

In the 2000s, as a measure against the hollowing out of cities, a growing need emerged to convert office buildings with low profitability in urban areas to residential houses, with the conversion of existing office buildings into condominiums undertaken as an example of the transformation of building spaces to meet needs. Consequently, technological development was undertaken in this regard. In recent years, there has been an accumulation of startups and the creation of shared office spaces in these buildings which encourages innovation while preserving the decorations and fittings remaining throughout the buildings and taking advantage of cultural resources designated as registered tangible cultural properties by the national government [17] (Figure II.3).

Though scrap-and-build was traditionally been more prevalent in Japan than in the rest of the world, it is thought that the types of renovation outlined above will become mainstream if spaces can be easily adapted from the perspective of the SDGs.

Fig. II.3 A renovation that utilizes the history of the existing office building (Hori Building) [18]

3.1.3. Transformation and transportation of space environment

Transforming the internal environment of buildings is already being developed in the form of projection mapping technology, technology utilizing high-definition monitors, and systems linking them to stimulate the five senses and function like real windows (e.g. [19] [20]). In addition, not only these technologies (which require constant power-sharing), but wallpaper that requires power only when the screens are updated, using paper-like e-ink that does not disappear, are growing in popularity (e.g. [21]). Such wallpaper may be changed according to the mood of the day, and may provide appropriate evacuation instructions in times of disaster. In addition, demonstration experiments are already being conducted overseas: attempting displaying information directory on crosswalks and road signs that change according to the traffic volume at different times of day (e.g. [22]).

Modifying environmental elements within buildings must always be interlinked with building sensors and equipment and communication functions. Various technologies have already been developed. For example, technology is incorporated into buildings that allow internal building sensor data to be exchanged using communication protocols, so that the user can do everything from controlling the air conditioning to making changes in the physical space, all from the cyber side [23].

In an advanced example, computational design has realized a building in which a 24-hour, 365-day indoor light environment is calculated and constructed, and 1,000 or more panels of different shapes are arranged accordingly [24] (Fig. II.4). In this building, by combining the sensor data and the communication technology described above, the internal building environment is sensed when a person arrives, and the windows become opaque or transparent, as the user prefers, and by “liking” an environment on one’s smartwatch, the building learns that this is a comfortable environment, and uses those settings in the future.

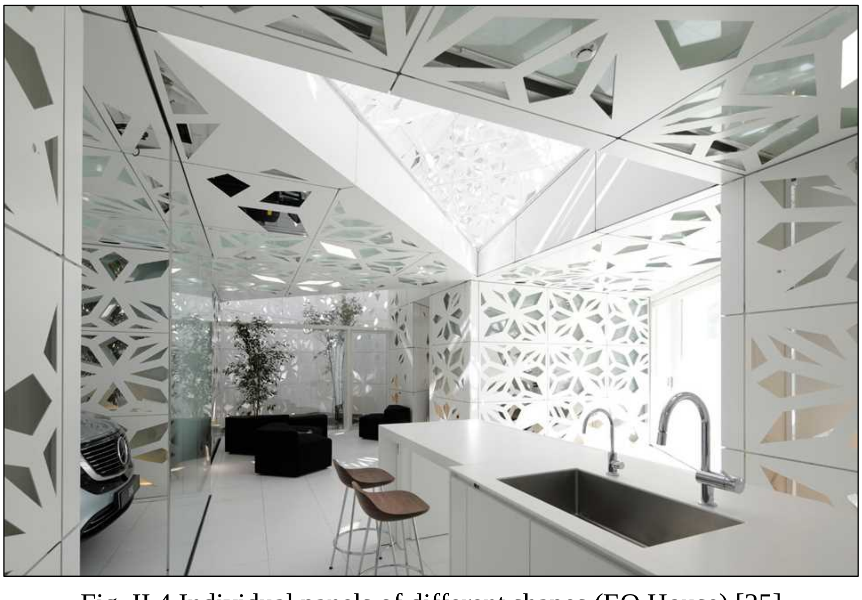

Fig. II.4 Individual panels of different shapes (EQ House) [25]

These technologies will make it possible to transport the spatial environment by storing human preferences as settings and applying them to new spaces through the dynamic transformation of physical space described in 3.1.1 and the use of sensing data described later in 3.3.1. It is expected that in the future, by linking with the skeleton infill mentioned in 3.1.2, infill parts will be unitized, and movable parts like cars will also be used as infill. This concept of a mobile living space unit has also been proposed by the Ueno team of the Moonshot Millennium Program, suggesting future needs and feasibility.

3.1.4. UI for building environment control

Even if the space becomes flexible and can be manipulated by the user, it cannot be said that the goal has been achieved, if it is not easy to operate and cannot be controlled according to the user's needs. In addition, "comfort" in operation is essential for a rich experience. Currently, equipment is commonly controlled by a dedicated controller or in conjunction with a PC or smartphone application, but today, gesture-based command estimation using sensing technology and interactive instructions using natural language have also been realized. On the other hand, programming education became compulsory in Japan from 2020 [26], and future generations will be able to give complex instructions to machines with ease.

In terms of presenting feedback and controls, it is difficult to present a three-dimensional space on a two-dimensional screen. For example, if the information is projected on a wall or in real space rather than just on a personally owned device such as a smartphone, multiple people can receive information that can be shared intuitively. There are many points to be designed, such as the granularity of controllable choices and the timing of presentation.

Apple announced in the worldwide developer conference in June 2021 that the next operating system will enhance smart home integration, stating the evolution of integrated experiences and control of multiple IoT devices. They also have their own guidelines for the user interface that summarizes the design philosophy for operation such facilities through Apple devices [27]. It suggests importance not only for ensuring the variability of each space and facility but also for designing the experience from the user's point of view when they are integrated. However, the current smart home is mainly limited to the operation of retrofitted IoT devices, and the dynamic transformation of the space itself has not yet been discussed.

New research and development are required to operate the unprecedented event, "dynamic control of space," using these ever-evolving new technologies.

3.1.5. Physical Spaces for Exchanges with Cyberspace

As part of Society 5.0 [28], the future society that Japan aims to achieve, it has been proposed that the country "transform into a sustainable and resilient society through the integration of cyberspace and the physical space." Efforts are being made to analyze sensing information collected in cyberspace through the IoT and feed it back into physical space. [28] As for utilization in the construction field, for example, a plan has been announced to build a database that can be shared between the cyberspace and the physical space, named “Common Ground” [29] (Fig. II.5), which incorporates the geometry data of indoor spaces and the IoT information of construction facilities, while promoting the utilization of both digital twin spaces. A small-scale space for experiments [30] has also been prepared.

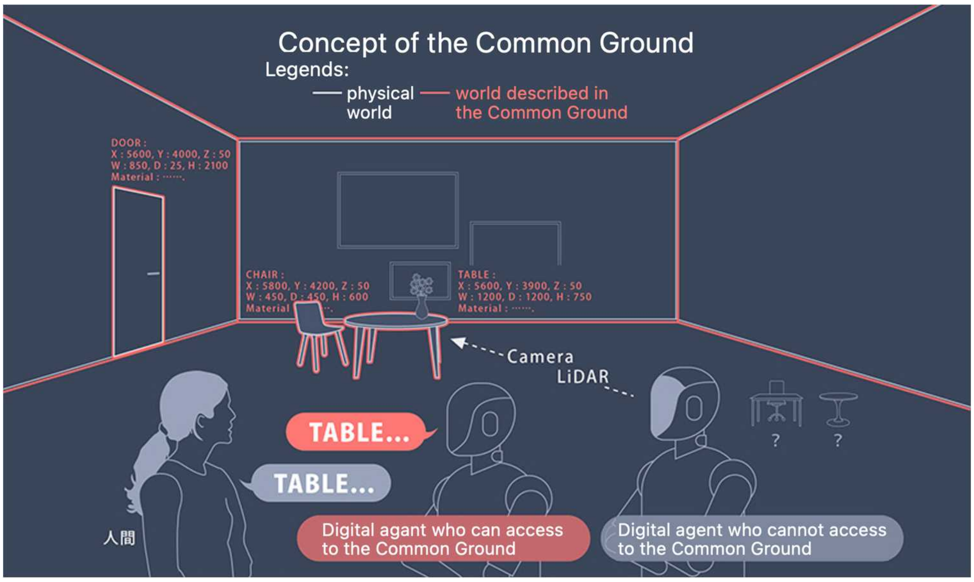

Fig. II.5 Concept of the Common Ground (translated from [30])

Some forms of technology that connect the physical space to cyberspace include VR (Virtual Reality) technology, which allows you to experience immersive visual images in cyberspace using head-mounted displays (HMDs). Another similar form of technology is MR (Mixed Reality) technology that reflects camera images and sensing information in physical space that has been developed through AR (Augmented Reality) technology. AR technology provides visual information by superimposing virtual information such as CG into the physical space. In addition, SRs (Substitutional Reality) are also being developed, in which live images from cameras with eye positions are displayed on HMDs by interweaving historical images previously taken at the same location [31] [31]. Extended Reality (xR) technology, which refers to all of these technologies collectively, not only connects cyberspace and the physical space but also removes the boundaries between the two spaces.

The substitution of some interactions in the physical space with those in cyberspace reduces the constraints on individual and corporate bases and contributes to the expansion of the possibility of base selection. At present, however, the development of devices connected to these cyberspaces and sensory communication technologies continues, even though the examination and development of physical spaces that are optimal for exchanges in cyberspace are not sufficient.

3.2. Living where bases are freely chosen

3.2.1. Creating bases with local governments

Table II.2 is an introduction to some case studies and the present state of base building by communities and local residents obtained through the hearings with groups that were the target of examination and investigation in this survey

Table II.2 Examples of Local Government Efforts

Regions and Localities	Initiatives and Issues
Saga Prefecture	Groups of people emigrate to urban areas such as Fukuoka to enter university and in order to gain employment. Rather than creating temporary surges in activity through tourism, in order to lead to people staying in the area over the long term and also inward migration, bases have been set up for the creation of a "related population" (people who are linked to the local population in a variety of ways) such as community spaces where workcation sessions and citizen-participation-type events are held. The distance from urban and metropolitan areas is a challenge, but through collaboration with the game Romancing Saga, the company is working to raise awareness of the area through the creation of populations with different spatial relationships in cyberspace through the Saga Prefectural Field.
Sendai City (Miyagi Prefecture)	Although university students gather here from prefectures in the Tohoku region, the population emigrates to the Tokyo metropolitan area for employment. As a Special Zone in the National Strategy, telework is being promoted to attract enterprises that are attractive places to work. Since the Great East Japan Earthquake, the number of social entrepreneurs active in the community has increased, but a challenge remains in that each independent activity has not led to long-term settlement or social innovation. In the construction of a platform based on the Sendai City × Tohoku University supercity concept, by giving an ID to “virtual citizens" (not only residents but also people who contribute to community development), attempts are being made to organically connect various virtual citizens in the cyberspace. However, one of the challenges is that the opening up of data is not promoted from the point of view of personal information.
Kimitsu City (Chiba Prefecture)	While facing the challenge of a declining birthrate and an aging population across expansive mountainous areas, the area suffered great typhoon damage in 2019. At that time, the local government was unable to implement measures that anticipate the damage; nor was it able to provide proper evacuation guidance. It felt the need to create hazard maps at the level of city blocks and buildings, while also feeling the importance of climate and disaster prediction using sensing technologies. Based on the lessons learned from this disaster, they are keenly aware of the necessity of establishing a local government base near residential areas. They are planning to renovate school buildings, which are undergoing consolidation and closure due to the declining birthrate, into regional bases, and are seeking to create a base that can function in times of disaster, even though it is used by citizens in normal times.

With the exception of some urban areas where the population is increasing, many localities and rural areas face the challenge of population decline. Rather than expecting a step-by-step process from tourism and travel to migration and resettlement, the creation of diverse opportunities for interaction with the local community in response to a hierarchy of needs, such as work stations and local exchanges and experiences, is being increasingly considered to be more efficacious. In addition, initiatives such as increasing the numbers in the "related population" and "virtual citizens", those who have diverse relationships with local communities and local residents, as well as creating new systems and places for building deeper relationships between people and local communities on an ongoing basis are becoming important [32]. Each region of Japan has a unique culture and natural assets, and we believe that encouraging the creation of bases by making use of the assets of these regions and localities will lead to the realization of the "diverse lifestyles" proposed by our team.

In addition, I would like to talk about trends in multi-base life that differ from migration and settlement in a single place. In a survey [33] by the Ministry of Land, Infrastructure and Transport, interest in dual-residence (or dual-life) became higher as the city became larger, with approximately 40% saying that they are "interested" or "somewhat interested" in the idea. As a measure to meet this interest, the "Japan Dual-Residence Promotion Council" (Executive Council: Regional Promotion Division, National and Regional Policy Bureau, Ministry for Land, Infrastructure and Transport) [34] was established—639 organizations (as of June 1, 2021) in 597 municipalities across 42 prefectures participated. Plans have been made to establish the "Migration and Exchange Information Garden" to provide information on housing, employment, and living supports, as well as providing consultation services, and to implement special tax allocations regarding expenses incurred related to dual-residencies [35].

The movement of individuals is only the beginning of the initiatives engaged in by these national and local governments. Inter-regional migration that offers personal well-being through a return to rich natural experiences, a feeling of belonging to a community, and an attachment to one's community, are becoming more popular now than in the previous era of increasingly myopic focus on urban development. In contrast, for residents in areas that have become depopulated, access to things like shopping areas, medical and welfare services, and cultural facilities, is becoming a challenge, therefore, depopulated areas also make demands from urban areas. The volunteer activities that have occurred in response to successive large-scale disasters and the reconsideration of the ways of working, living, and lifestyles in the midst of the coronavirus crisis have spurred an increase in the number of people who have residences in multiple areas. The movements of these people have given rise to concepts such as "related populations" and "virtual citizens" which go beyond individual-level exchanges, with it becoming necessary to incorporate them as important elements that will take up the mantle of creating a future vision for community development.

While local and national governments have made efforts like those laid out above, the search continues for specific research and development methods for potential needs, such as eliminating the troublesomeness of moving and settling in a specific area and providing bases that combine the passing down of land history and culture with the enjoyment of convenience. Furthermore, in the disaster areas, there is a need for proposals from the perspective of creating a base capable of flexibly responding to different needs during normal times as well as during disasters, and optimizing the process of evacuation based on data such as people, vehicles, buildings, and weather. Nevertheless, these require cross-sectional technological development, and therefore, these needs are not being met currently.

3.2.2. Public Awareness and Life-Orientation

In order to uncover the future image that should be achieved in "the type of city in which different lifestyles can be realized," which is what is proposed by Flex-Infrastructure, an online questionnaire survey (valid responses, 1235) was carried out. Regarding the areas examined in the questionnaire, questions were set up as part of a stage evaluation looking at problems and complaints people had about their present life and living environment with keywords established around how people's ways of life and working had suddenly changed during the coronavirus crisis. Moreover, the following were also investigated; awareness surrounding the smart society, in which advanced information technology such as AI and IoT has been utilized in recent years, and the acceptability of the handling of personal data. A summary of some of the most representative results of the questionnaire survey is given below.

Figure II.3.6 shows responses regarding the type of life and living environment that people desire in the cities in which they currently live and those in which they will live in the future. The desire for the conveniences of everyday life such as shopping and low levels of traffic was overwhelmingly high. Looking at differences in the objects desired in the present and the future, it can be seen that there is a huge increase in the number of respondents who desire items related to disaster response, planning, and design for proper access to facilities for disabled persons and the elderly, medical services, and having a relationship with the local community.

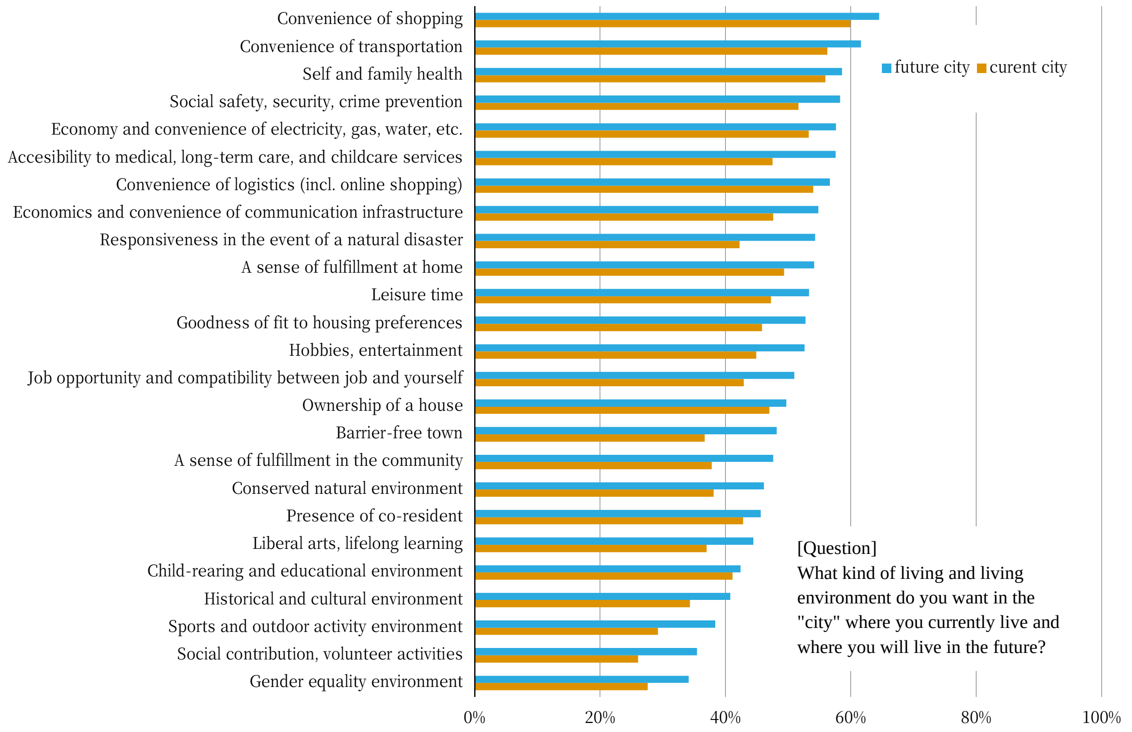

Fig. II.6 Responses on the living and living environment desired by the resident

Figure II.3.7 shows responses regarding lifestyle and the living environment at the place in which the respondent would reside in the future, assuming the respondent will migrate from their current place of residence to somewhere new. The results were almost symmetrical regarding these factors improving or not improving when migrating to an area with a larger population than the current location, or when migrating to an area with a smaller population. Figure II.3.8 also assumes migration from one's current place of residence and shows the factors that would impede migration from current settlements. Changes in the lifestyles of co-habiting family members and a lack of access to the workplace appear at the top of the list, regardless of the region to which they would hypothetically migrate. The economic problems of securing a residence when migrating to areas with large populations, and a deterioration in the convenience of daily life when migrating to areas with low populations are offered as the primary obstacles.

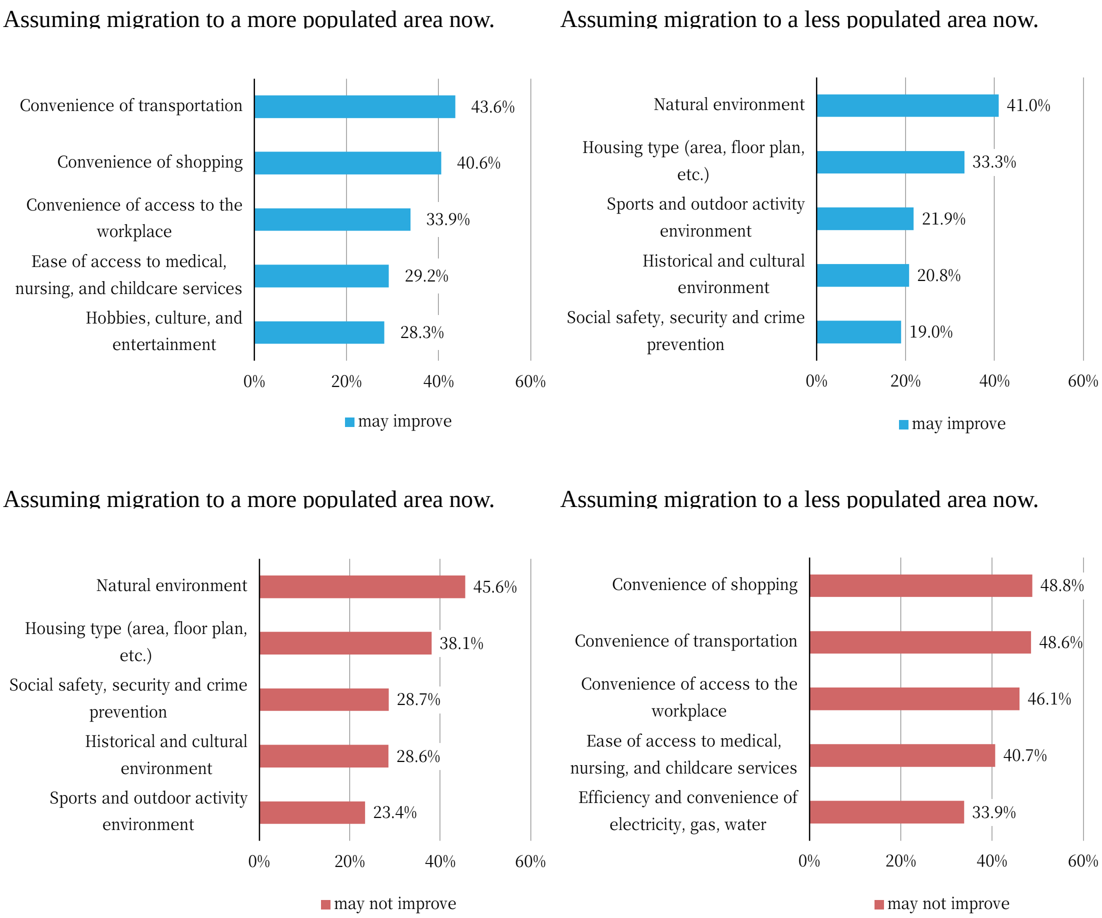

Fig. II.7 Responses regarding lifestyles and the residential environment assuming migration from the current place of residence (top five)

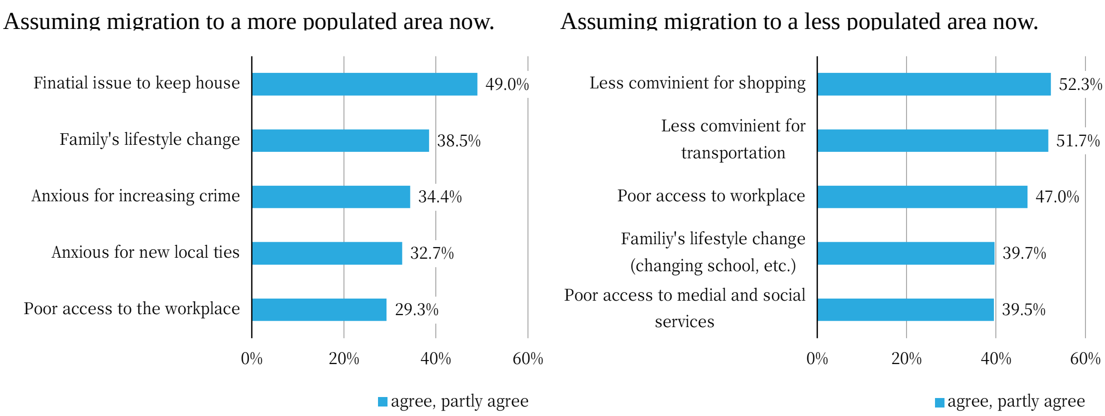

Fig. II.8 Responses regarding factors that would hinder migration to a certain area assuming migration from the current place of residence (top five)

Looking at the results of the questionnaire, while it is natural that the life and living environment that a person wants for themselves in the city is one of convenience, the items in which the scores greatly increase looking into the future are services like disaster response and medical treatment, as well as relationships with the local community. As such, we came to understand that the services demanded are services that are required in a city connected by Flex-Infrastructure rather than individual dwellings operating independently. In addition, regardless of the size of the population in the area to which a person was moving, changes in lifestyles, such as families living together, and access to workplaces ranked highly as factors hindering migration from the current place of residence. This suggests the possibility that diverse lifestyles and styles of working can exist if an environment is created in which classes at school and work at workplaces can be flexibly accommodated without limits as to location.

3.3. “Places” optimization by sensing data

3.3.1. Tying together spaces and sensing information

With Flex-Infrastructure, it is necessary to grasp the attributes of users on a space-by-space basis, so techniques that can link collected sensing information with space IDs are required. When the space in a building with a certain ID is sensed and information is transferred to some kind of spatial control system or service application, the data from the IoT sensor installed in the building is usually on the building management system. In cases where the data to be used is on a personal wearable device or smartphone, these are on different data infrastructures, so how they cooperate with one another is problematic. In addition, if personal information such as location information and usage information for payment services on smartphones such as GNSS, W-Fi, and BLE Beacons, can be used, it is possible to identify the building ID which should be subject to data cooperation. However, there are issues with this such as consent to the disclosure of user data.

With regard to the former, this problem can be solved if, for example, a system can be established in which routers in buildings and devices installed in stores in buildings are integrated and managed by building owners by linking them with building IDs. However, at present, no efforts have been made towards the construction of such links between data. The latter group has not been actively working on making data open.

3.3.2. Learning and estimating from user preferences for place

Recent developments in sensing technologies such as various camera images, BLE (Bluetooth Low Energy) beacons, and LiDAR (Light Detection And Ranging) have been introduced into the market in quick succession in recent years. These new technologies have made it possible to accurately grasp the environmental conditions in a building space and also identify and locate humans and robots as well as the flow of people. In addition, by utilizing various satellite data outdoors, it is possible to understand information on the location of people and objects in outdoor spaces, as well as information on things like greenhouse gases, water circulation, and climate change in the target space. Sensing technologies related to human emotions and preferences are also advancing with the development of deep learning, to the point where emotions can be estimated in real-time from still images and videos.

As a form of technology for learning and estimating the user's preferred place, which is supposed to be applied to Flex-Infrastructure, it is possible to read and recognize human emotion, mood, and character traits from facial expressions and speech, as well as to utilize them as a trigger for spatial control.

These attempts to recognize emotions, including psychological interpretations, have been engaged in since the term Affective Computing was devised in 1997. Recently, with the development of deep learning, feature extraction and estimation can be handled uniformly. For example, CNN (Convolutional Neural Network) which is used for feature extraction from still images and GRU (Gated Recurrent Unit), LSTM (Long short-term memory), and C3D (3D CNN) which are used for feature extraction from moving images. In addition, motions of the face, head posture, line-of-sight direction, voice information, or multi-modal information, which combines all of the above, are also used. The modeling of emotional concepts is also progressing, with emotional expressions now incorporated into Pepper from SoftBank Robotics [36].

In this way, emotion recognition technology has been roughly established, and in the future, it is expected to develop technologies to understand the content of communication, as well as to develop capacities to engage in communication by sensing signs, and communication through the five senses [37].

3.3.3. Wide area optimization by sensing information

In predicting disasters, with the development of computers, the predominant method was to model natural phenomena and make predictions by using numerical calculations. The more refined the numerous pre requisite conditions used for calculation (e.g., topography and building data) and the higher the computational power, the more precise the predictive accuracy will be and the more reliable the upgrading of disaster forecasting will be also, therefore proceeding in this direction to improve the quality of disaster forecasting provides a more certain future.

While the above uses model-driven techniques, data-driven techniques have also been developed in recent years for predicting disasters from the data itself. For example, information from social network services linked to location information has been used to identify areas where influenza has occurred quicker than ever before, and to predict the outbreak of short, sharp bouts of localized heavy rains. In addition, this data are not only leveraged in predictions themselves, but there are also plans to construct models from a large amount of sensing data. It is assumed that new physical models that we have not yet discovered will be uncovered by data-driven techniques in the future. In addition, techniques for data assimilation which link observed data with simulation using the model have also been developed, and techniques that predict the future with high precision in accordance with the real-time situation have also been established. Using these numerous avenues, the use of big data is expected to contribute to the development of new disaster prediction technologies.

Moreover, sensing data is very effective not only in forecasting but also in disaster response. The information of sensors installed in buildings can be used for the evaluation of the soundness of a building, and the satellite data directly reflects the state of damage. In the case of severe disasters that are difficult to predict, there is no specific response method, and it is necessary to judge the optimum countermeasures instantaneously and in a timely manner. For that reason, it is most important to understand the situation accurately, and a large amount of sensing data is considered to play a major role in this respect.

3.4. Truly open data sharing

3.4.1. Autonomously evolving communications infrastructure

Autonomous networks are networks that require minimal human intervention and perform their configuration, monitoring, and maintenance by themselves and their usefulness and realization have been proposed in recent years. A focus group (FG-AN) for autonomous networks was established at the ITU-T (International Telecommunication Union's Telecommunications Standardization Sector) in December 2020, and discussions on future communication networks have begun [38]. This network is a system that decentralizes the operation of those events that were previously operated based on rules determined by human decision-making, by making them machine-controlled using artificial intelligence and cloud networks.

The University of Electro-Communications proposes an autonomously "evolving" communication infrastructure that takes it a step further and is engaging in exploratory research such as the "Platform for Progressing the Integration of Mechanical and Human Intelligence, with the Cyber and Physical World" as part of the JST's Mirai Project. This research proposes telecommunications infrastructure that encompasses the linking and combining of data, and the analyzing and discovery of human and mechanical knowledge, in addition to inspection and monitoring systems that can ensure stability when the infrastructure evolves autonomously [39]. President Tano of the University of Electro-Communications introduced this communication infrastructure at an open symposium sponsored by the Flex-Infrastructure Consideration Group. It is assumed that a variety of open data sources will be connected, service applications freely developed by third parties will be utilized, and new service applications will be developed, with data generated from such services (Fig. II.9).

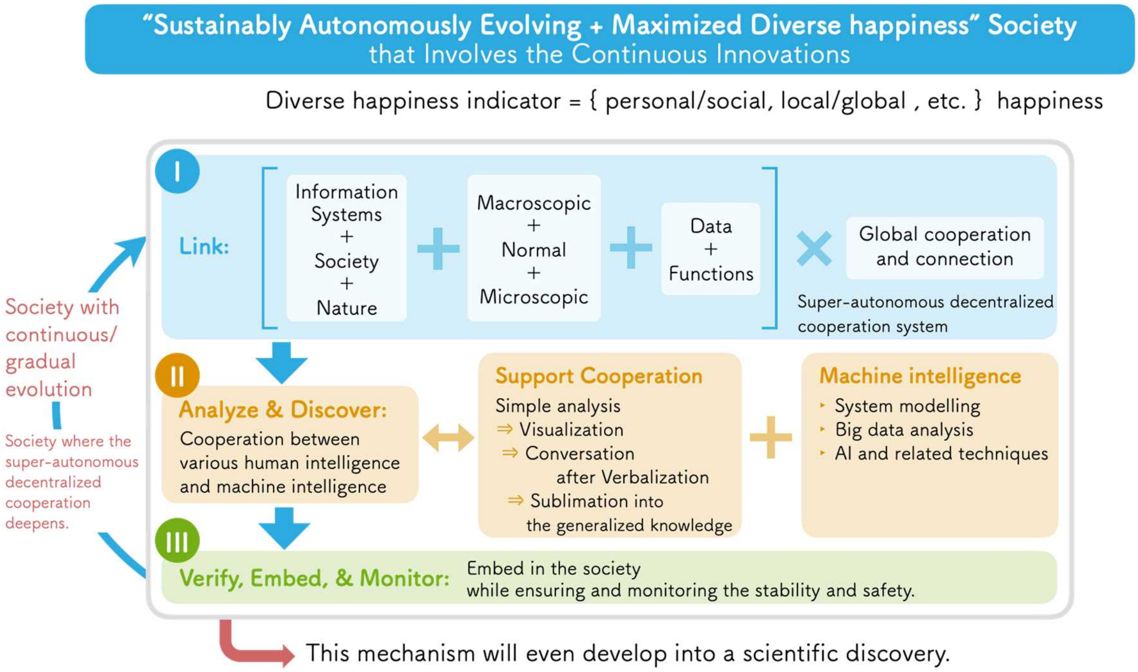

Fig. II.9 Overview of the platform for progressing the integration of mechanical and human intelligence with the cyber and physical world (created by based on [40])

Furthermore, the following three points were suggested as challenges for new value creation through this autonomous evolution:

① Requires many fundamental technologies

⇒ Technology that contributes to people's happiness can only be realized not only with science and engineering, but also with art, business, and policy.

② Requires social test grounds

⇒ The true value of this technology will be demonstrated only when diverse industries and people are involved and a variety of data and functions are made public.

③ Breaking down the resistance to open data and functions

⇒ The current situation, where data and functions are occupied by particular groups of companies with vested interests and therefore there are few participants, can lead neither to collaboration nor to innovation.

Only by bringing together diverse research and presenting a successful example can solve these issues and let society begin to change.

As Flex-infrastructure aims to use a wide range of data and create services to meet various needs, developing such an autonomously evolving information infrastructure is required to realize a flexible place.

3.4.2. Privacy-protected data-sharing and communication

Flex-Infrastructure assumes a model in which information obtained from a variety of sensors, such as sensors within buildings, wearable devices, smartphones, and other devices is shared on the cloud, and a large number of players conduct an analysis, share the results of the analysis with each other, and a large number of users leverage these results.

Information obtained by sensors also includes information related to privacy, such as location information, information on purchases, and the clothing an individual may be wearing that day. Therefore, from the perspective of personal protection, the service provider is required to obtain consent when using the information. This consent is generally given every time a service provider provides a service, so that consent must be obtained again from the user if the service provider is to provide another service or to provide data to a third party in order to do the same. In order to alleviate this inconvenience, Privacy Policy Management (PPM) [41] has been proposed, which systematizes the set of criteria to which the user agrees, with standardization carried out through organizations like oneM2M and ITU-T. In addition, to popularize PPM, demonstrative experiments [42] aimed at the share distribution of data have been conducted.

The reasons why the data-sharing mechanism has become more complex is due to differences in data-sharing concepts among governments (G: Government), companies and the private sector (B: Business), and consumers (C: Consumer). For example, through B2C, a consent and contract are provided for the temporary use of data at the time of service provision. Through B2B2C, B must enter into an agreement with C so that B may provide the data obtained from C to a third party. Through G2B and G2C, G exchanges data with B or C in the form of open data. Considering the fact that the way of thinking about data-sharing changes based on the type of player, it is necessary to examine the data-sharing platform to proceed with the analysis.

Regarding the data storage technology employed, data was previously stored through the individual storage medium of each terminal, however, at present, it is mainly based in the cloud. However, with regard to future technologies, it is expected that cloud collaboration and other technologies will be developed from the types of cloud solutions that are currently mainstream. If Edge Computing technology, which is currently being pursued, advances, it will replace the technique of accumulating only necessary information rather than accumulating all information. In addition, emerging blockchain technologies can retain data in a decentralized manner while guaranteeing data transfers, rather than placing data in specific locations. Currently, as epitomized by GAFA, some IT companies monopolize data storage services. However, if these technologies advance, it is technically possible for users to manage their data themselves with authority, rather than entrusting personal data to a single company.

3.4.3. Smart cities

① Smart cities in Japan

The Smart City Guidebook [43], which was published in April this year by the Cabinet Office in collaboration with the Smart City Public-Private Partnership Platform, showed that "improving the well-being of citizens", which is an aim shared with Flex-Infrastructure, is significant and necessary when striving toward the creation of smart cities. The Guidebook sets out the three basic philosophies of being centered on citizens (users), having a focus on a vision and issues, and inter-sector and inter-city collaboration. At the same time, it also sets out five basic principles: ensuring fairness and inclusion at each stage from the initial response and preparation of smart cities to the formulation of plans (strategies), the demonstration, implementation, consolidation, and development of smart cities, ensuring privacy, ensuring security and resilience, ensuring interoperability, openness, and transparency and ensuring operational, and financial sustainability. In addition, 31 local governments applied to be considered as Super City National Strategic Special Zones, applications for which were publicly invited by the Cabinet Secretariat for the Promotion of Regional Revitalization. An overview of the applications has been published [44]. In a hearing [45] to Sendai City in June, it was determined that the Tohoku University Campus was being developed in accordance with this principle.

The urban OS described in the Guidebook offers a variety of different types of infrastructure that links data such as data on the environment, images, maps, and location information to various environmental sensors, camera links, and applications such as traffic and tourism apps, as well those used to prevent disasters and crime. Although there are similarities between the urban operating system and autonomously evolving communications infrastructure, which is the main component technology of Flex-Infrastructure, the former does not assume physical changes in buildings or spaces, and also does not specifically mention the livelihoods of people who are conscious of living at multiple locations. Furthermore, the current model of Smart Cities and Supercities considers sharing data in accordance with the rules for protecting personal information, and a data-sharing infrastructure is being built, restricted by the data to be handled. Flex-Infrastructure is trying to expand the scope of the data that can be shared and is aiming to create new services that leverage a wider range of data.

① Smart cities overseas

Table II.3 shows some representative cases of projects being engaged overseas, and some cases that we would like to use as a reference for advancing the project.

Table II.3 Examples of Overseas Smart Cities and Supercities

Area	City	Overview
North America	Toronto	Led by Sidewalk Labs, a Google subsidiary (affiliated with the alphabet). A great deal of castigation and criticism has been received regarding the handling of data obtained from various sensors, and the initial plan has been reduced and delayed repeatedly. The suspension of the project was announced for financial reasons in May 2020.
Asia	Singapore	Led by the Singapore Land Authority and the Infocomm Media Development Agency of Singapore. Virtual Singapore was developed, a tool to virtualize almost all aspects of life in Singapore, such as buildings, infrastructure, and green spaces, the prediction of damage from disasters, power generation from solar panels, and hours of sunshine before construction.
	Dubai	Led by the Dubai government. Smart Dubai 2021 was developed with the vision of becoming the "happiest city on earth”. Initiatives adopt a wide variety of dimensions such as convenience and life safety, with a 100% digital government, unmanned taxis, flying taxis, and plans to install automatic driving police vehicles with built-in drones.
Europe	Copenhagen	Led by Copenhagen City, universities in Japan and IT companies, etc. With the vision of becoming the world's first city to achieve carbon neutrality by 2025, they aim to improve traffic congestion and improve the safety of citizens. They have developed the "Living Lab," a demonstrative experiment method for citizen participation in a developed country. They are top-ranked in the United Nations ranking of happiness.

A common issue for overseas smart cities and supercity projects is the handling of information obtained from cities. For example, there is a strong resistance to newcomers, especially to private companies other than local companies accessing information on citizens and providing civil services. In the case of Toronto, local residents and politicians expressed concerns about the handling of information by Google, the IT giant, leading to delays and the eventual cancellation of the project. The digital ineptitude of national and local governments, as well as citizens, is said to be a problem underpinning this. In contrast, Denmark is also referred to as an IT-based nation, is ranked first in the world e-government rankings (2018/2020 consecutive year, United Nations Department of Economic and Social Affairs), and is proceeding to make efforts in the field of open data. The My Number system that was introduced in Japan in 2015 is similar to the CPR number that was introduced in Denmark in 1968 and has been consistently producing results for more than half a century. Information on the medical diagnosis of everyone across the nation has been input into a database a long time ago, and medical history and information on allergies are shared properly even if a person’s doctor changes. It is also used for telemedicine consultation services across Europe. Although Denmark is ranked fourth in the world (in 2021, the Ministry of Finance) in terms of the national burden ratio and is among the countries highest in terms of negative items, it ranks consistently high every year in terms of global happiness (2^{nd} in 2021). In the capital city of Copenhagen, measures to reduce CO_2 have been successful, and in the area of commuting, the number of bicycles has increased in greater numbers than the number of cars, resulting in healthier citizens. Thus, environmental conservation leads to a transformation in mobility which results in a good cycle of health maintenance.

3.4.4. Public awareness of data sharing and smart cities

From the online survey presented in 3.2.2, some major results regarding awareness of future smart cities are presented below.

Figure II.10 shows responses regarding how people currently view the idea of Smart Cities. They were strongly associated with an improvement in the conveniences of daily life, with a weak association with improving health, global environmental problems, and societal diversity.

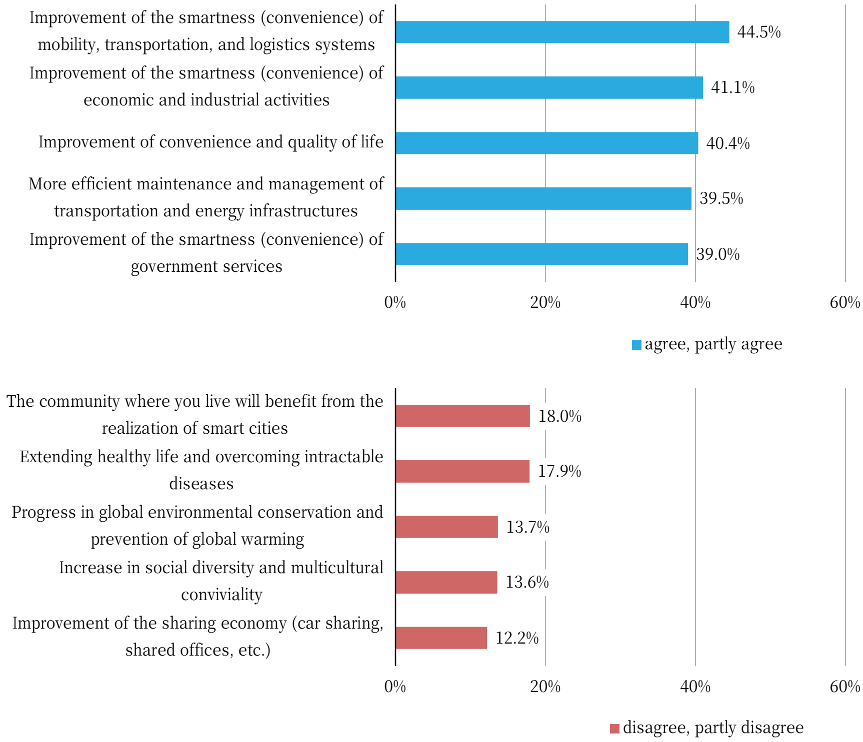

Fig. II.10 Responses regarding how people view smart cities (Top 5)

Fig. II.11 shows responses regarding the handling of personal information and data on behaviors and activities in smarter societies when services are provided on the basis of such data. One exception was that people were highly receptive to the use of information on personal locations in the event of a major disaster, but the acceptability of data utilization, in general, was not high. The acceptability of using data such as that dealing with gender and vital signs, from which individuals are difficult to identify, is high. Moreover, personal information and behavioral data ranked highly as data that people did not want to be used, and data on positional information and physical characteristics ranked highly in this regard when looking at actions.

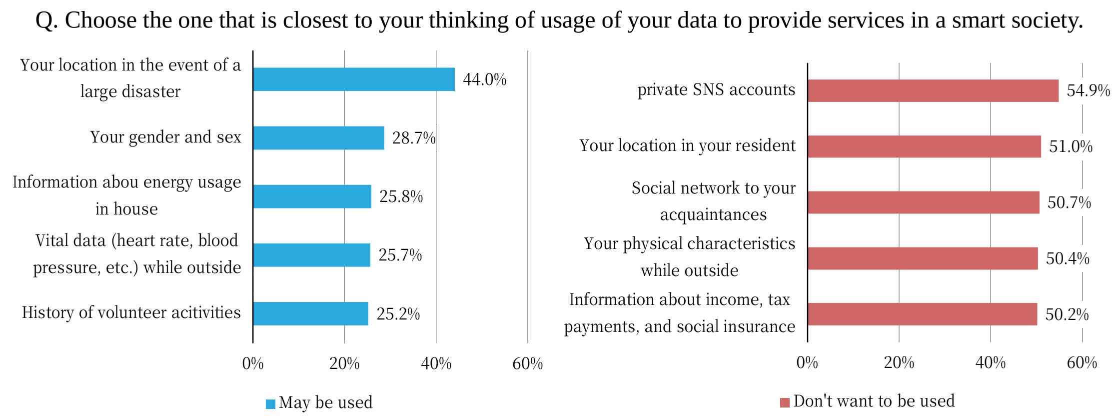

Fig. II.11 Responses regarding the handling of data surrounding personal information, behavior, and activities (top five)

III. Plan for Realization

1. Area and field of challenging R&D, research subject for the realization of the Goals

1.1. Area and field to promote challenging R&D

Fig. III.1 shows the relationship between the fields of research and components to develop for the proposed Flex-Infrastructure. There are two major engineering fields: one is related to hardware, such as architecture and facilities, and the other is related to software, such as information and communication. The socio-cultural fields that support these fields include psychology and UX, which are related to individual comfort and happiness, and social, economic, and policy fields, which are related to the implementation and diffusion of this infrastructure. To realize our concept, it is necessary to promote scientific and technological development, while at the same time promoting collaboration among these fields to solve problems.

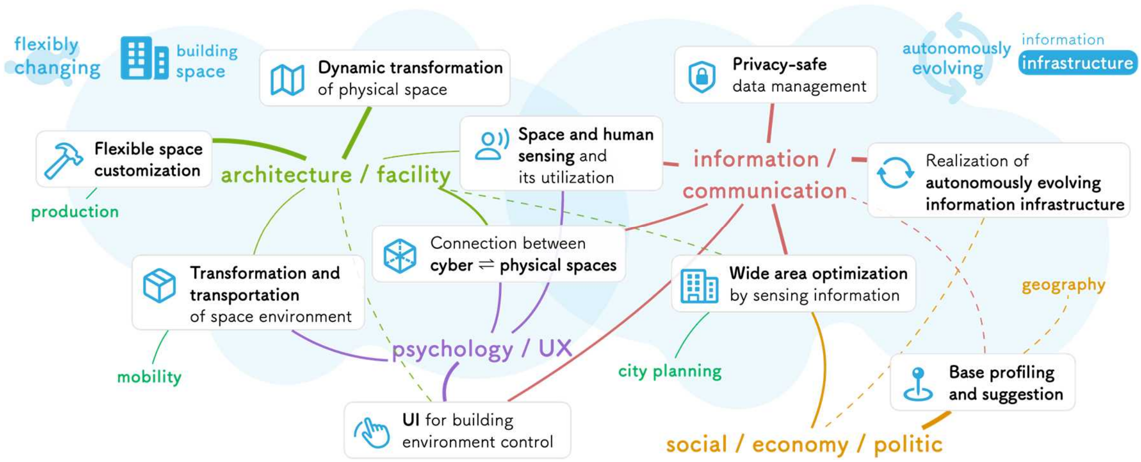

Fig. III.1 Areas and fields to realize Flex-Infrastructure

1.2. Research subject for realization of MS Goal

In addition to the scientific and technological components shown in Table II.1, the realization of the social vision of the Flex-Infrastructure requires PoCs to integrate the elemental technologies and implement the model of the desired social vision and verify the functions. In addition, among the science and technology components, "realization of an autonomously evolving information infrastructure" has a PoC-like character in itself. Fig. III.2 shows the relationship between the elemental science and technology components and the PoCs.

The points regarding the area into which each research subject should provide a breakthrough are shown in Table II. The verification of implementation and functions of Flex-Infrastructure should be conducted agile in relatively small-scale new buildings and in renovations of existing buildings considering the efficacy of investment in R&D. Proposed PoC studies are given in 1.2.1 and 1.2.2 below.

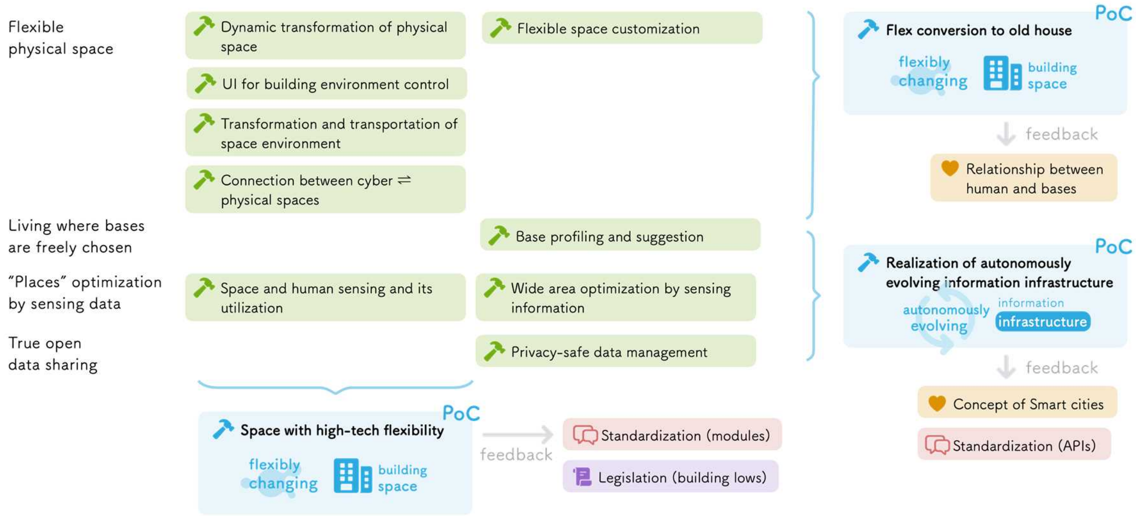

Fig. III.2 Relationship between research components and implementations and function verifications of Flex-Infrastructure

1.2.1. PoC: New building spaces with high flexibility

It is desirable to attempt PoC on a small but new building by combining large-scale deformations such as deformations of parts and various new technologies. For example, a small, low-rise office used by a large number of users could be simulated (Fig. III.3). While providing the necessary functions of an office space, it is conceivable to implement autonomously evolving infrastructure, to incorporate non-structured modifiable components and movable furniture and partitions in the initial stage, as well as verifying links with the control of air conditioning, lighting, ventilation, and spatial transformation using new sensing technologies such as gestures and emotion recognition as triggers. The addition of various sensing functions and the extension of the objects of control may be carried out at any time.

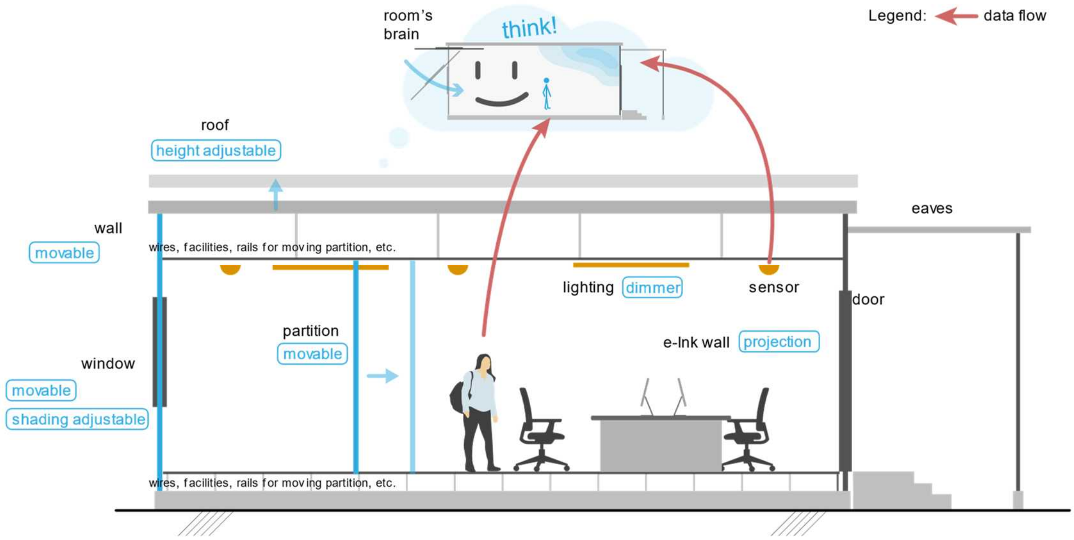

Fig. III.3 Image of a small office in which Flex-Infrastructure is being implemented and verified

1.2.2. PoC: Attempting a Flex renovation on an old house and using it as part of a multi-base lifestyle

New spaces in which to live a flexible life should not just be those new buildings built as part of a process of scrap-and-build. As a disruptive attempt to provide a variety of "places", we strongly endorse the renovation of existing buildings using advanced technologies. A new dwelling that inherits the history of a particular "place" and combines comfort and design is considered one of the options for realizing various forms of happiness from the point of view of utilizing the local stock in a particular area. Based on the renovation of old traditional Japanese houses and other such buildings, it is possible to verify various sensing technologies and control functions in the same way as is done with new buildings (Fig. III.4).

If the target building is located in a rural area, a multi-base lifestyle could also be attempted. It would also be beneficial to conduct psychological and sociological research, such as continuous surveys into user lifestyles and development based on research that shows changes in the psychology of users and feedback on what should be improved. Using the various data obtained by sensing, attempts could also be made to create technology that leads to new services such as the enhancement of disaster prediction and information on base selection.

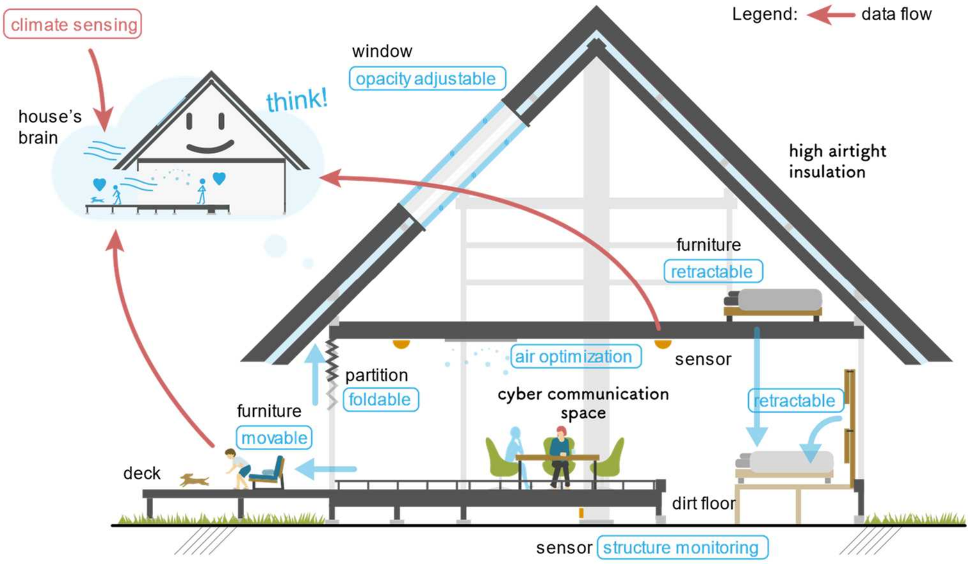

Fig. III.4 Image of an Japanese traditional house in which Flex-Infrastructure is being implemented and verified

2. Direction of R&D for the realization of goals

2.1. R&D Milestones and decision to continuation

Fig. III.5 shows the research and development required for the realization of the social vision of Flex-Infrastructure from 2030 to 2050, and Table III.1 shows the milestones for each decade. From 2030 to 2040, it was assumed that related regulations and systems would be adjusted while demonstrating in the preceding areas; and from 2040 to 2050, each technology component and the demonstrated Flex-Infrastructure system would be deployed nationwide.

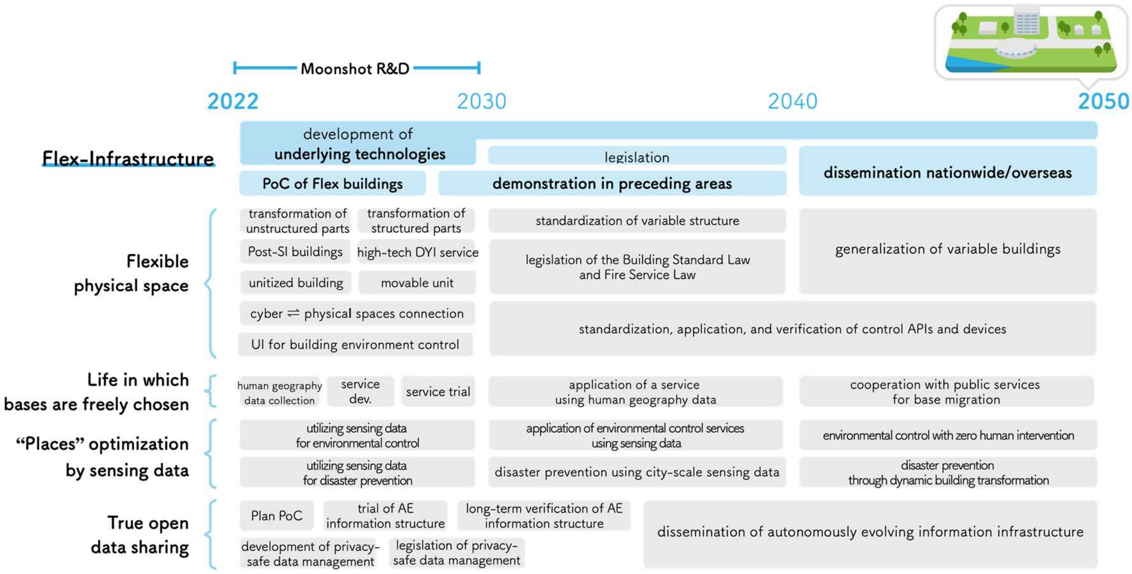

Fig. III.5 Roadmap for all of the technical and social issues constituting Flex infrastructures

Table III.1 Milestones from 2030 to 2050

	2030	2040	2050
Flexible physical space	・Complete preliminary implementation of buildings that uses sensing data to dynamically adjust the environment.	・Finish legislation. ・Emerge the developed technology as a commercial product. ・Increase active use of stock buildings.	・The norm in life with flexible physical space.
Autonomously evolving information infrastructure and data utilization	・Complete Implementation and functional verification of Flex-Infrastructure at the PoC level.	・Implement of Flex-Infrastructure in prior regions voluntary.	・Disseminate Flex-Infrastructure nationwide.
Base choice	・Development of advanced centers suitable for multi-base living.	・Increased diversity in the choice of locations. ・Increase in the number of related population.	・Increase in population of young people in regional cities.

As for the criteria for judging the continuation of R&D, the major items of "flexible physical space" and "'places' optimization by sensing data" are considered to be realized through the integration of engineering elemental technologies and can be implemented in society even if each elemental stage is completed. Therefore, it is not necessary to stop the R&D altogether but to consider reducing the scale and flexibility of the goal, or extending the development period for each elemental technology.

In the case of developments in the industry after the moonshot R&D, economic rationality rather than feasibility is considered to be the criterion for judgment. On the other hand, as for "life in which bases are freely chosen" and "true open data sharing," social and industry trends will also be involved, and it will be necessary to make decisions from time to time. As for "privacy-safe data management," there is a possibility that the agreement process and specifications will be changed depending on the compromise between the needs of users and the technical possibilities. For "autonomously evolving information infrastructure" and "base profile and suggestion", as well as for trials in actual buildings such as Flex traditional house, agile research and development is aimed, making implementation decisions as needed based on the degree of completion of the elemental technologies, social needs, and feedback while using them. Since the role of the PoC is to show a complete example to society, research and development will be continued while searching for the best solution during the PoC period, and seek the judgment of society through the PoC regarding the subsequent operation and diffusion.

2.2. Ripple effects

During the PoC and elemental technology development period until 2030, the creation of new industry candidates as a result of PoC implementation is expected. In addition, as APIs and modules are regulated in each industry, the development of products and services conforming to them will be promoted. After 2030, a variety of service businesses using sensing technology and open data are expected to emerge in areas where autonomous evolutionary communication infrastructure has been established.

3. International cooperation

3.1. Referencing case studies of leading overseas smart cities

As described in 3.5.2, successful smart cities outside Japan should be frequently referenced.

In order to "realize the diverse forms of happiness" advocated for by our team, human data is indispensable. We would like to begin discussions on international standardization, including what can be expanded by Flex-Infrastructure, by incorporating good examples through case studies in each country and interviews with the parties concerned.

3.2. Cooperating with international industrial standards

In addition to producing fine products that meet the needs of domestic users, Japanese technology sometimes falls into a situation in which domestic companies are so focused on the domestic market that their products can only be used in Japan. Regarding construction technology, many unique technologies in Japan conform to the climate, disasters, building laws, and regulations of Japan. In contrast, in the software industry and the field of IoT devices, many products originating overseas have already been distributed. As for Flex-Infrastructure, while developing technologies for "places" that suit the climate and lifestyles of Japan, consideration should be given to flexibly incorporating foreign technologies and facilities into domestic buildings. While ensuring that the technology developed is compatible with international industrial standards, it is desirable that Japan take the initiative to promote standardization with ISO while aiming for overseas expansion.

4. Interdisciplinary cooperation

4.1. Cooperation on building deformation mechanisms

In demanding variability in buildings, factors like the movement of non-structural components, the deformation of structural components, and the trackability of deformed components in facility systems are necessary. It is necessary for the construction industry, as well as the material industry and the analysis software industry to cooperate to solve technical problems such as the confirmation of fatigue characteristics and the fire resistance of materials with the increase of moving parts, performance verification through structural analysis, and verification experiments on the component bases, in addition to reflections on the design technique.

Moreover, in order to popularize variable buildings, it is necessary to standardize the specifications of joints and movable parts with respect to the hardware of movable parts and movable mechanisms. It is necessary for the construction industry and the manufacturing industry of moving parts to work together to promote the standardization of these specifications.

4.2. Linkage to the control of buildings

Equipment used in buildings comes equipped with a mechanism for the mutual use of its functionality and external control in accordance with the ISO standard called BACnet[3]. However, sensors and drive controls related to building deformation are not included in their objects. In addition to the Institute of Electrical Installation Engineers of Japan, which has issued BACnet System Interoperability Guidelines [46], the communications device industry which provides sensors for Flex-Infrastructure and the software industry which provides drive control should discuss the verification and extension of APIs in cooperation with each other and attempt to standardize them.

4.3. Collaboration on the construction of autonomously evolving communications infrastructure

In order to realize Flex-Infrastructure, various types of open data need to be connected and linked to the communication infrastructure. The data to be handled is both input data such as sensor information and output data such as information to be delivered to the service application, and these APIs must be standardized. In addition, regarding the expansion of building management data described as an example in II-3.3.1, linking sensing information with building IDs is also necessary to arrange and standardize rules for connections with the databases to be linked.

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[3] Building Automation and Control Networking Protocol

Focusing on the platformer industry in communication networks, this is a matter to be solved in cooperation with industries such as the application software industry, the IoT device industry described in III 4.2, and university researchers in academic fields related to these industries.

5. ELSI (Ethical, Legal, Social Issues)

5.1. Laws related to construction

At present, there is no provision in the Building Standards Act for deformed buildings, and it is not possible to apply for building confirmation. In addition, if partitions are moved, the floor area of the room changes, the fire protection area cannot be determined and it is assumed that the evacuation route also changes, thus making it difficult to apply the Fire Service Act in such a state. Regarding the Building Standards Act, it is necessary to cooperate with the Ministry of Land, Infrastructure, Transport, and Tourism and accrediting organizations such as the Building Center of Japan to discuss the development of laws and regulations. Similarly, with regard to the Fire Service Act, it is necessary to consult with the Ministry of Internal Affairs and Communications and the local fire department at the time of the verification experiment, including regarding the development of laws.

In addition, the Building Standards Act aims to protect the residential environment and stipulates 12 types of districts designated under zoning regulations related to the domains of residential, commercial, and industrial based on the City Planning Act, restricting the construction of buildings in those areas. This limitation of use is likely to interfere with the flexibility of the proposed "place". The National Strategic Special Zones Act stipulates National Strategic Special Zones that ease restrictions on use for the purposes of the swift development of facilities required for economic growth. However, it is necessary to consider the direction of the easing of restrictions on use, considering the results of the PoC in special zones and other areas.

5.2. Administrative and welfare services for moving bases

A problem with the lifestyle of freely moving back and forth between multiple bases is crossing between areas controlled by different local governments and using administrative procedures and services such as residency cards and school education that are linked to a particular administration. For example, the current Basic Resident Registration Law and the School Education Law do not assume that there is more than one place of residence. You register a certificate of residence with the local government in one of the areas where you live and school children are required to receive compulsory education at public schools in the designated school district in which they live or at private schools to which they are able to commute. Consequently, life in a second area of residence is limited to weekends and consecutive holidays. For local governments, the funds for providing services to residents are provided by taxes allocated to them by the national government or municipal taxes. However, there will be residents in sub-residential areas from whom municipal tax will not be collected by the local governments concerned. As a way of paying taxes to these kinds of sub-residential areas, a method for making use of the hometown tax payment system exists, but there is a limit on the amount of tax reduction on the balance of tax collected, and it is considered necessary to reform the tax system from the perspective of individuals living in multiple areas.

As for medical care and other services that are deeply related to the health of individuals, it is difficult to continue outpatient visits when moving to a site far from a primary care doctor, because the current situation is that of outpatient visits and in-person medical examinations between individuals and medical institutions. By establishing a system that enables individuals to manage their personal health data and disclose it to medical institutions as necessary, even if the medical institution changes, a stable and continuous program of treatment can be received. Furthermore, the proposal of the Higuchi team of the Moonshot Millennium Program [47] suggests that the future spread of health care, including telemedicine, using data on vital signs even for those who are not sick, will enable individual health management without the need to attend actual medical institutions.

In the utilization of administrative and welfare services which straddle local governments, it is possible to continue the utilization of the My Number card as a form of ID for linking individual data.

5.3. The protection of personal information

The protection of personal information is an important issue from the point of view of the sensitivity of the personal data as collected as part of the questionnaire survey. At the same time, the keynote speech by President Tano of the University of Electro-Communications at the open workshop and his remarks at PD [34] show that the distribution of data basically creates various services that contribute to human well-being by making it open source. It is necessary to develop and install a communication system that can offer various services while maintaining transparency in data handling through communication and data retention using open standards and appropriate APIs.

In addition, it takes time to resolve issues surrounding the social utilization of personal information, which is expected to be in the public interest, such as the optimization of traffic using human flow data and the development of health and medical services using data on vital signs. However, it is necessary to establish rules concerning the open utilization of personal information (secondary and tertiary) through dialog with the individual people who are the data providers and the communities where they gather. The Smart City Guidebook, published by the Smart City Public-Private Partnership Platform, shows that the balance between "protection" and "utilization" is important in order to distribute and utilize various types of public-private data, and it is necessary to obtain consensus on the handling of data by using workshops in which citizens participate, public consultations, Living Labs and Civic Tech, etc.

IV. Conclusion

In this survey-based research, the "realization of a society in which everyone can live safely and happily in a flexible ‘place’ by 2050" was proposed as an ambitious goal. This is a proposal to improve the convenience of the physical spaces in buildings and towns, the places where we live our lives, and to rectify disparities among people living in Japan based on the places where people live and their current circumstances, while also enriching their lives.

The following are the development technologies necessary for the realization of this societal vision, based on the present problems and technological trends in Japan and overseas. To begin with, in order to realize flexibility in "places", research and development which raises the variability of building spaces, and improvements in physical spaces which incorporate the convenience of cyberspace in order to increase the flexibility of spaces is required, in addition to the selection of bases. In addition, in order to provide "places" that are tailored to the circumstances of the time, sensing, and information, infrastructure that can sense the situation and convey it to "places" is required. As part of this information infrastructure, in order to realize services and predictions arising from large amounts of sensing by a great number of devices, the utilization of shared open data is necessary which does not rely on a particular enterprise and institution. Furthermore, regarding the selection of the base made once this society has been realized, how they cooperate with each other, and how they provide services that contribute to the well-being of residents must also be considered. It is not only the perspectives from engineering fields such as building technology and communication technology, but also the viewpoints provided by UI/UX which connect these technologies with humans and the indispensable observations of human geography and lifestyle theory that connect the attractiveness of the region with the people.

As a roadmap to realization, first of all, we propose an agile development by 2030 in which elemental technologies that have not been realized and are at the conceptualization stage at present are advanced to the practical level by research and development in each industry field. Furthermore, as a result of this integration, we propose that a PoC is implemented on small-scale buildings or systems, demonstrating its effectiveness. By 2040, we hope to establish a model in which the examples presented in PoCs are implemented in several cities and areas, evolving autonomously through the voluntary developments of local governments and companies, and by 2050 we will expand this Flex-Infrastructure-based rich lifestyle, such that it can be enjoyed by people living all across Japan.

The fields in which research and development are required in order to realize the societal vision proposed in this survey and research project are wide-ranging. It is important that technological development is encouraged towards this goal in tandem with the cooperation of each industry, and technology which contributes to the happiness of local inhabitants is produced by creating an environment in which open innovation does not immediately run into conservative management, and that contributes to the welfare of all inhabitants.

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