Chapter

Comprehensive Strategy for Sustainable Housing Design

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Abstract

Sustainable housing needs to be designed to maximize occupants' well-being and minimize the environmental load. The pursuit of combining these two different aspects toward sustainability is a goal-oriented task. The science of control can be applied to all goal-oriented tasks. Therefore, applying control science, we have been progressing in research on sustainable housing design. Our previous study has produced the control system for promoting sustainable housing design in which sustainable design guidelines and sustainability checklist are incorporated. Based on these accomplished results, this study has comprehensively visualized the process of producing and revising the sustainable design guidelines and sustainability checklist. Following this visualized process, also this study has concretely shown the production and revision processes of the sustainable design guidelines. The study results suggest that the comprehensive visualization can make these processes more manageable and help system designers to produce and revise the guidelines more efficiently. Furthermore, these results have led to indicating how to adjust the guidelines to different countries or regions as well as changing situations over time.

Keywords: sustainable housing, control system, sustainable design guidelines, sustainability checklist, production process, revision process, comprehensive visualization, communication

1. Introduction

Housing is the most important place that supports people's well-being. Sheltering residents from severe climate and weather, housing basically provides areas and facilities for sleeping, preparing meals, eating, and hygiene. People also conduct other activities, such as childcare, nursing care, communication, recreation, and learning, in their homes. Furthermore, the progress of information technology is currently increasing the number of people who work at home.

Meanwhile, housing is closely related to a variety of environmental problems. Typically, energy use at homes and the construction and demolition of houses have been significant causes of climate change, depletion of natural resources, and waste. Moreover, current and future impact caused by climate change is becoming a serious threat to human activities and people's well-being [1, 2]. Thus, this emerging threat requires housing design to strengthen the function of shelter.

Sustainable housing needs to be designed to maximize residents' well-being and minimize the environmental burden. The pursuit of combining these two different aspects toward sustainability is a goal-oriented task. The science of control can be applied to all goal-oriented tasks and has produced extraordinary results in many fields, especially engineering. Accordingly, applying control science, we have been progressing in research on sustainable housing design. In 2017, the already produced research results were compiled into the monograph titled *Sustainable Home Design by Applying Control Science*.

The core of the already produced results is the control system for promoting sustainable housing design where sustainable design guidelines and sustainability checklist are incorporated. Utilizing these research results, recently we have strived to clearly demonstrate the process of producing and revising the sustainable design guidelines and sustainability checklist. Moreover, following this demonstrated process, we have made the newest revision of the design guidelines. This chapter reviews these study results and discusses the meaning of the study.

2. Control system for promoting sustainable housing design

The "control system for promoting sustainable housing design" is demonstrated in **Figure 1**. The upper area of the figure is the theoretical world; the lower area is the practical world.

"Disturbances" are adverse effects on controlled objects which are caused by environmental, social, or economic problems. Concrete examples of the disturbances include harmful influences caused by environmental pollution and various impacts resulting from climate change. The route from "disturbances" to "sustainability" is "adaptation." This route has been added, based on the recent scientific understanding that adaptation measures to current and future impact caused by climate change are also necessary toward sustainability [1, 2, 5].

The purpose of control is the achievement of "sustainability." The model of sustainability (**Figure 2**) shows that sustainability needs both internal stability and fundamental stability, in order to realize the long-term well-being of all humankind or ultimate goal, within the finite global environment and natural resources or absolute limitations [6]. Internal stability means social and economic stability; the conditions for internal stability are "health," "safety," "mutual help," and "self-realization," which are important for the well-being of humans [6]. On the other hand, fundamental stability means environmental stability and a stable supply

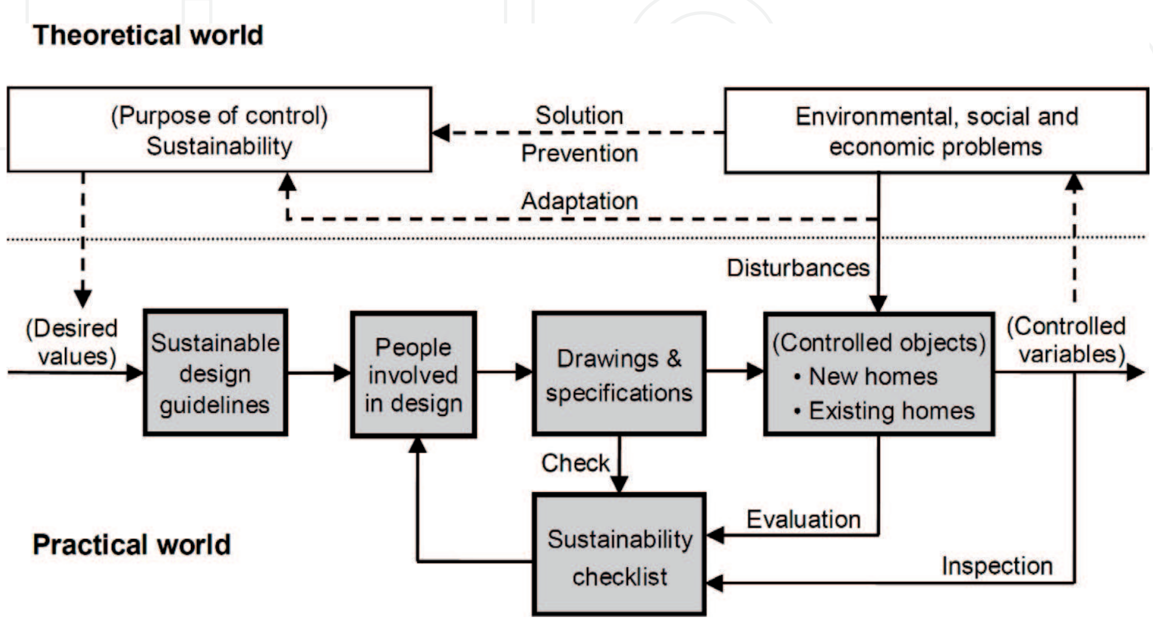

Figure 1.
Control system for promoting sustainable housing design [3, 4].

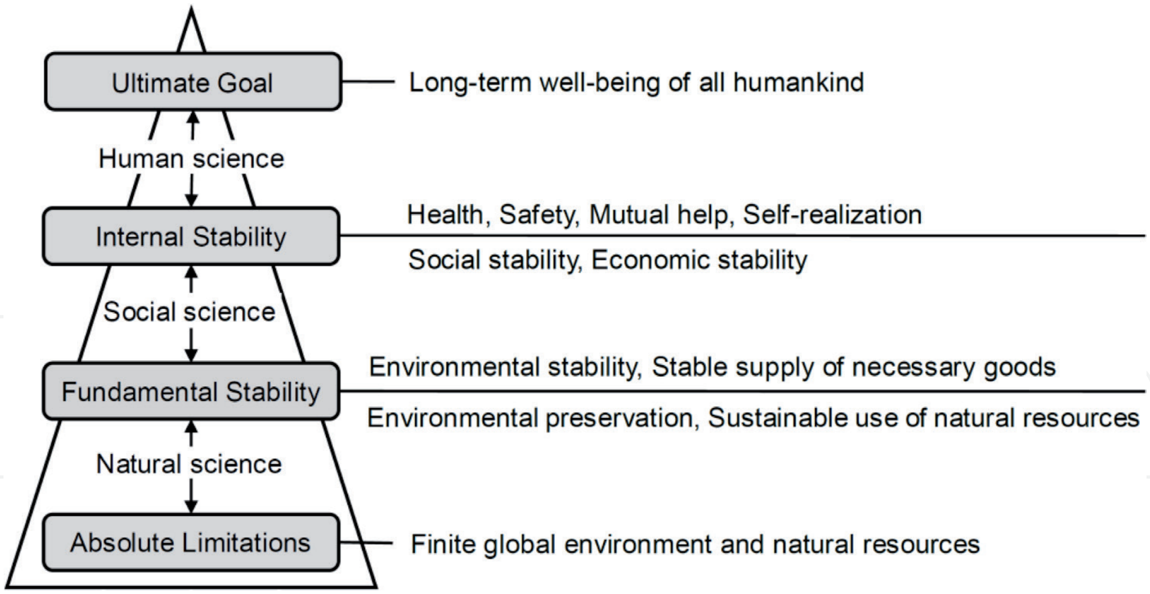

Figure 2.
Model of sustainability [6].

of necessary goods; the conditions for fundamental stability are “environmental preservation” and “sustainable use of natural resources” [6].

“Desired values” are derived from the purpose of control, namely, sustainability. Meanwhile, “controlled variables” are the variables that relate to controlled objects and need to be controlled for primarily solving or preventing the problems or adapting to disturbances [3, 4]. The control objective of this control system is to adjust the controlled variables to their desired values.

In the practical world, controlled objects are both “new homes” and “existing homes.” “People involved in design,” such as homeowners, architects, designers, and homebuilders, adjust the controlled variables to their desired values, by utilizing the “sustainable design guidelines” and “sustainability checklist.” Both the design guidelines and checklist have almost the same structure, namely, elements, variables, and their desired values. However, the checklist is created to easily compare measured or estimated variables with the desired values and search for controlled variables [3, 4].

When objects are new homes, first, information on the desired values reaches “people involved in design” through the “sustainable design guidelines.” People involved make “drawings and specifications,” so that the variables of home’s elements can attain their desired values as much as possible. At important steps in the design process, people involved check the drawings and specifications, by referring to the “sustainability checklist” [3, 4].

When existing homes are objects, the design process begins with “inspection” on the home as an object. The “people involved in design” measure or estimate each element’s variables of that home by referring to the “sustainability checklist.” After the inspection, the people involved usually make “drawings and specifications” for improvement, so that controlled variables satisfy their desired values as much as possible [3, 4].

3. Process of producing and revising the design guidelines and checklist

The process of producing and revising the sustainable design guidelines and sustainability checklist is shown in **Figure 3**. The upper and lower areas divided by the dotted line represent the “theoretical world” and the “practical world,” respectively.

The central part demonstrates the course of preparing and using the “sustainable design guidelines” and “sustainability checklist.” First, system designers produce

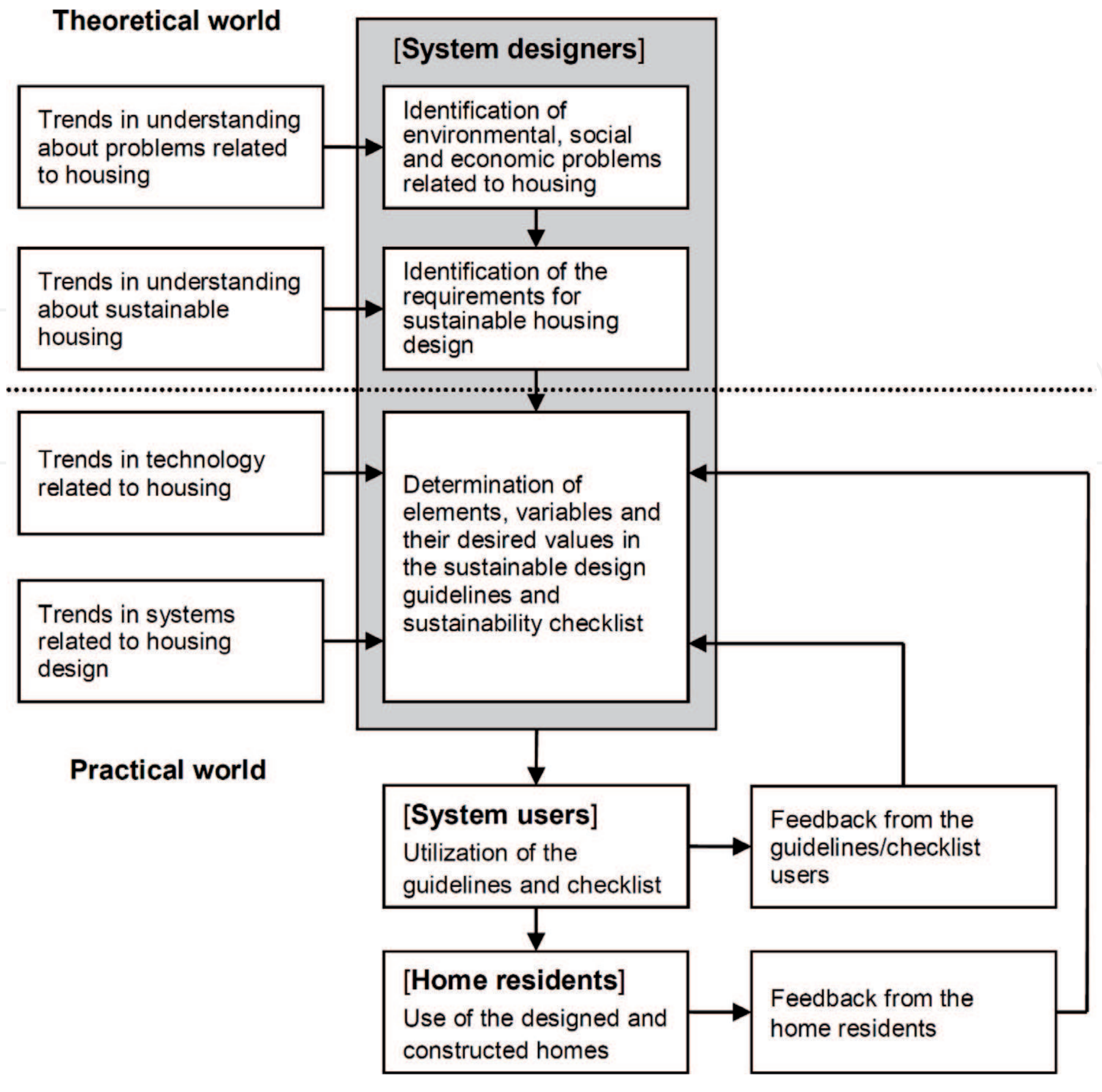

Figure 3.
Process of producing and revising the sustainable design guidelines and sustainability checklist.

or revise the guidelines and checklist through the three-stage process. Next, system users utilize the guidelines and checklist. After that, the residents use the actual homes that have been designed with the guidelines and checklist.

The four blocks on the left show the items to check when producing or revising the guidelines and checklist. The contents in these four items can change over time. Meanwhile, the two blocks on the lower right show the items to check when revising the guidelines and checklist, based on the feedback from the system users and home residents.

3.1 Process of producing the design guidelines and checklist

The process of producing the design guidelines and checklist consists of three stages: (1) identification of environmental, social, and economic problems related to housing, (2) identification of the requirements for sustainable housing design, and (3) determination of elements, variables, and their desired values in the design guidelines and checklist.

3.1.1 Identification of problems related to housing

Producing the guidelines starts with the identification of environmental, social, and economic problems related to housing. Observing trends in understanding about problems related to housing, system designers search for the problems that should be identified. The basis for the identification is that the problems affect the total six stability conditions, namely, health, safety, mutual help, self-realization, environmental preservation, and sustainable use of natural resources. When identifying problems, system designers take up both global/general problems and local/particular problems in their region or country. Examples of global/general problems are global warming and climate change, depletion of natural resources, and waste. Meanwhile, damage caused by earthquakes is included in local/particular problems.

3.1.2 Identification of the requirements for sustainable housing design

In the second stage, based on the identified problems related to housing, system designers identify the requirements for sustainable housing design. For example, if "depletion of natural resources" and "waste" are identified as problems in the first stage, the "extension of housing lifespan" and "use of resource-saving or waste-prevention materials" are usually identified as the requirements. These two requirements are related to "sustainable use of natural resources," one of the six stability conditions. Similarly, "damage caused by earthquakes" requires "higher resistance to earthquakes," which is related to "safety," another stability condition. In addition, observation of "trends in understanding about sustainable housing" also helps the system designers to identify such requirements.

3.1.3 Determination of elements, variables, and their desired values

In the third stage, the requirements for sustainable housing design are converted into the "element-variable-desired value" structure of the guidelines and checklist. The purpose of this conversion is the convenience of users in the practical world. The structure of "element-variable-desired value" shows design targets of each part of homes; therefore, it enables users to easily understand what should be designed and the courses of design.

3.1.3.1 Elements

The previous publications have presented a method of selecting important elements of homes, based on two main factors: "material" and "space." "Material" regards housing as the aggregate of material elements, such as framework, exterior, thermal insulation, windows and doors, interior, piping, and equipment for harnessing natural energy. "Space" considers housing as the aggregate of spatial elements, such as rooms and areas [3, 4]. In addition, material elements and spatial elements are equivalent to actual parts of homes. Accordingly, when designing, checking, evaluating, or inspecting homes, system users can easily compare the guidelines and checklist with the actual home or drawings [3, 4].

When selecting elements, system designers also consider the requirements for sustainable housing design. In other words, the elements that are required for sustainable housing design need to be included in the set of elements. For instance, "equipment for rainwater use" should be selected as one of material elements, even though it is not common in current ordinary homes [6].

3.1.3.2 Variables

After selecting elements, system designers examine the relationships between each element and the relevant stability condition(s), as well as the related requirement(s) for sustainable housing design. Subsequently they determine the element's variables that can indicate the degree of stability [3, 4].

Choosing only one element, namely, “framework,” the rest of this part shows how to determine the variables. System designers examine the relationships between “framework” and “sustainable use of natural resources,” the relevant stability condition, as well as the “extension of housing lifespan” and “use of resource-saving or waste-prevention materials,” the related requirements. As a result, they can identify “durability” and “materials,” indicators of “sustainable use of natural resources,” as variables of “framework.” Moreover, if the country or region is in an earthquake-prone area, the system designers consider the relationships between “framework” and “safety,” the relevant stability condition, as well as “higher resistance to earthquakes,” the related requirement. They can subsequently identify “resistance to earthquakes,” an indicator of “safety,” as an additional variable.

3.1.3.3 Desired values

After determining variables, system designers set the desired values of these variables that can meet the relevant stability conditions. Setting variables’ desired values requires observing two items in the practical world: “trends in technology related to housing” and “trends in systems related to housing design.” Observing trends in technology is significant for determining variables’ desired values of material elements. Meanwhile, observing trends in systems related to housing design is necessary and useful for setting the desired values of most variables [7]. In this context, systems related to housing design include both compulsory and voluntary systems. Compulsory systems are building codes and regulations; voluntary systems are typically assessment and rating systems, standards, and design guidelines.

For example, if “durability” and “materials” have been identified as variables of “framework,” the desired values of these variables can be determined in the following way. As for “durability,” the system designers can set its desired value, considering a necessary level of framework’s lifespan or deterioration resistance. Similarly, they can determine the desired value of “materials,” based on a necessary level of utilizing materials which promotes resource-saving or waste-prevention, such as renewable, recycled, and recyclable materials. When determining the desired values of “durability” and “materials,” it is significant to refer to relevant information in voluntary systems. Information on these desired values is usually included in voluntary systems, such as assessment and rating systems, and standards, whereas such information is outside the scope of building codes. Accordingly, system designers can set these desired values, by utilizing related criteria and information which are included in the relevant voluntary systems [7].

Meanwhile, if “resistance to earthquakes” has been identified as a variable of “framework,” the desired value is a sufficient level of preventing damage caused by earthquakes. In quake-prone countries, quakeproofing standards are usually stipulated in the building codes. However, if system designers consider that the standard value specified in the building codes is insufficient, they make an addition to the standard value, so as to suit the desired value [7]. On the other hand, if they consider that the standard value is suitable to the desired value, they can use it as it is. In the latter case, the variable and its desired value can be omitted from the guidelines and checklist, because people naturally conform to compulsory building codes [7].

3.2 Process of revising the design guidelines and checklist

The “sustainable design guidelines” and “sustainability checklist” need to be revised, for adjustment to changing situations as well as for higher accuracy and user-friendliness. The revision process can be divided into three spheres:

(1) changes in the theoretical world, (2) changes in the practical world, and (3) feedback from the users. After making preparations from the above three perspectives, system designers modify the tables of the guidelines and checklist.

3.2.1 Changes in the theoretical world

Noticeable changes over time in the theoretical world are necessary to be reflected in the guidelines and checklist. First, after searching for recent changes in problems which affect the six stability conditions shown in **Figure 2**, system designers can amend the list of problems. Based on the amended list of problems, the system designers can also amend the list of the requirements for sustainable housing design. When amending these two lists, it is also necessary to observe the latest trends in "understanding about problems related to housing" and "understanding about sustainable housing." After that, system designers consider modifications on the "element-variable-desired value" structure of the guidelines and checklist.

3.2.2 Changes in the practical world

In addition to changes in the theoretical world, changes in the practical world need to be reflected. Changes over time in the practical world include "changes in technology related to housing" and "changes in systems related to housing design."

In order to search for "changes in technology related to housing," system designers need to watch the housing industry and regularly observe products related to housing. Housing-related products are closely connected with material elements in the guidelines. Therefore, if there are remarkable technological changes in housing-related products, such changes can be smoothly taken up in the guidelines, by arranging relevant material elements' variables and their desired values.

Meanwhile, changes in existing systems related to housing design also occur. Such changes include revisions or alterations of compulsory systems, including building codes, and voluntary systems, such as assessment and rating systems, and standards. System designers can include such changes in the guidelines, usually by modifying relevant variables' desired values.

3.2.3 Feedback from the users

As demonstrated in the lower part of **Figure 3**, "feedback from the system users" and "feedback from the home residents" are also necessary to be considered. The feedback from the system users is information about reactions to the guidelines and checklist, including comments on the validity and user-friendliness of these systems. Such information is used as a basis for the improvement of the systems. Meanwhile, the feedback from the home residents is information about reactions to the homes that have been designed with the guidelines and checklist. Such information, including comments on the homes' amenities and sustainability performance, is also useful for the improvement of the systems.

4. Illustration of producing and revising the design guidelines

4.1 Design guidelines produced in Japan

We produced sustainable design guidelines, with a mind to utilization in Japan. The English translation of the design guidelines has been demonstrated in Table 2 in the monograph's Chapter 4, "Methodology of Applying Control Science to

Sustainable Housing Design." This section briefly reviews the process of producing the design guidelines, anew following the three-stage production process shown in Section 3.1 and **Figure 3**. In addition, the design guidelines shown in the monograph's Chapter 4 were through a revision; however, this section considers the design guidelines as the newly produced version, for the convenience of explanation.

4.1.1 Identification of problems related to housing

The process of producing the guidelines starts with identifying environmental, social, and economic problems related to housing. In this case, identified main problems are shown in the second column of **Table 1**. In this table, the identified problems are divided into two types: "global/general problems" and "local/particular problems." Global/general problems include global warming and climate change, depletion of natural resources, waste, and increase of medical and nursing care expenses due to aging population. On the other hand, main problems considered as local/particular are short lifespan of houses, poor indoor thermal performance, damage caused by earthquakes, and poor landscape. In addition, the boundary between the two types is not so distinguishable.

4.1.2 Identification of the requirements for sustainable housing design

After determining the problems related to housing, we identified the requirements for sustainable housing design. For instance, "global warming and climate change" require "energy saving," "use of renewable energy," and "conservation of green space," for sustainable housing design. Similarly, "poor indoor thermal performance" demands "improvement of indoor thermal performance." In addition, items shown in the right column of **Table 1** are relevant stability conditions.

4.1.3 Determination of elements, variables, and their desired values

Based on the method of selecting material and spatial elements of homes, as well as the requirements for sustainable housing design, first we determined the elements in the design guidelines. The total number of elements was 26, made up of 14 material elements and 12 spatial elements. The material elements were framework, exterior, thermal insulation, windows and doors, interior, bathtub, piping, water heater, appliances, lighting fixtures, equipment for harnessing natural energy, equipment for rainwater use, water-using equipment, and outdoor facilities [3]. The spatial elements were total floor, specified bedroom, areas relating to water use and hot-water supply, position and area of windows, toilet, bathroom, stairs, doorways, hallway, main access route to the entrance, slope, and garden area [3].

After selecting the elements, we determined the variables and their desired values. Choosing only one element, that is, "thermal insulation," the rest of this section shows the details of determining the variable and its desired value. First, we identified "thermal insulation performance" as the variable, considering two requirements, namely, "improvement of indoor thermal performance" and "energy saving," as well as the relevant stability conditions. Higher thermal insulation performance contributes to occupants' better "health" as well as "environmental preservation" and "sustainable use of natural resources" through a reduction in energy usage for heating and air conditioning.

After that, observing trends in systems and technology related to housing thermal insulation performance, we set the desired value of the variable. The set

Type of problems	Main environmental, social, and economic problems related to housing	Requirements for sustainable housing design	Stability conditions
Global/general problems	• Global warming and climate change	• Energy saving • Use of renewable energy • Conservation of green space	• Enviro-preservation • Sustainable resources
	• Depletion of natural resources • Waste	• Extension of housing lifespan • Use of resource-saving or waste-prevention materials	• Sustainable resources
	• Harmful influences caused by climate change	• Adaptation measures	• Health • Safety
	• Flood risks due to rainwater flowing out • Water shortage risks	• Rainwater permeation into the ground • Water saving • Use of rainwater	• Enviro-preservation • Sustainable resources • Health • Safety
	• Increase of medical and nursing care expenses due to aging population	• Accessible and universal design	• Health • Safety
Local/particular problems (in Japan)	• Short lifespan of houses	• Extension of housing lifespan	• Enviro-preservation • Sustainable resources
	• Poor indoor thermal performance	• Improvement of indoor thermal performance	• Health • Enviro-preservation • Sustainable resources
	• Damage caused by earthquakes	• Higher resistance to earthquakes	• Safety
	• Poor landscape	• Consideration for landscape	• Health

Table 1.
Problems related to housing and requirements for sustainable housing design identified for the design guidelines produced in Japan.

desired value was "Grade 4" in the "energy-saving action grades (thermal insulation performance grades)" of the Japan Housing Performance Indication Standards (JHPIS) [3]. "Grade 4" is the highest in the above grades. In addition, housing thermal insulation performance is not stipulated in the building codes in Japan. Accordingly, utilizing the JHPIS, a national voluntary system, we determined the desired value.

4.2 The latest revision of the design guidelines

The design guidelines, the production process of which has been illustrated in the above, have most recently been revised. This latest revision has dealt with the three perspectives previously mentioned: (1) changes in the theoretical world, (2) changes in the practical world, and (3) feedback from the users.

4.2.1 Changes in the theoretical world

First, observing recent trends in understanding about housing-related problems, we have searched for the problems that affect conditions for stability. As a result, we have identified four additional problems which should be dealt with, as shown in the second column of **Table 2**. Two of them are global/general problems; the other two are local/particular problems. Based on these four problems, additional requirements for sustainable housing design have also been identified. After that, these additional requirements have been incorporated into the structure of "element-variable-desired value." The following describes the essentials of the identification and incorporation processes, by each requirement.

4.2.1.1 Storage of electricity

The Paris Agreement of 2015 has aimed to hold global temperatures "well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5°C" [8]. According to the latest IPCC report of 2018, limiting global warming to 1.5°C compared with 2°C would reduce challenging impacts on ecosystems, human health, and well-being [9]. In such very recent situations, the use of renewable energy, especially solar and wind power generation, is rapidly growing in many countries [10]. However, the amount of electricity derived from solar and wind sources fluctuates with time of day, season, and random factors including weather. Accordingly, sharp increase in solar and wind power generation is also increasing breakdown risks in electricity systems [11, 12]. Responding to such changing situations, we have added "storage of electricity" as a requirement for sustainable housing design. Battery electricity storage systems are developing fast, with falling costs and improving performance [13]. In addition, storing electricity leads to securing emergency power source, which is one of adaptation measures against climate change.

When "storage of electricity" is incorporated into the guidelines, "storage battery" has been added as a new material element. In the guidelines, this "storage battery" has been placed just after an existing material element, "equipment for harnessing natural energy," since storage batteries are often installed together with solar power generation systems. Subsequently, two variables of this new element, namely, "type" and "linkage," have been identified. The desired value of "type" has been identified as "stationary battery or electric vehicle battery," because both types are acceptable. Meanwhile, the desired value of "linkage" has been determined to be "interconnection with the home electrical system."

4.2.1.2 Considerations for homeworking, telecommuting, and lifelong learning

Recently housing has been becoming more important as a place of work. The development of information technology and spread of the Internet are facilitating home-based businesses. Meanwhile, an increasing number of companies have been adopting telecommuting [14, 15]. A great advantage of working at home is compatibility with childcare or nursing care. Moreover, working at home is also favorable for the environment because it can reduce energy for commuting.

Meanwhile, life longevity is increasing the necessity of lifelong learning. According to a best-selling book, *The 100-Year Life: Living and Working in an Age of Longevity*, an increasing number of people experience multiple careers, instead of a conventional single career, and inevitably continue to learn [16]. Now people not only recreate themselves in their free time but also need to "re-create" themselves at various places [16].

Type of problems	Environmental, social, and economic problems related to housing	Requirements for sustainable housing design	Stability conditions
Global/general problems	• Breakdown risks in electricity systems due to increasing solar and wind power generation	• Storage of electricit	• Sustainable resources • Health (in crises) • Safety (in crises)
	• Insufficient considerations for homeworking, telecommuting, and lifelong learning	• Considerations for homeworking, telecommuting, and lifelong learning	• Self-realization
Local/particular problems (in Japan)	• Problems resulting from insufficient communication	• Floor planning suitable for good communication among residents	• Mutual help • Self-realization
	• Declining trend of food production and farming population	• Considerations for food production and agricultural learning at housing sites	• Self-realization

Table 2.
Additional problems and requirements for sustainable housing design identified for the latest revision of the design guidelines.

In the past, homes were not considered important as places of work and lifelong learning. Therefore, if attempting to start working or learning at home, people sometimes face difficulties due to a shortage of space and facilities. Taking such situations into account, we have added "considerations for homeworking, telecommuting, and lifelong learning" as a requirement for sustainable housing design.

When "considerations for homeworking, telecommuting, and lifelong learning" is incorporated into the guidelines, "area(s) for working and learning" has been added as a new spatial element. In addition, we consider that the "area for learning" is used by both adults and children. After that, we have identified two variables of this new element, namely, "place(s) in the home" and "equipment." The desired value of "place(s) in the home" has been determined to be "in or near the living/dining room and kitchen area." A reason for this setting is that "in or near the living/dining room and kitchen area" is convenient for combining working or learning with childcare or nursing care. Moreover, this layout is also expected to facilitate communication among residents, as shown in **Figure 4(a)**. Meanwhile, the desired value of "equipment" has been set at "table/desk and shelf (fixed or movable) and Internet connection."

4.2.1.3 Floor planning suitable for good communication among residents

In Japan, many studies on sociology and housing have pointed out that inappropriate room planning is related to social problems, such as school nonattendance and social withdrawal [17–20]. In the Japanese housing market, there are many homes, the floor plans of which are like the conceptual layout shown in **Figure 4(b)**. In homes with such floor plans, children easily enter their private rooms without seeing other family members and can stay isolated. As a result, lack of communication can cause underdeveloped communication skills and moreover school nonattendance [17, 19]. School nonattendance and social withdrawal are closely related to domestic violence [19] and difficulty in entering higher-level schools and finding jobs. Therefore, aiming to prevent these social problems, we have identified "floor planning suitable for good communication among residents" as an additional requirement for sustainable housing design.

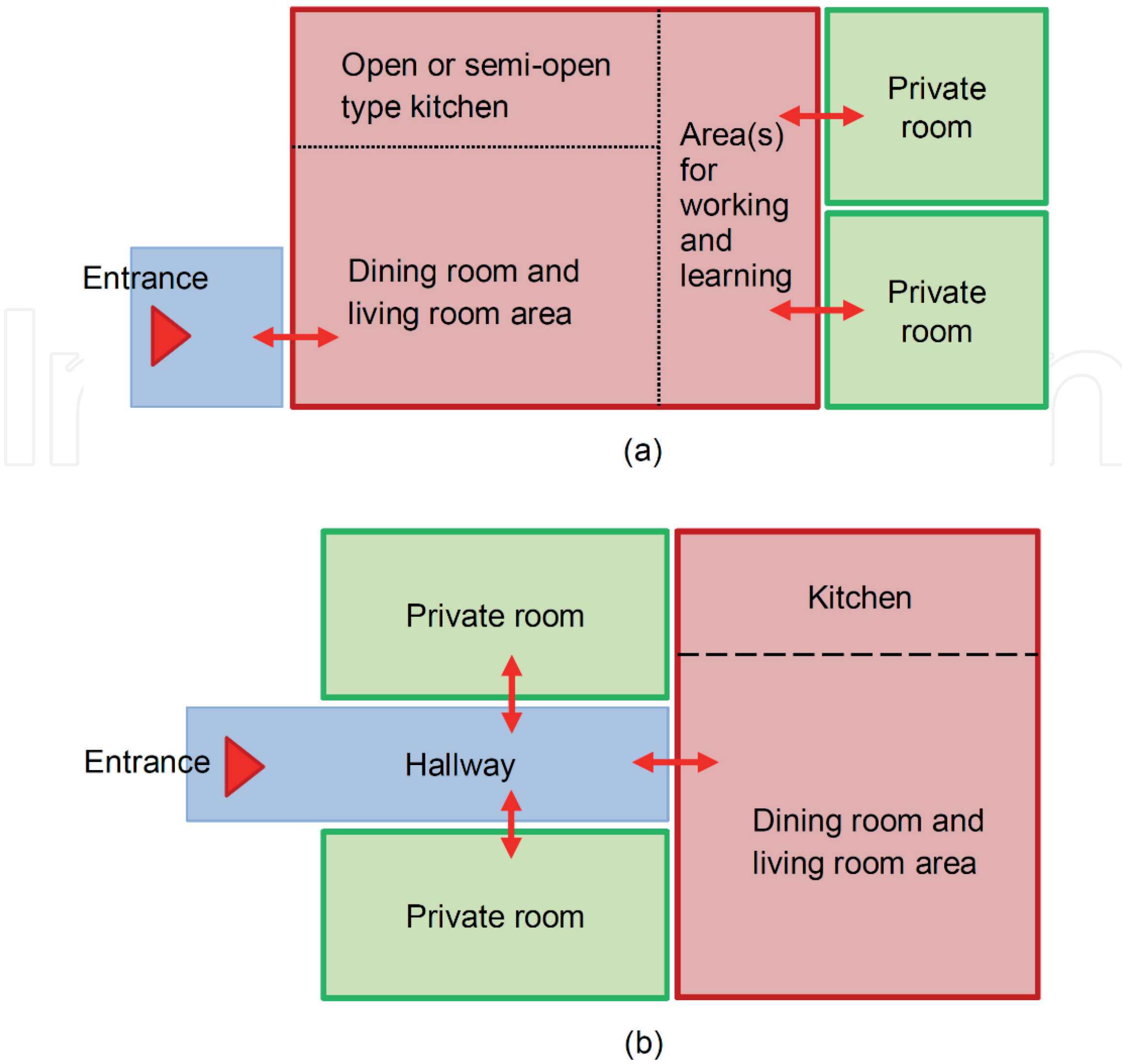

Figure 4.
Conceptual layouts favorable and unfavorable for communication.

The key space to communication among residents is the "living/dining room and kitchen area"; therefore, we have added this area to the design guidelines as a new spatial element. After that, we have identified two variables of this element, that is, "place in the home" and "type of kitchen." The desired value of "place in the home" has been determined to be "between the entrance and private room area," because many experts recommend this placement for more frequent communication [17–20]. Meanwhile, the desired value of "type of kitchen" has been set at "open or semi-open." Recently open- and semi-open-type kitchens are popular in the Japanese housing market since these types of kitchens are favorable for good communication, as compared with closed-type kitchens. The conceptual layout that includes these considerations, as well as "area(s) for working and learning," is demonstrated in **Figure 4(a)**. In addition, there has been a survey on more than 200 homes where successful examinees to famous junior high schools have lived. The results of this survey have revealed that most of these children have learned in or near living/dining room areas, while actively communicating with their family members [21].

4.2.1.4 Considerations for food production and agricultural learning at housing sites

The recent situation of Japan's farming population and food production has been declining alarmingly. The farming population has decreased from 2.61 million in 2010 to 1.75 million in 2018 [22]. The average age of the farming population has risen from 65.8 years old in 2010 to 66.8 in 2018 [22]. The total area of abandoned farmland has increased from 123,000 ha in 1980 to 423,000 ha in 2015 [23]. There has also been a long-term declining trend in the food self-sufficiency rate. The calorie-based food self-sufficiency ratio in 2017 is only 38% and the monetary-value-based self-sufficiency ratio is 65% [24].

Currently homes in Japan are usually separated from food production. One of the measures for encouraging people to be involved in food production is "food and agriculture education," which can be conducted at homes, schools, and local communities. Food and agriculture education at home is mainly connected with farmwork at vegetable gardens. According to a survey, experience of growing vegetables at home has positive effects on children's intention to engage in farming as work in the future [25]. Moreover, after starting as a vegetable gardener, more than a few people try to be a professional farmer [26].

Discovering that housing is related to Japan's food and agriculture problems, we have added "considerations for food production and agricultural learning at housing sites" as a requirement for sustainable housing design. In addition, there are also other reasons why this consideration has been added: (1) farm work is beneficial to health [27], (2) farming leads to securing emergency food, (3) farming encourages communication with family members and neighboring residents [27], and (4) farming can help people commune with nature.

When "considerations for food production and agricultural learning at housing sites" is incorporated into the guidelines, "vegetable garden and/or fruit trees" has been added as a new variable of the existing spatial element "garden area." Subsequently, the desired value of "vegetable garden and/or fruit trees" has been set at "included."

4.2.2 Changes in the practical world

Observing recent changes in technology and systems, we have revised the desired values related to two points: (1) thermal insulation performance standards, and (2) energy-efficient water heaters. Moreover, we have modified the desired value of rainwater equipment, following a slight change in the description of the related system.

4.2.2.1 Thermal insulation performance standards

Japanese housing thermal performance has traditionally been low. However, it is gradually improving, due to changes in housing-related technology as well as requirements for energy saving and occupants' health. As a result, recently a new national voluntary system, the "net zero energy house (ZEH) certification standards," has emerged and shown higher thermal performance criteria than the usual criteria [28, 29].

Recognizing these changes in the practical world, we have lifted the desired value regarding thermal performance in the guidelines. To be concrete, we have revised the desired value of "thermal insulation performance" of the two material elements, "thermal insulation" and "windows and doors," to the relevant criteria stipulated in the ZEH certification standards. The ZEH thermal insulation performance criteria are evaluated based on "average heat transmission coefficient (U_A)." The standard value of "U_A" varies, depending on climate classification. For instance, the criterion of "U_A" for the area where Tokyo is included has been set at "0.6 W/(m^2 K) or less" [28, 29].

4.2.2.2 Energy-efficient water heaters

Following the rise of a new type of energy-efficient water heater in the market, we have modified the desired value of "type of water heater." At the same time, this revised version has adopted a way of offering choices as energy-efficient types, instead of quoting an assessment level used in Japan's national assessment and certification system, *CASBEE for Detached Houses*. The offered choices are the following four types: (1) solar, (2) electric heat-pump, (3) electric heat-pump and instantaneous gas combined, and (4) fuel-burning latent-heat recovery instant-supply. The third type, which is often called "hybrid," is the aforementioned new type of energy-efficient water heater [30].

4.2.3 Feedback from the users

4.2.3.1 Feedback from the system users

After finding a thought-provoking suggestion in recent feedback from the guidelines/checklist users, we have decided to include it in the latest revision. The main point of this suggestion is that lighting fixtures used in living spaces should be products with brightness and color adjustment functions, for energy saving and occupants' health.

Required brightness of indoor artificial lighting varies according to circumstances, such as natural lighting through windows and occupants' visual comfort. Moreover, lighting capable of adjusting brightness and color is also favorable for residents' health. Exposure to bright lights at night suppresses the secretion of melatonin and can affect sleep and potentially cause diseases, such as sleep disorder and diabetes [31, 32]. Although light of any color can suppress melatonin secretion, especially blue light at night has greater effects [31, 32]. Therefore, especially in living spaces, lighting fixtures fitted with brightness and color adjustment functions are favorable for both energy conservation and residents' health.

On the other hand, LED lighting fixtures with brightness and color adjustment functions are on the market at reasonable prices. Accordingly, we have made a revision to the desired value of "type of light" for "lighting fixtures" in the guidelines, namely "LED," adding "lighting fixtures used in the living spaces are fitted with brightness and color adjustment functions" as a supplementary note to "LED."

4.2.3.2 Feedback from the home residents

There have not been any reactions from the home residents which have led to the revision of the guidelines. Meanwhile, we have had a remarkable comment from the occupants who live in the home of the case study that has been introduced in Chapter 5 of the monograph. The comment says that "this home's thermal insulation performance is satisfactory, but this thermal performance level is never excessive." The building envelope's heat loss coefficient (Q) of this house is "$Q = 1.9$ [$W/(m^2\ K)$]" [33], which can be converted into "$U_A = 0.61$ [$W/(m^2\ K)$]." "$U_A = 0.61$ [$W/(m^2\ K)$]" is almost equal to the net zero energy house (ZEH) thermal performance criterion for this area division. Accordingly, this comment has supported the adoption of the ZEH thermal performance criteria, as the desired value of thermal insulation performance.

Finally, all of the above revision items have been incorporated into the table of "element-variable-desired value" structure. The final revised version of the guidelines is shown in **Table 3**; the added and modified descriptions are written in *italics*.

Element	Variable	Desired value	Stability condition
Framework	Resistance to earthquakes	JHPIS 1-1: Grade 2 or over	• Safety
	Durability	JHPIS 3.1: Grade 3	• Sustainable resources
	Materials	CASBEE LR_H2 1.1: Level 4 or over	• Sustainable resources
Exterior (outer wall, roof, etc.)	Fire resistance (outer wall)	JHPIS 2-6: Grade 3 or over	• Safety
	Shape and color	Consideration for the landscape	• Health
	Durability	CASBEE Q_H2 1.2 and 1.3: Level 4 or over	• Sustainable resources
	Materials	CASBEE LR_H2 1.3: Level 4 or over	• Sustainable resources
Thermal insulation	Thermal insulation performance	*Thermal performance criteria stipulated in the net zero energy house (ZEH) certification*	• Health • Enviro-preservation • Sustainable resources
Windows and doors	Thermal insulation performance	*Thermal performance criteria stipulated in the ZEH certification*	• Health • Enviro-preservation • Sustainable resources
	Sunlight adjustment capability	CASBEE Q_H1 1.1.2: Level 4 or over	• Health • Enviro-preservation • Sustainable resources
	Sound insulation performance	CASBEE Q_H1 4: Level 4 or over	• Health
	Measures to prevent intrusions	CASBEE Q_H1 2.3: Level 4 or over	• Safety
	Protection of glass against impacts	With shutters	• Safety
Interior	Measures against formaldehyde	CASBEE Q_H1 2.1: Level 5	• Health
	Materials	CASBEE LR_H2 1.4: Level 4 or over	• Sustainable resources
Bathtub	Heat insulation	Insulated	• Enviro-preservation
Piping	Measures for maintenance	JHPIS 4.1: Grade 3	• Sustainable resources
	Method of water and hot-water piping	Header and pipe-in-pipe system	• Enviro-preservation • Sustainable resources
Water heater	Type of water heater	*Energy-saving type (solar, electric heat-pump, electric heat-pump and instantaneous gas combined, fuel-burning latent-heat recovery instant-supply type)*	• Enviro-preservation • Sustainable resources
Appliances	Energy-saving standard achievement rate	100% or more (three or more stars)	• Enviro-preservation • Sustainable resources

Element	Variable	Desired value	Stability condition
Lighting fixtures	Type of light	LED *(lighting fixtures used in the living spaces are fitted with brightness and color adjustment functions)*	• Enviro-preservation • Sustainable resources
Equipment for harnessing natural energy	Harnessed natural energy	100% or more of the total energy usage	• Health (in crises) • Safety (in crises) • Enviro-preservation • Sustainable resources
Storage battery	*Type*	*Stationary battery or electric vehicle battery*	• Health (in crises) • Safety (in crises) • Sustainable resources
	Linkage	*Interconnection with the home electrical system*	
Equipment for rainwater use	Rainwater equipment	*Rainwater tank (80 lit. or more) or system with a rainwater tank (80 lit. or more) for daily use*	• Health (in crises) • Safety (in crises) • Enviro-preservation • Sustainable resources
Water-using equipment	Water-saving functions	CASBEE LR_H1 2.1: Level 4 or over	• Enviro-preservation • Sustainable resources
Outdoor facilities (fence, etc.)	Form	Not blocking sightlines	• Safety • Mutual help
	Appearance	Consideration for the landscape	• Health
	Materials	CASBEE LR_H2 1.5: Level 5	• Sustainable resources
Total floor	Total floor area	75 m^2 or more [Note 4]	• Health
Specified bedroom	Routes to toilet and bath area, dining room, kitchen, and entrance	Accessible without steps	• Health • Safety
	Internal floor space	9 m^2 or more	
Living/dining room and kitchen area	*Place in the home*	*Between the entrance and private room area*	• *Mutual help*
	Type of kitchen	*Open or semi-open*	
Area(s) for working and learning	*Place(s) in the home*	*In or near the living/dining room and kitchen area*	• *Mutual help* • *Self-realization*
	Equipment	*Table/desk and shelf (fixed or movable) and Internet connection*	
Areas relating to water use and hot-water supply	Areas in the home	Placing them closer	• Enviro-preservation • Sustainable resources
Position and area of windows	Natural ventilation	CASBEE Q_H1 1.2.1: Level 5	• Health • Enviro-preservation • Sustainable resources
	Ratio of total window area to floor area in each living space	20% or more	
Toilet	Internal length or spacing	JHPIS 9.1: Grade 3 or over	• Health • Safety
	Handrails which help users sit and stand	Installed	

Element	Variable	Desired value	Stability condition
Bathroom	Floor space and width	JHPIS 9.1: Grade 3 or over	• Health • Safety
	Handrails help users go in and out of the bathtub	Installed	
Stairs	Grade of steepness	JHPIS 9.1: Grade 3 or over	• Health • Safety
	Handrails	Installed	
Doorways	Differences in level	No differences	• Health • Safety
	Width	75 cm or more (Bath: 60 cm or more)	
Hallway	Width	78 cm or more	• Health • Safety
Main access route to the entrance	Surface	Level or sloping	• Health • Safety
	Width	90 cm or more	
Slope	Grade of steepness	1/8 or less	• Health • Safety
	Handrails	Installed	
Garden area	Ratio of the garden area to the exterior area	40% or more	• Enviro-preservation
	Vegetable garden and/or fruit trees	*Included*	• *Health* • *Mutual help* • *Self-realization*

(1) "Material elements" are from "framework" to "outdoor facilities," and "spatial elements" are from "total floor" to "garden area."
(2) JHPIS means the Japan Housing Performance Indication Standards (for new homes).
(3) CASBEE means CASBEE for Detached Houses (for new construction)—Technical Manual 2018 Edition.
(4) At least one story's area (excluding stairs) is 40 m^2 or more.

Table 3.
The latest revised version of the sustainable design guidelines.

5. Discussion

This section discusses the study results from the following three perspectives: (1) comprehensive visualization of process for producing and revising the guidelines, (2) adjustment to different and changing situations, and (3) meaning of using the guidelines and checklist.

5.1 Comprehensive visualization of process for producing and revising the guidelines

Section 3 of this chapter has demonstrated the process of producing and revising the sustainable design guidelines and sustainability checklist. Especially **Figure 3** has comprehensively visualized both the production and revision processes in one diagram.

The production process has been shown through the three stages: (1) identification of problems related to housing, (2) identification of the requirements for sustainable housing design, and (3) determination of elements, variables, and their desired values. Following this three-stage process, Section 4.1 has briefly reviewed the production process of the already produced design guidelines. The previous publications, including the monograph, mentioned the production process and explained especially the third stage in detail. However, they could not show the consecutiveness of the three stages. On the other hand, the diagramming of the production process has clarified the overall perspective of producing the design guidelines.

Meanwhile, the revision process has been demonstrated from the three perspectives: (1) changes in the theoretical world, (2) changes in the practical world, and (3) feedback from the users. Following this process, we have made the latest revision of the design guidelines, as shown in Section 4.2. When comparing this latest revision with the previous one, we consider that this schematization has made the process more manageable and helped us to revise the guidelines more efficiently.

5.2 Adjustment to different and changing situations

The previous publications have already indicated that the "element-variable-desired value" structure in the guidelines has a mechanism of "adaptability to regional differences" and "flexibility toward changes over time" [4, 7]. This chapter has more concretely supported this indication. It has shown how to help system designers to adjust the guidelines to different and changing situations.

Tables 1 and **2** in Section 4 have demonstrated local/particular problems observed in Japan, in addition to global/general problems. As a result, such local/particular problems have naturally been taken in the process of producing and revising the guidelines. The produced and revised guidelines are suitable for the Japan's situation. If the same method is adopted in other countries or regions apart from Japan, similar results are expected to be obtained.

Meanwhile, Sections 3.2 and 4.2 have shown the process of revising the guidelines and its concrete example, respectively. These study results include theoretical and practical ways to adjust the guidelines to changing situations over time.

5.3 Meaning of using the guidelines and checklist

The guidelines and checklist are "user-friendly" because of their compactness as well as ease of comparison. The guidelines and checklist are simple tables. Meanwhile, material and spatial elements are equivalent to actual parts of homes; therefore, people involved in design can easily compare them with the actual home or drawings [4, 7].

The guidelines and checklist have another characteristic, "comprehensiveness." The main factor of this feature is the use of the "model of sustainability," which has been shown in **Figure 2**. This model contains "mutual help" and "self-realization," in addition to common considerations, such as health, safety, environmental preservation, and natural resources. As a result, as demonstrated in the latest revision of the guidelines, considerations for communication, working, and learning have been included. Furthermore, these inclusions have led to indicate a new aspect of homes, where residents are learning and working while communicating with one another.

The sustainable design guidelines and sustainability checklist can be used in various steps in the design processes, as demonstrated in **Figure 1.** If system users refer to them in such processes, they can easily and comprehensively check points for sustainable housing design. Houses are used for a very long time. Meanwhile, renovation after the construction wastes resources, labor, and money. In order to achieve sustainable housing as well as avoid regrets after the construction, it is meaningful to use the guidelines and checklist.

6. Conclusion

The previous study has provided the control system for promoting sustainable housing design where the sustainable design guidelines and sustainability checklist are incorporated. Based on these accomplished research results, this study has comprehensively visualized the process of producing and revising the design guidelines and checklist. Following this process, this study has also illustrated the production and revision processes of the design guidelines. The study results suggest that the comprehensive visualization can make these processes more manageable and help system designers to produce and revise the guidelines more efficiently.

Moreover, this study has indicated how to adjust the guidelines to different and changing situations. It has included a method of identifying housing-related problems, in which local/particular problems are identified, in addition to global/general problems. If this method is adopted in a country or region, the produced and revised guidelines are expected to suit to the situation of that country or region. Meanwhile, the provision of the process of revising the guidelines and its concrete example helps system designers to adjust the guidelines to changing situations over time.

The guidelines and checklist have a characteristic of comprehensiveness, resulting from using the model of sustainability. This model contains mutual help and self-realization, in addition to usual considerations, such as health, safety, and environmental preservation. As a result, the latest revision of the guidelines has led to include considerations for communication among residents, as well as working and learning at home.

Utilizing the "control system for promoting sustainable housing design" and the "model of sustainability," this study has illustrated the "process of producing and revising the design guidelines and checklist." These schematizations form a comprehensive strategy for promoting sustainable housing design. This comprehensive housing strategy is expected to be used to maximize people's well-being and minimize the environmental load.

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