

Expectations for DX Progress in the Field of Building and Infrastructure

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Abstract

In order to avoid divergent discussions on DX in the field of building and infrastructure and to provide an opportunity to obtain extensive advice from DX experts and academics, I will summarize the challenges and expectations for DX development in this field.

1. Introduction

The demand for decarbonization is accelerating in the social infrastructure field and needs to be addressed in conjunction with pressing issues such as the frequent occurrence of natural disasters, a declining working population, and progressive aging (Fig. 1). The social infrastructure to be considered, the DX expected as a means, and the issues such as decarbonization are wide-ranging. Perspectives on these topics can vary depending on one’s position and role in the market, leading to divergent debates among industry stakeholders. Even within a single company, the advancement of DX is breaking down traditional boundaries between manufacturing, sales, technology, and research, and making discussions on essential issues even more critical.

Under such circumstances, this paper briefly summarizes the situation in the social infrastructure field and aims to provide an opportunity to obtain effective advice from DX experts and academics, and also to discuss the progress of DX. For this reason, we will introduce related matters while classifying and organizing them, but it is assumed that accurate explanations of each item will be obtained by referring to the relevant literature.

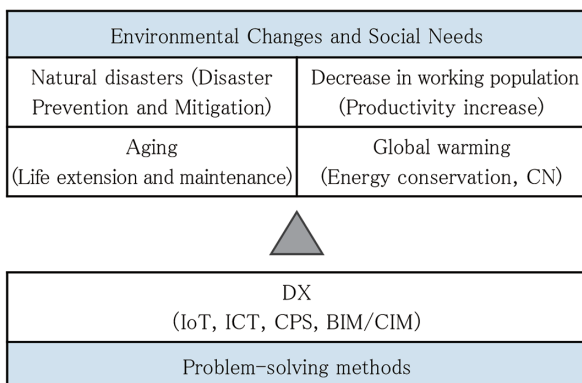


Fig. 1 Environmental changes, social needs, and problem-solving methods

2. Definition of “Social Infrastructure” in this Paper

The Ministry of Land, Infrastructure, Transport and Tourism lists roads, flood control (rivers, erosion control), sewers, ports, public housing, parks, beaches, airports, and government facilities as “social infrastructure that requires maintenance and management.”¹⁾ These are facilities managed by the national and local governments. The targets also include low-rise housing, high-rise buildings, non-residential buildings such as factories and warehouses, and facilities related to energy and railways. The broad definition of social infrastructure that summarizes these is defined as “buildings and infrastructure,” which is the subject of this paper and is organized as shown in Table 1. Various factories, including steel works and energy facilities such as power plants, are categorized as industrial infrastructure.

3. DX in Social Infrastructure Field

3.1 Three DXs

DX has different meanings and expectations in the social infrastructure field. This paper categorizes DX into three types, as shown in Table 2. These types are not definitive but are intended to illustrate the current situation and highlight the features of the field in

Table 1 The broader meaning of social infrastructure covered in this report

Social infrastructure	Roads, railroads, water supply, electricity (transmission facilities), gas, communications (towers), ports, levees, dams, stations, airports, Important buildings (hospitals, city halls, schools)
Industrial infrastructure	Various plants including steel works, Power plants and other energy facilities
Building	High-rise buildings (offices, condominiums, hotels, commercial facilities) Low-rise residential buildings (apartment buildings, detached houses, commercial facilities), warehouses

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Table 2 Classification of DX in this report

DX-A	Technology to reproduce/transcend human proficiency with data science (big data, machine learning, etc.)
DX-B	Technology for data sharing and virtualization of machining/construction processes (3D databasing and virtualization, etc.)
DX-C	Cases where the business model and/or concept is more important than the technology (using/not using the latest technologies listed above)

question.

DX-A: Aims to reproduce or surpass the skills of experts by using data science.

It involves the technology to analyze digital information obtained from IoT and big data using AI, etc., and to reproduce information processing formerly considered a black box as the expertise of skilled engineers or produce new results that go far beyond human thinking. In its quarterly magazine,²⁾ Nippon Steel Corporation promotes digital reform as the twin pillars of business process reform and production process reform. DX-A corresponds to the image of DX held first by many people involved in the manufacturing industry.

DX-B: Aims to make the completed form virtually visible before processing or construction.

DX-B aims to improve the efficiency of the construction process by sharing post-construction images by allocating 3D models or checking for temporal and spatial interferences and centers on the use of building information modeling (BIM) and construction information modeling (CIM). The Ministry of Land, Infrastructure, Transport, and Tourism has been promoting i-Construction and working to standardize 3D data, make it open data, improve the environment for its utilization, and create new businesses. It is expected that digital twins or cyber-physical system (CPS) models will be used to improve the efficiency of post-construction maintenance and management.³⁾ CPS models are leading the way in the aviation industry. DX-B is the first image of DX that many people in the construction industry have.

DX-C: Other technologies

In addition to the above, there are issues before developing and utilizing the latest technologies, such as AI, and the difficulty of systematization is relatively small. Some can be addressed using existing technologies. Even if some of the technologies equivalent to DX-A and DX-B mentioned above are utilized, the essential issues often are how to sell and design the business model. In this paper, to share the situation and prevent the discussion from diverging, we have organized DX-C separately from the other two DX-A and DX-B technologies.

3.2 Towards Society 5.0

Another valuable reference is Society 5.0, advocated by the Cabinet Office.⁴⁾ Society 5.0 presents a range of initiatives and policies aimed at promoting economic development and addressing social issues from multiple perspectives. A central concept in Society 5.0 is the advanced fusion of virtual space (digital information) and real space (physical objects), which is commonly referred to as DX. When applied to typical processes in the social infrastructure field,

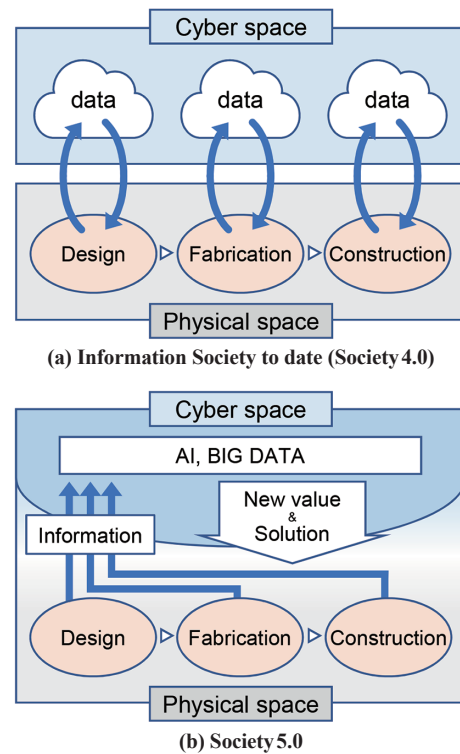


Fig. 2 Schematic diagram of change from the Society 4.0 to Society 5.0 in the field of building and infrastructure

such as design, fabrication, and construction, the principles of Society 5.0 can be organized as depicted in Fig. 2. In contrast to the conventional information society (Society 4.0), where each process operates independently with separate access to digital information, calculations, analyses, and visualizations are performed based on human instructions. In Society 5.0, there is a shift towards aggregating and managing information as big data that will be analyzed using AI for designers and builders who would receive hints and improvement measures for their work processes. While it may take time for these evolved systems to become commonplace within the social infrastructure field, the momentum towards embracing changes aligned with the principles of Society 5.0 continues undeterred.

In the face of these impending changes, there are current strategies that can improve real-world processes. Optimization, standardization, and modularization (as depicted in Fig. 3) serve as effective means to achieve these objectives. In this paper, the respective approaches are organized as follows:

- (a) Optimization: This involves eliminating waste in structural design, structural details, and the construction process. By doing so, it helps to save materials and labor while reducing the CO₂ emissions. It is crucial to balance maintaining convenience and achieving economic efficiency.
- (b) Standardization: The aim of standardization is to reduce the CO₂ emissions by promoting the use of standardized materials. By limiting the variety of materials and components used in construction projects, it becomes possible to meet diverse market needs.
- (c) Modularization: This approach optimizes and standardizes larger elements, groups, and functions.

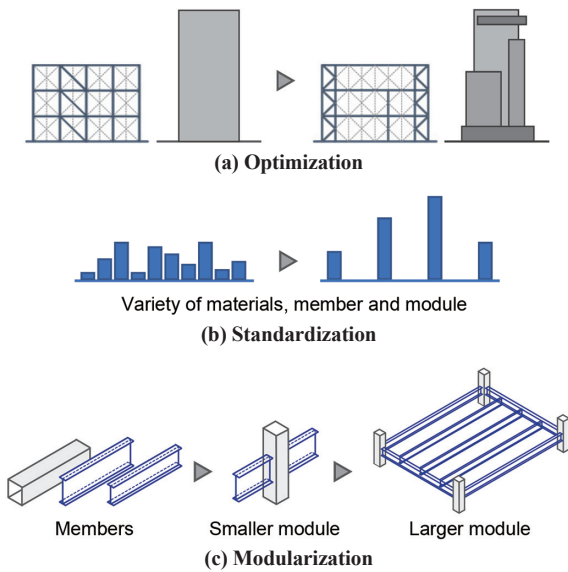


Fig. 3 Three approaches to R&D for Society 5.0

4. Issues and Expectations in Social Infrastructure Field towards Carbon Neutrality

4.1 Contribution to life cycle CO₂ emission reduction

To effectively reduce the CO₂ emissions, it is crucial to consider the entire life cycle of social infrastructure projects. DX holds the promise of eliminating partial optimization in this regard. The life cycle of social infrastructure encompasses various stages, including material manufacturing, planning, design, fabrication, construction, operation, maintenance, removal, and recycling. The ultimate objective is to achieve comprehensive optimization throughout each life cycle step. To facilitate discussion on CO₂ emission reduction strategies, here are some examples of key considerations for each process.

The CO₂ emitted during the planning and design process is relatively small in the life cycle. Reducing the weight of structural members and reducing their number are effective. By increasing the strength of materials and adopting more rational usage technologies, this process holds the key to reducing the CO₂ emissions generated in subsequent processes. In the planning and design process, it is expected to make these visible in advance, and the BIM and CIM technologies described below will be responsible for this.

Improving the efficiency of cutting and welding is a key measure in the fabrication process. **Figure 4** shows an example of the relationship between steel thickness reduction and welding work reduction. Although this example is a somewhat rough comparison based on the so-called 6 mm conversion rate,⁵⁾ it can be seen that the welding work reduction rate becomes more effective as the steel thickness increases. Thus increasing the strength of steel and reducing its thickness is an approach that will produce results.

The construction and removal processes account for a certain part of CO₂ emissions, and construction companies and other organizations are taking the lead in efforts to reduce the CO₂ emissions. To discuss the life cycle, a technological development that considers “ease of making” and “ease of disassembling” will accelerate in the future.

A large portion of the life cycle CO₂ emissions is accounted for by CO₂ emitted during material manufacturing and operation. For roads, bridges, etc., reducing the CO₂ emissions during operation is primarily an issue for automobiles. On the other hand, the CO₂ emit-

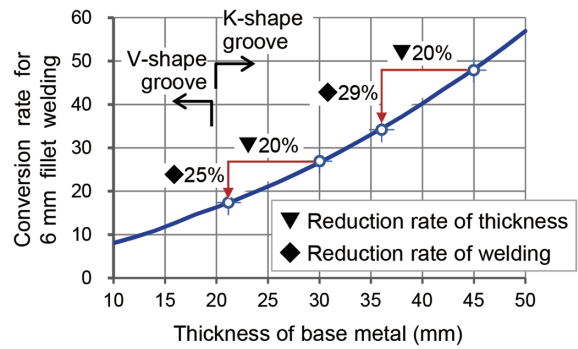


Fig. 4 An example of the relationship between steel thickness reduction and welding (welding material and work) reduction

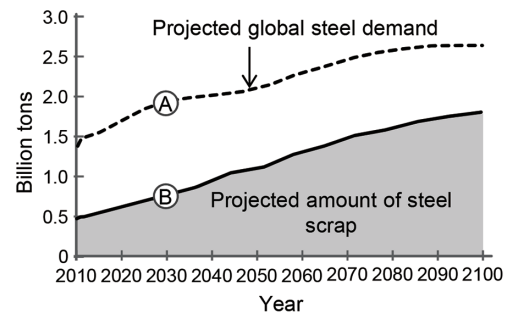


Fig. 5 Future projection for amount of steel scrap and global steel demand⁹⁾

ted during the operation of building structures, especially homes and offices, has a greater impact on the life cycle CO₂ emissions than the CO₂ emissions during material manufacturing. The CO₂ emissions during operation will be discussed later. Tools for estimating the life cycle CO₂ emissions, including those during operation, are available, such as those shown in Reference 6).

Regarding the CO₂ emitted during material manufacturing processes, Nippon Steel has set a target of reducing the total CO₂ emissions by 30% starting in 2013 and with a target of 2030. In addition, as part of our 2050 vision, we are aiming for carbon neutrality through multiple means.⁷⁾ Most of the steel materials are horizontally recycled. Furthermore, according to Reference 8), it is estimated that domestic steel materials, including those used in construction, automobiles, home appliances, beverage cans, etc., can be recycled five times on average every 100 years. On the other hand, according to Reference 9), it is said that the amount of steel recycled in society cannot be suddenly increased. To achieve both CO₂ emission reduction and economic development, we can understand the importance of supplying steel in a well-balanced manner by using blast furnaces and electric arc furnaces (**Fig. 5**). The entire market must share the CO₂ emissions in an objective and essential way throughout the entire life cycle on the assumption of recycling. There are high expectations for DX as a means of achieving this goal.

4.2 Ongoing changes (progress of BIM/CIM)

As mentioned in Chapter 3, BIM/CIM is an example of ongoing DX in the social infrastructure field. Data linkage using these methods has already commenced. Their utilization is more advanced overseas in regions such as Europe, the USA, and ASEAN countries than Japan.

BIM/CIM is a mechanism for sharing 3D construction data

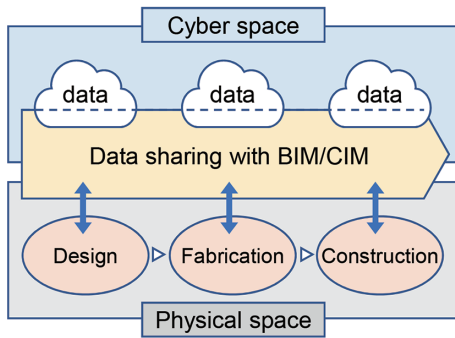


Fig. 6 Construction data sharing using BIM/CIM

throughout the construction process. Since there is already an abundance of information available, we will not delve into the details in this article. A simplified image is shown in Fig. 6. As shown in Fig. 2, the process can be summarized in three parts: design, fabrication, and construction. It is said that BIM/CIM serves as a platform that enhances labor productivity through data sharing. For example, with BIM in the domestic building steel framework field, data is separated into the design and fabrication processes. However, issues with data exchange between the two processes remain. Design BIM mainly uses 3D information on the desktop, so the study is confined to a computer. With fabrication BIM, it is necessary to expand from 3D information (virtual/cyber) to steel frame fabrication (physical). This includes data compatibility, the coordination method (a method that optimizes and reduces costs through communication between the processes), and the data defect problem (the problem of where responsibility lies for compensation for damages resulting from data defects), among other issues. The current method that can maximize coordination benefits is one of the so-called “legacy systems” that are strengths of domestic companies and engineers. It is important to determine whether or not it is possible to advance Japanese-style BIM/CIM by taking advantage of these as well. This will likely become an issue in the future market.

Furthermore, an existing business already handles the exchange of BIM data for the design and fabrication processes. This is considered one of the fundamental issues. We expect this business to continue developing, and BIM/CIM will become even more popular.

4.3 Substantive changes to be accelerated

Nippon Steel will continue to develop materials and material utilization technologies that can make essential contributions from an LCA perspective. The following two approaches are possible.

4.3.1 Quantification of essential value through visualization and sharing of information: L-LCA (longer life cycle assessment)

The CO₂ emissions in the life cycle of building structures (hereafter referred to as LCCO₂) are higher during operation than during construction. Some estimates suggest that for a house in use for 60 years, operational CO₂ emissions are three times higher than construction CO₂ emissions. Figure 7 shows an example of the calculation results of the LCCO₂ composition of a low steel framed house based on the data of the Forestry Agency.¹⁰⁾ The so-called embodied CO₂ remains at around 20% of the total until the completion of construction. The CO₂ from heating and cooling is estimated at 30% of the total with current insulation specifications. Improving the thermal insulation property effectively reduces CO₂ emissions and even

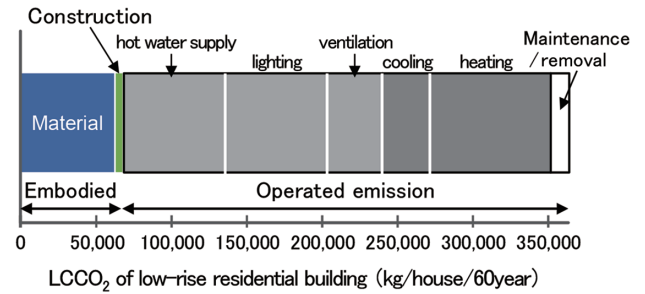


Fig. 7 Life cycle CO₂ emissions in low-rise housing over 60 years and its composition (an example)

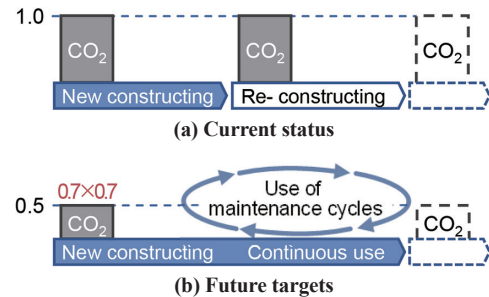


Fig. 8 CO₂ reduction target due to weight reduction and longer operating life

the LCCO₂ during operation.

It is considered difficult to reduce the CO₂ emissions during the operation of road bridges and other structures by improving their performance. Countermeasures include extending the lifespan of the structures and increasing their maintenance efficiency. For example, one approach is to reduce the CO₂ emissions during manufacture and material weight by 30% and to halve the embodied CO₂ emissions ($0.7 \times 0.7 \approx 0.5$) as the product of both reduction effects. Next, the aim is to compress the CO₂ emissions to one-quarter of the original CO₂ emissions ($0.7 \times 0.7 \times 0.5 \approx 0.25$) by doubling the life of the structure by strengthening its maintenance (Fig. 8). Although it may not be easy to establish the conditions to achieve this aim, it is a worthy research goal.

There are high expectations for DX to make the CO₂ emission reduction effects of improving insulation specifications and extending the lifespan of infrastructure, including maintenance, visible to owners, designers, and even society as a whole.

Steel is a material with the great advantage that almost all of it, except for a few percent that is discarded, can be horizontally recycled. We believe that one of our essential contributions is to aim for overall optimization within this process so that we can evaluate products over a longer life cycle, including repeated recycling. This is an important value that should be shared throughout the market for the future of the global environment and is referred to in this paper as L-LCA (longer life cycle assessment).

BIM/CIM is expected to be a platform for sharing information on the CO₂ emissions, organized from the L-LCA perspective. The design information and CO₂ emissions at that time are shared, as illustrated in Fig. 9. The diagram shows a series of construction processes, with the symbols S, P, D, F, C, O, M, and R referring to material, planning, design, fabrication, construction, operation, maintenance, and recycling, respectively. In the L-LCA value system, it is necessary to achieve overall optimization over a longer life cycle in

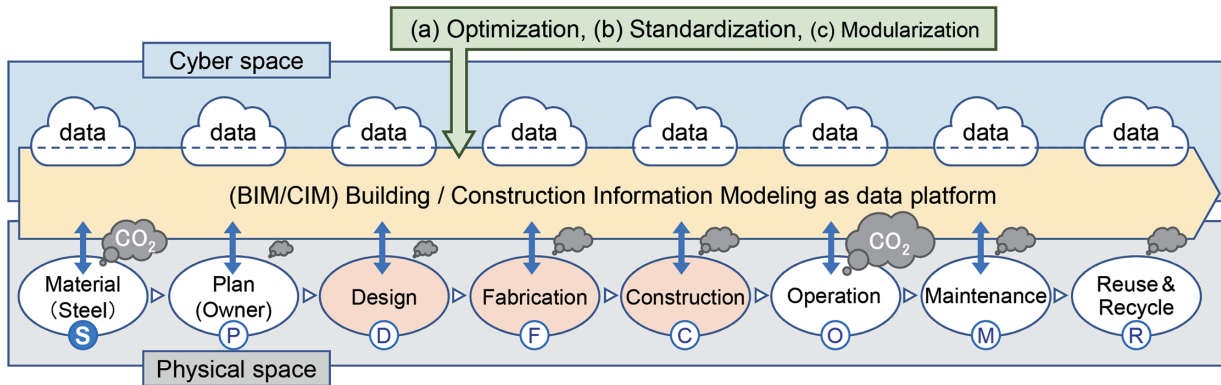


Fig. 9 Ideal construction/operation data sharing in the field of building and infrastructure

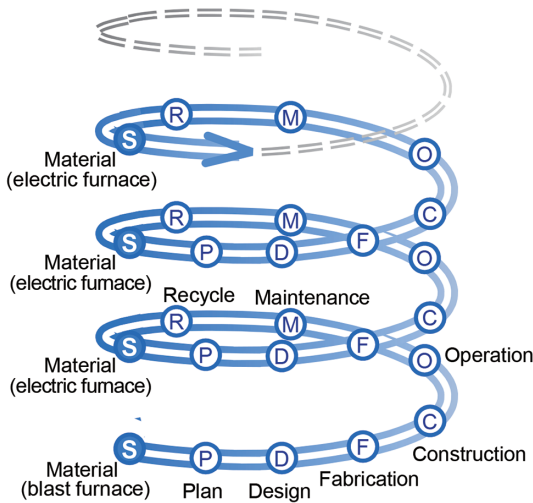


Fig. 10 Construction process and recycling spiral (Ideal longer life cycle)

the resource circulation spiral illustrated in Fig. 10. The ability to quantify and share this will bring us closer to the essential issues. This is the greatest expectation for DX in the social infrastructure field.

4.3.2 Addressing challenges by promoting optimization, standardization, and modularization

When minimizing CO₂ emissions, steel structures are becoming more complex. Hybrid wood and steel structures and the increasing use of both blast furnace and converter slags in concrete structures exemplify this. When issues such as material saving, labor saving, and longevity are added, designs will inevitably become even more complex.

Steel manufacturers have developed and own some of the latest design and utilization technologies for efficiently using steel materials. Overall optimization within L-LCA requires cooperation across the market. Nippon Steel will be more proactive than ever in providing design and usage technologies that contribute to problem-solving. There are high expectations for DX, especially cloud computing, as a way to achieve the optimization, standardization, and modularization mentioned above. For example, the optimal geometric design method for 3D steel frames, such as those used in architectural structures, is being developed mainly by construction companies. As a steel maker, Nippon Steel believes that we can contribute to CO₂ emission minimization from an L-LCA perspective by pro-

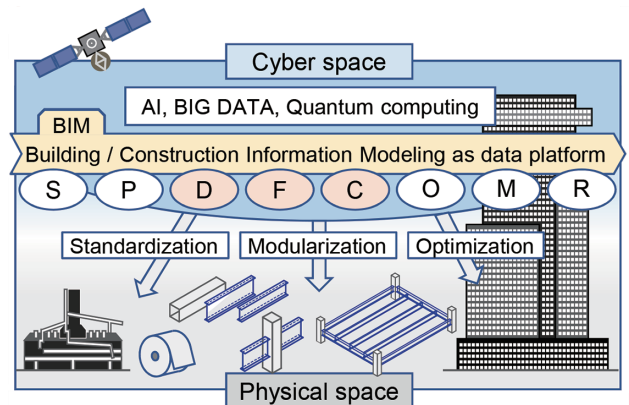


Fig. 11 Approach to a complex set of issues by promoting optimization, standardization and modularization

viding structural optimization combined with material properties and a mechanism that can be accessed from the BIM data platform.

Our discussion assumes that the issues of data linkage across companies and industry boundaries using BIM/CIM as a platform can be overcome. When we compare it to the concept of Society 5.0 presented by the Cabinet Office mentioned earlier, the future picture of the social infrastructure field can be summarized in a schematic diagram like the one shown in Fig. 11. This means that measures are needed to balance the ultimate goal of optimizing each aspect of social infrastructure with the standardization of materials, parts, and modules, goals that have some contradictory characteristics. There are also high expectations for DX as a means of achieving this.

5. Expectations for Other DX-related Technologies

In addition to the above, there are various other DX-related technologies. The following introduces some of them that will greatly contribute to solving social infrastructure issues. Note that AI technology and construction robot technology that involve machine learning are excluded from the subjects of discussion in this paper because the targets and policies for development are wide-ranging and because sufficient information is provided by construction companies actively promoting development.

5.1 Cyber-physical system (CPS) (Fig. 12)

It is hoped that the concepts of CPS and digital twins leading the way in the aviation industry will be introduced into the social infrastructure field, particularly for maintenance management. For exam-

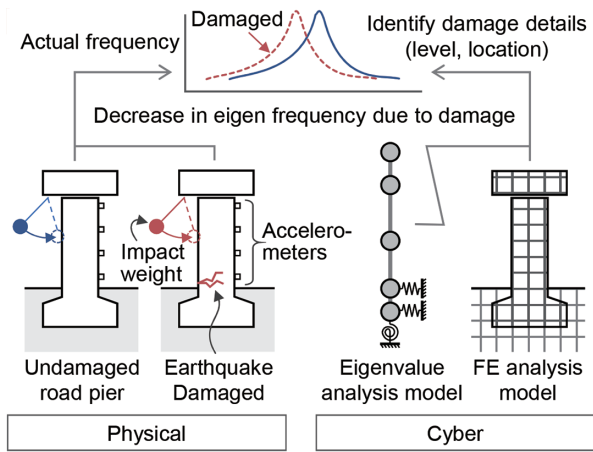


Fig. 12 An example of CPS in the field of building and infrastructure

ple, technology that measures the natural frequencies of road bridges damaged by earthquakes before and after the disaster and identifies damage modes that match the measured frequency changes has been put into practical use.¹¹⁾ Sensing technology will become more sophisticated, and 3D finite element models (FE analysis models) will be integrated into networks. A wide range of analyses will be performed daily, not only for bridges, but also for various social infrastructures.

5.2 Utilization of artificial satellites (Fig. 13)

There is technology that uses satellites, such as earth observation satellites and quasi-zenith satellites, to inspect and repair aging roofs, as well as to assess and repair roofs damaged by storm disasters.

Technology that uses drones to evaluate the soundness of roofs is becoming common in Japan. In the US, a system is provided that uses satellite images to obtain repair designs and estimates quickly and inexpensively.¹²⁾ They have developed a satellite-based system that starts inspecting the roof of a house as soon as the owner enters the address on an online program.

The flow of data and materials in the system is schematically shown in Fig. 13. To increase the value of this system further, it is necessary to simplify and shorten the final process of on-site roofing work. Furthermore, we can again realize that the optimization, standardization, and modularization shown in Fig. 3 are important development perspectives.

By acquiring and analyzing fixed-point observation satellite data, it is possible to trace the expansion and contraction of bridges and large buildings due to ground deformation and seasonal temperature differences. It is also possible to compare the effects of deterioration over time and ground movement on a year-by-year basis for each structure type. In addition, highly accurate GPS systems can achieve positioning accuracy in 1 cm increments in the open sky, making it possible to pinpoint repair areas precisely.¹³⁾

5.3 Expectations for quantum computing (Fig. 14)

As an expectation for the next 10 to 15 years, we can cite the application of quantum computing technology. This technology can solve problems that require a huge amount of time on conventional von Neumann-type computers in a short time, such as the traveling salesperson problem and the knapsack problem.¹⁴⁾ Although applying quantum computing directly to practical design is not realistic, it

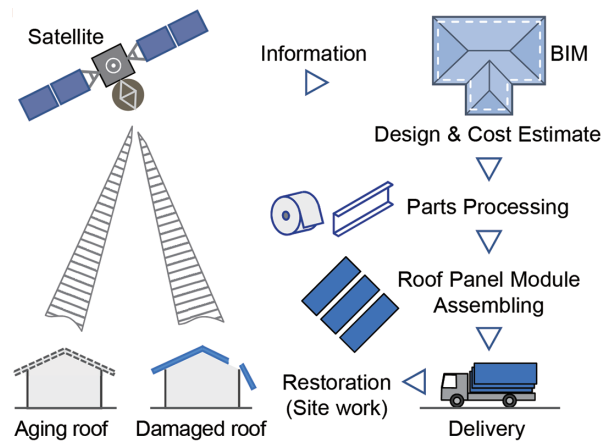


Fig. 13 Satellite-based roofing component repair and restoration system

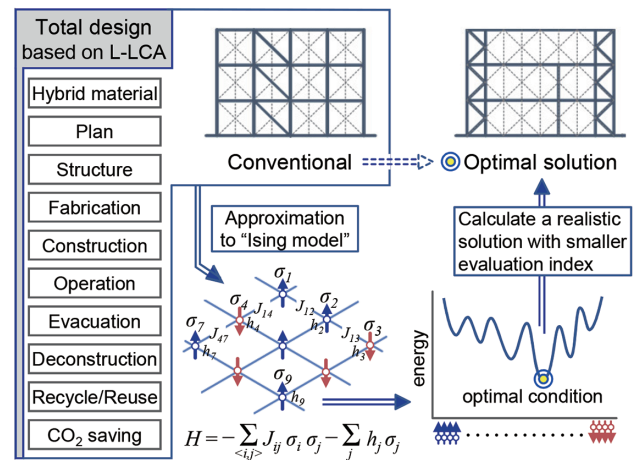


Fig. 14 Expectations for quantum computing: Schematic diagram of using quantum annealing to find a solution to a multi-objective optimization problem in integrated design

can become a technology that provides guidelines for optimal utilization of steel, concrete, wood, or their hybrid members in a building while meeting the client’s requirements.

In reality, solving problems using only quantum computing is only sometimes feasible. Instead, it is necessary to consider whether the large load design issues can be approximated to the Ising model, the basic equation among existing algorithms, and aim to increase the computational efficiency by replacing them with quantum algorithms as subroutines. Under decarbonization policies, designers will be required to minimize the CO₂ emissions by reducing material complexity, minimizing the number of joints, shortening construction periods, compressing heating and cooling costs during operation, optimizing evacuation routes in case of fire, and considering dismantling and recycling (Fig. 14). Given that the Ministry of Economy, Trade and Industry is strongly committed to utilizing quantum computing for national resilience, it will become necessary to consider expanding the DX infrastructure capabilities developed in the steel manufacturing process to the L-LCA integrated design technology in the social infrastructure field and to enhance technological competitiveness in the future.

6. Conclusions

We have summarized the challenges in the respective fields and

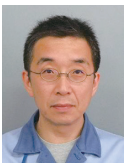
expectations for the progress of DX to prevent the discussion on DX in the social infrastructure field from becoming too chaotic and create an opportunity to obtain a wide range of advice from DX experts and academics.

To achieve highly effective CO₂ emission reduction, aiming for total optimization rather than partial optimization is necessary. We defined L-LCA (longer life cycle assessment), which seeks essential value on a longer timeline than before, up to repeated recycling and reuse. We have presented expectations for DX as a means to quantify and share the CO₂ emission reduction effects in the construction spiral of material (S)-planning (P)-design (D)-fabrication (F)-construction (C)-operation (O)-maintenance (M)-reuse (R).

We have demonstrated the need to accelerate optimization, standardization, and modularization discussions to evolve to Society 5.0. Optimization to meet market needs and standardization to reduce the CO₂ emissions and improve productivity are contradictory trends. We have expressed expectations for DX as a means to achieve both of these goals.

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