FORMATION OF SUSTAINABLE CONCRETE BY SOCIAL PERSPECTIVES IN THE JAPANESE CONCRETE INDUSTRY

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***ABSTRACT*:** It is difficult to determine what constitutes sustainable concrete since the term sustainability itself is not clearly defined. The first part of this research proposes one approach to this problem by combining sociology of technology theory with a model for technology formation. Sustainable concrete could be visualized as the integration of sustainable knowledge with concrete engineering knowledge, but the input of the social groups is necessary to select the appropriate criteria. The next part of this research was conducted to survey the perspectives on sustainable concrete held by social groups in the Japanese concrete industry by interviewing people involved in concrete technology and development, and to integrate those perspectives into the formation model. There was little difference between social groups regarding sustainable concrete, and they defined sustainable concrete as that which is durable and evaluated using life cycle cost and life cycle CO_2 emissions. The utilization of waste and recycled materials is also important, but only if durability and quality can be maintained. Since cement is the primary contributor of CO_2, its volume should be reduced as much as possible. The similarity of responses between the social groups indicates that even among those knowledgeable about sustainability, there still remains uncertainty regarding what role each social group will be responsible for in an industry which practices sustainability.

KEYWORDS: sustainable concrete, technology formation, social perspectives

1. INTRODUCTION

Sustainable development is commonly defined as development which “meets the needs of the present without compromising the ability of future generations to meet their own needs” (UN, 1987). However, although this definition was established over 20 years ago, there has been little progress in developing a general-purpose definition. One means of considering sustainability is as the integration of the “three pillars” of sustainability: the environment, society, and the economy. This relationship is shown in Figure 1, and illustrates the dependency between the three pillars.

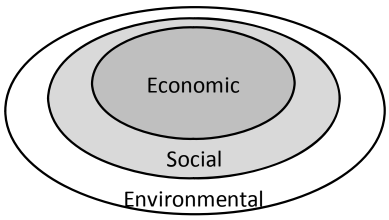

Figure 1 Visualization of sustainability (Cornell, 2009)

Increased awareness of sustainability has led the concrete industry to consider its practice, looking particularly at the environmental impact. There are many proposals for adopting sustainable practice but, just as sustainable development is only a concept and not a tangible plan of action, so too is it difficult to determine what constitutes "sustainable" for concrete materials. Another problem is the diverse number of perspectives in the concrete industry. There are many stakeholder groups (or social groups) – from private and public owners to contractors and manufacturers – and each have their own perspectives and goals.

1.1 Objectives

The objectives of this research are to propose a framework for defining sustainable concrete by considering the perspectives of the relevant social groups in the Japanese concrete industry, and then to investigate those perspectives and apply them to the methodology. The framework will be constructed by combining a technology formation model with sociology of technology theory on how technology is selected by social groups, and the perspectives on sustainable concrete as held by the social groups will be investigated through interviews.

2. VISUALIZING SUSTAINABLE CONCRETE

Concrete is a technology with a history which spans thousands of years, from the simple concrete of the Roman Empire to modern, micro-mechanically designed materials. Although the basic materials remain the same, advances in technology have increased the knowledge base used to design and build concrete infrastructure. This section discusses the dependency of concrete on knowledge and design information and proposes how to visualize the development of sustainable concrete.

2.1 Technology formation

A technology, or artifact, is something which is made by humans to achieve human goals. Visualized simply, an artifact is formed by the transcription of design information onto media or materials, as shown in Figure 2, and the design information itself is an accumulation of information and knowledge built up over time (Yoshida and Yashiro, 2007).

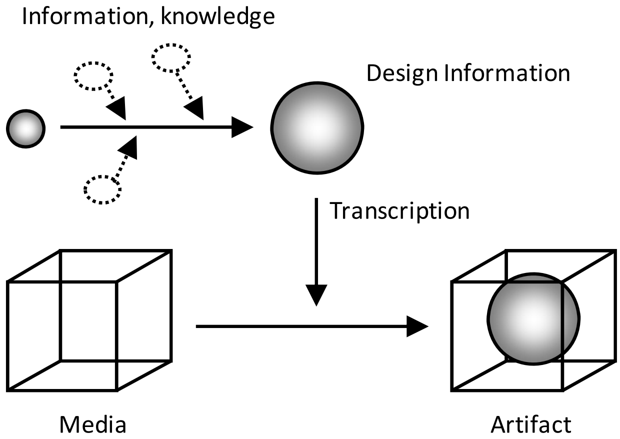

Figure 2 Formation of an artifact (Yoshida and Yashiro, 2007)

2.2 Formation of concrete

The formation of concrete can be visualized by modifying the model in Figure 2 with the media, design information, and knowledge necessary to develop concrete, as illustrated in Figure 3.

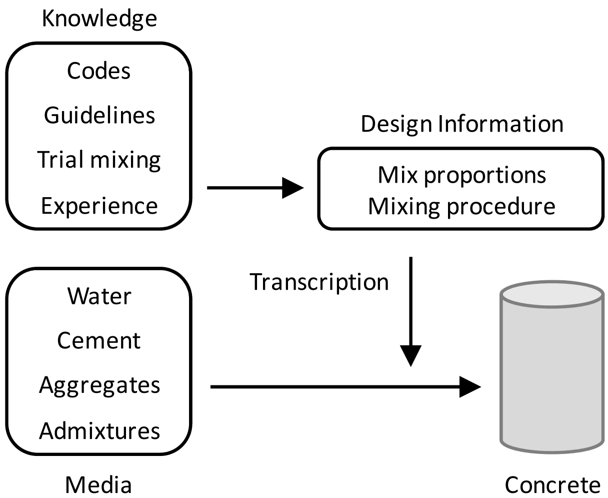

Figure 3 Formation of concrete materials

The basic paradigm for concrete has not changed since the times of the Roman Empire: the media utilized for concrete are cement, water, aggregates (fine and coarse), and admixtures, and the design information used to make concrete are the mix proportions and mixing procedure. Although this paradigm remains basically unchanged, the development of knowledge has produced concrete of a different form.

2.3 Example of concrete formation

In order to demonstrate more clearly the relationship between knowledge, design information, media, and the resulting concrete material, a simple example will be given considering the increase in concrete compressive strength over the last 60 years.

As summarized by Bentur (2002), the difficulty in achieving high-strength concrete is related to the relationship between strength and the water-binder ratio of the concrete. It is widely known that decreasing the water-binder ratio increases strength (Figure 4); however, this also reduces the amount of mixing water and thus the workability is also reduced, making mixing, pumping, placing, and so forth difficult to perform. However, the development of super plasticizers (high-range water reducers) made concrete with low water-binder ratio possible without compromising workability.

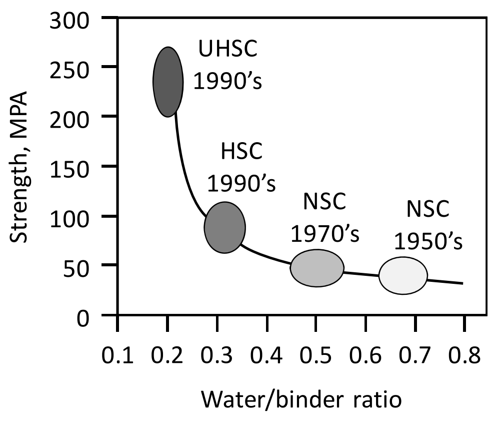

Figure 4 Development of concrete strength over time (Bentur, 2002)

In addition, the importance of microfiller (such as silica fume) for achieving high packing density by filling void space was also understood, as was the importance of cement and microfiller grading control. However, if the strength of the mix becomes higher than the coarse aggregates, then specialized aggregates need to be use to match the added strength of the matrix.

From this example, the dependency of strength on the design information and media can be clearly seen. High-strength concrete could not be achieved without specialized media – microfiller, super plasticizers, high-strength aggregates – or without knowledge regarding the proper mixing proportions – grading of cement and microfiller, dosage of super plasticizers. As the development of these media and knowledge advanced over time, concrete with higher compressive strength could be practically used.

2.4 Formation of sustainable concrete

For normal concrete, there is typically no consideration of the sustainable aspects when designing the material, as codes have not (until recently) contained specification of environmental or sustainable performance. Sustainable concrete should, therefore, be formed from the integration of sustainable knowledge and media with the traditional concrete engineering knowledge and media, as shown in Figure 5. The integration of sustainable knowledge will come from specification of sustainable performance for the concrete mixture; for example, specifying a certain level of CO_2 reduction will require inventory knowledge for calculating CO_2 emissions. Although sustainability contains a large number of aspects, it is most likely that the environmental performance will be considered more than others since current actions focus primarily on the environmental impact.

Focusing on the environmental aspect only, most proposals for sustainable practice consider the reduction of CO_2 and the use of recycled and waste materials as the two primary environmental performances. Since Portland cement is the main source of CO_2, reduction scenarios typically focus on reducing the amount of Portland cement used in concrete, either by replacing cement with high volumes of fly ash (Malhotra, 1999) or utilizing super plasticizers to reduce the amount of mixing water and thus the amount of cement (Sakai, 2009). In the first case, fly ash acts as sustainable media, but in the second case there is no sustainable media; for both cases, the sustainable knowledge is CO_2 reduction, and engineering knowledge is then required to develop the proper mix proportions and procedures for producing concrete with the necessary performance.

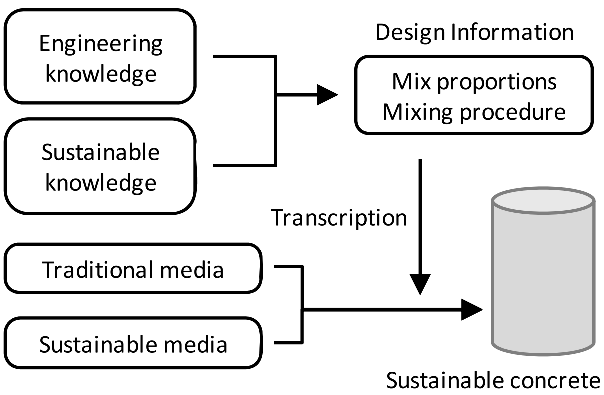

Figure 5 Formation of sustainable concrete

Both of the previous examples not only reduce CO_2 emissions, but also conserve concrete-making materials and reduce material consumption – one of Mehta's (1999) foundations for sustainable development in the concrete industry. Specifying the use of recycled and waste materials may also require the use of sustainable media such as recycled aggregates. However, the production of normal coarse aggregate emits less CO_2 compared to recycled aggregates (JSCE, 2006). Therefore, the use of recycled and waste materials may cause an increase in the CO_2 emissions; furthermore the mechanical performance of low-grade recycled aggregates, which have roughly the same CO_2 emissions as normal aggregates, is lower than that of higher-grade recycled aggregates, so new knowledge about the trade-off in performance between these two is necessary for the formation of sustainable concrete. This example with recycled aggregates demonstrates three key points: how to balance different environmental considerations, how to balance different mechanical performances, and how to balance the environmental with the mechanical.

Another approach to reducing material consumption is by increasing the durability of concrete materials (Mehta, 1999). By specifying durability as a sustainable performance, the engineering and sustainability knowledge are combined into one area of concrete engineering knowledge. The design of high durability concrete could then proceed without any other sustainable input, since sustainable performance was defined as durability at the knowledge level.

Many different approaches to sustainable concrete have been proposed, but so far these types of materials have not seen wide-spread use. In addition, there is uncertainty in selecting which knowledge criteria to apply for defining sustainable concrete because there are a wide variety of social groups related to concrete, each of which look at concrete from a different perspective.

3. DEVELOPMENTAL FRAMEWORK

The previous section proposed that sustainable concrete be developed by integrating engineering and sustainable knowledge, but raised the question of how to select which knowledge criteria are used for the development process – primarily due to the conflict of interests which may occur between the diversity of social groups within the concrete industry. The sociology of technology may be useful for answering the question of how to deal with conflicting social groups.

3.1 Social Construction of Technology

The Social Construction of Technology (SCOT) is used by constructivist sociologists of technology to explain how technological development occurs. In SCOT theory, technological development proceeds primarily due to the interactions between relevant social groups, rather than other factors such as market demand (Pinch and Bijker, 1987). The relevant social groups for a technology are those which possess some perspective on the artifact, with each group representing a different perspective on the problems and solutions related to the target technology. The development process proceeds as the social groups define and negotiate their problems and solutions in the context of the meaning they apply to the artifact. Although this process is not linear (it follows the complex social interactions which occur between the relevant social groups), a simple linear representation is given in Figure 6.

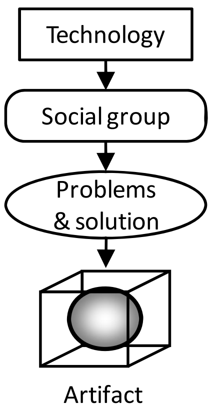

Figure 6 SCOT concept of technology development

3.2 Relevant social groups

The first step in adapting the SCOT concept to sustainable concrete is to select the target technology and identify the relevant social groups. Since this research is focused on sustainable concrete materials, the target technology is shown as "sustainable concrete" in Figure 7. The social groups relevant to sustainable concrete are the different social groups which comprise the concrete industry, and are broke down as shown in Figure 7 based on their role in the process of producing concrete material or structures.

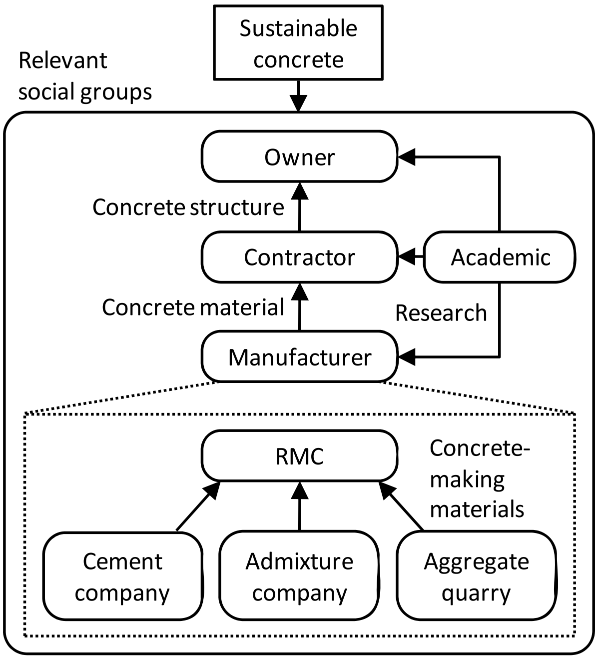

Figure 7 Social groups relevant to sustainable concrete

The four primary social groups are the "owner," "contractor," "manufacturer," and "academic." In this simplified illustration, the manufacturer group serves to produce the concrete material, the contractor uses the concrete material to construct the structure for the owner, and the academic provides research and support at different levels of production. The manufacturer group can be further broken down into sub-groups which produce the concrete-making materials for the ready-mix concrete plan (RMC), which produces the actual concrete itself. The owner group also contains a variety of distinct sub-groups, such as government (public infrastructure); railway, utility, or transportation companies (private infrastructure); the research centers which serve those groups; and so forth.

3.3 Perspectives of social groups

The next step in adapting the SCOT model is to identify the problems and solutions held by the relevant social groups. These problems and solutions represent the unique perspectives held by each social group. For the development of sustainable concrete, the perspective on sustainable materials is the primary interest, as shown in Figure 8.

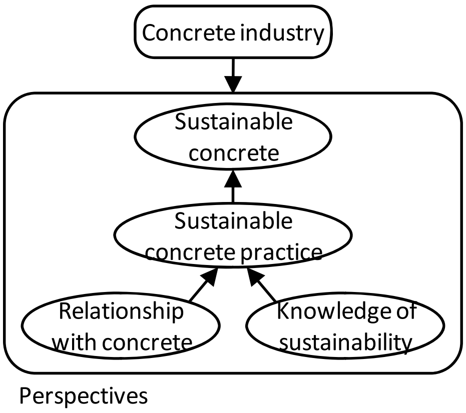

Figure 8 Evaluating social groups' perspectives and key topics

However, the problems and solutions for sustainable materials may be related to different problems, such as general sustainable concrete practice in the industry itself, the group's specific interaction with concrete, and the level of knowledge of sustainability. As shown in Figure 7, the social groups all perform different roles in the production of concrete infrastructure; in addition the perspective on sustainable materials may also be greatly affected by the level of knowledge of sustainability. Finally, sustainable concrete material is just one aspect of the overall need for sustainable practice in the concrete industry. While concrete materials do contribute to the industry's environmental impact, there may be other means of adopting sustainability in practice that do not necessary affect concrete material directly, such as structural design or construction method. Since each group interacts with concrete in a different way and has a different target, consideration of these different problems and solutions is necessary.

3.4 Perspectives of social groups

The final step in adapting the SCOT model is to integrate the problems and solutions given by the social groups' perspectives into the formation model for sustainable concrete, which is illustrated in Figure 9. Part of the social group's perspectives on sustainable concrete is the knowledge and media used for making sustainable concrete, which may come from either or both their relationship with concrete and the knowledge of sustainability. This information can be applied to the model shown in Figure 5. Once these knowledge and media are decided, the design information can be established and the form of the sustainable concrete determined. However, as mentioned in the discussion on SCOT, it may be necessary to negotiate the differences between the perspectives of different social groups before a single form can be settled upon.

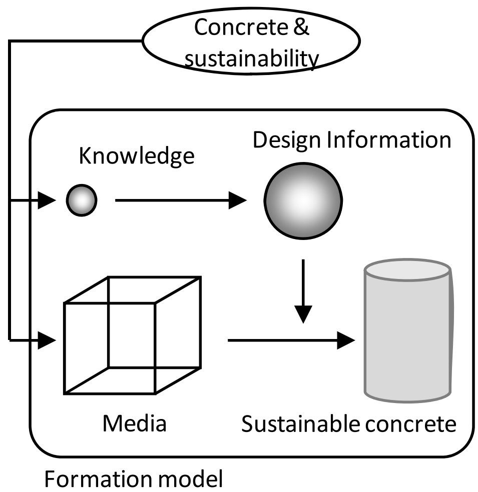

Figure 9 Integrating social groups' perspectives into the formation model

3.5 Developmental framework summary

A general summary of the developmental framework for sustainable concrete as derived from the SCOT model for technology development is given in Figure 10. This framework visualizes the formation of sustainable concrete as the negotiation between the perspectives of the social groups in the Japanese concrete industry. These perspectives can be used to select the knowledge and media for the formation of sustainable concrete, but it will be necessary to evaluate the perspectives held by these social groups.

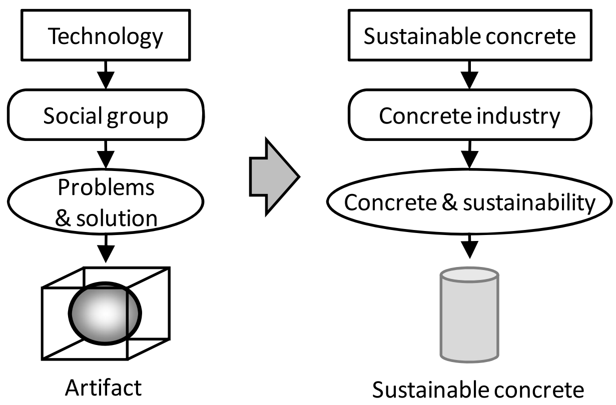

Figure 10 Developmental framework summary

4. EVALUATING SOCIAL PERSPECTIVES

In order to evaluate the perspectives of the Japanese concrete industry on sustainable concrete, a series of in-depth interviews were conducted with representative members of the different social groups in the concrete industry.

4.1 Interview methodology

For this study, the Japanese concrete industry was selected due to the authors' access to experts through domestic industry contacts. The perspectives were evaluated using semi-structured interviews, which fall between structured interviews, which are rigid and standardized, and unstructured interviews, which are flexible and follow a general outline (Punch, 2005). After contact was made with the interview subjects, they were provided with an interview summary which contained an overview of the primary questions to be asked. The interview was then conducted following the primary questions but deviating as necessary to provide clarification on topics of interest. The interviews were generally conducted in English, but when Japanese was used results were translated to English before analysis.

The purpose of the interviews was to qualitatively examine the differences between social groups regarding how they utilize and evaluate concrete materials, their knowledge of sustainability, and their concept of sustainable practice and materials.

4.2 Distribution of interviewees

The distribution of interviewees is shown in Figure 11 and their organizations are given in Table 1. Thirteen interviews were conducted in total, with four interviewees each from the academic and manufacturing groups, three from the contractors group, and two from the owner group. Among these interviewees, 12 are involved in research or development, ten possess doctoral degrees, seven have worked in an academic setting, six are directors or managers, and one is a CEO.

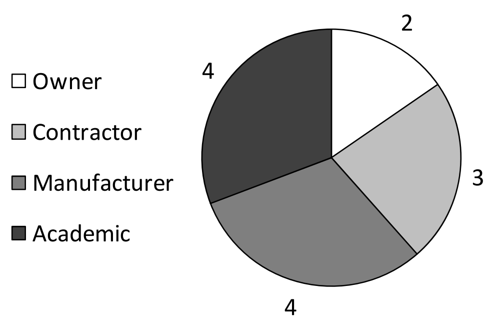

Figure 11 Distribution of interviewees

Table 1 Organizations of interviewees

Social group	Organizations
Academic	Private & public universities
Owner	Research institutes
Contractor	General contractors
Manufacturer	Ready-mix concrete, chemical co., cement co. slag cement co.

4.3 Relationship to concrete

Each social group has a clear relationship with concrete based upon their role in the current paradigm for concrete construction, and the criteria each groups uses for evaluation of concrete material is clearly related to each group's customer's requirements. The relationship of evaluation criteria between social groups is shown in Figure 12.

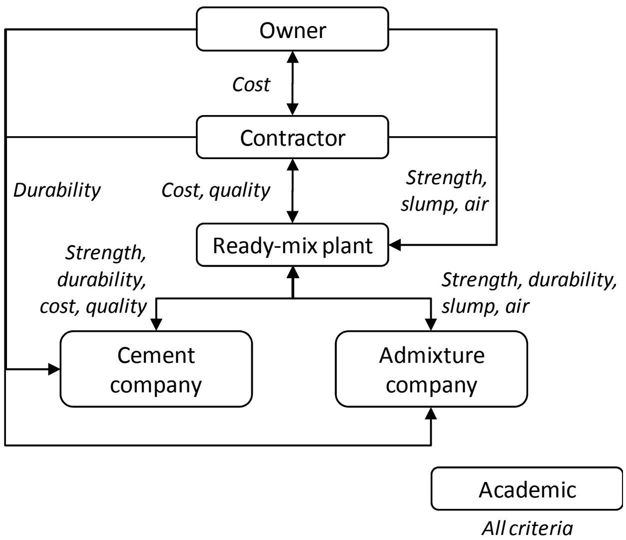

Figure 12 Concrete evaluation criteria between social groups

The owner provides design specifications and establishes a contract with a contractor to execute the construction for a specified cost, so four primary criteria are established at this point: the cost of materials (via contract) and the strength, slump, and air content (via specifications). Durability may also be specified, but this will be discussed later. If the mix design is of a JIS standard type, then the contractor elicits a bid for the materials from the ready-mix concrete plant without any modification of the materials or proportions, so the ready-mix plant has only to meet the cost for materials and necessary quality for satisfactory casting as required by the contractor and the concrete properties outlined by the specifications (from the owner). If the mix design is special or unusual, then the contractor may serve as a consultant to the ready-mix plant or mix the concrete themselves.

The ready-mix plant is focused on providing concrete for the lowest cost and highest quality, as well as meeting the design specifications, so cement manufacturers and admixture companies are also concerned with these properties. The cement company also tries to ensure quality by managing the chemical composition of the cement while meeting strength requirements at the lowest cost, while the admixture company is focused more on the fresh properties and strength development.

Since the ready-mix plant has no means for evaluating durability, such evaluation criterion has to be established between the cement or admixture companies and the owner or contractor directly. The academic field, which provides research at all levels of production, is concerned with all criteria.

4.4 Knowledge of sustainability

Although a clear difference could be seen in the roles for each social group concerning their relationship to concrete, there was no clear trend in definitions of sustainability or sustainability indicators. Even within the same social group, different definitions or indicators were provided, emphasizing the lack of a clear and established definition of sustainability. A general trend could be seen which followed the hierarchy shown in Figure 1, with more emphasis placed on environmental aspects than social or economic aspects, but no single social group differed significantly in the perspective from the other social groups. This may indicate that knowledge of sustainability depends on the individual's perspective more than their membership in a social group – at least within the concrete industry.

4.5 Concept of sustainable concrete practice

Similar to the definition for sustainability and sustainability indicators, there was no clear difference between social groups' perspectives on sustainable concrete practice. For sustainable indicators and materials, there was some agreement within the social groups, particularly the owner and contractor groups. The owner interviewees focused on durability and recyclability as indicators, with sustainable materials defined as reducing material consumption, and the contractor interviewees focused on life cycle cost (LCC) as an indicator and reduced material consumption for sustainable materials. However, in the other social groups, the interviewees provided a variety of answers; for the academic group, this may be explained by the wider perspective of researchers, and for the manufacturer group this may be explained by the difference in companies within the group.

Overall, however, there was little difference between social groups on sustainable concrete practice, and a conceptual model was constructed based upon the general trend showed in the responses. As shown in Figure 13, this model breaks sustainable concrete practice down into concrete and sustainability aspects, identifies the key evaluation criteria and specific actions necessary to implement those criteria, and also identifies general actions and actions necessary for both aspects. On the concrete side, LCC and durability were clearly identified as importance criteria for evaluating sustainable concrete practice, but to implement these criteria it is necessary to develop proper durability evaluation methodology, a standardized means for evaluating LCC, and reduce the focus on initial cost and increase awareness of total life cycle performance.

On the sustainability aspect side, several indicators were emphasized – life cycle CO_2 emissions ($LCCO_2$), environmental impact, recyclability, and resource consumption – but again, to implement these indicators it is necessary to develop a standardized methodology for calculating $LCCO_2$ and establish inventory values in a transparent manner, as well as increase the consideration of life cycle performance over initial performance. The use of recycled materials is important for reducing resource consumption and improving recycling practice and recyclability, but this will require an understanding of the balance between reduced quality and improved sustainability.

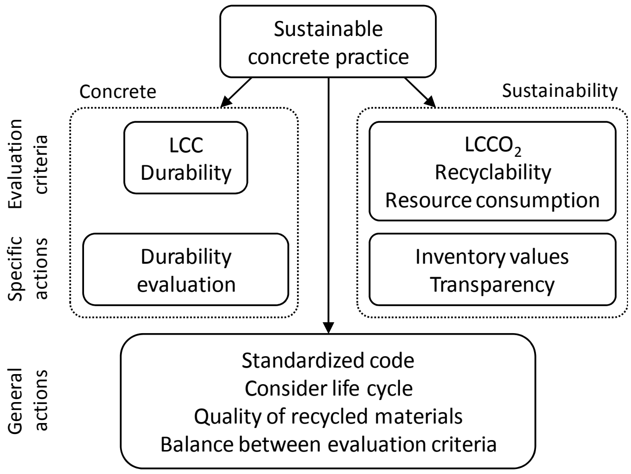

Figure 13 Conceptual model for sustainable concrete practice

4.6 Barriers to sustainable concrete practice

The barriers to sustainable practice identified in the surveys are summarized and categorized in Table 2 by six categories: institutional, organizational, social, economic, technological, and knowledge. Institutional barriers number the greatest and include two general areas: lack of codes, standards, and specifications; and problems with the current project bidding system. The social barriers focused on the reluctance to use new materials or practices as well as perceptions of concrete. The two organizational barriers identify the structure of the industry and division between stakeholders, and the economic barriers indicate the difficulty in balancing company profits against the needs of society or the environment. The technological barriers include low level of technology and lack of durability evaluation, and are targeted primarily at the ready-mix concrete industry. Finally, general problems with knowledge include lack of information on environmental impact, knowledge gaps between people, doubts about climate change, and so forth.

Table 2 Barriers to sustainable practice based on interview results

Institutional
Lack of standardized code; no transparency in calculating inventory data; no definition of sustainable materials; fast construction schedule; lack of consideration of full life cycle; focus on initial cost; bidding system can't evaluate additional value; balance between different criteria
Social
No motivation to use sustainable materials; reluctance to utilize new materials or technology; perception of recycled materials as low-quality; perception of concrete as not sustainable
Organizational
Lack of vertical integration; conflict of interest between stakeholders
Economic
Difficult to balance company benefits vs. society; adopting sustainable practice reduces profits
Technological
Difficult to evaluate durability; low level of technology
Knowledge
Lack of information on environmental impact; lack of knowledge on sustainability; doubts about CO_2 and climate change

When examining the barriers to sustainable practice, there was little correlation between interviewees within the same social group but a similar general trend overall. This may indicate that, while their roles are clearly defined in current concrete practice, the interviewees are unsure of their roles in sustainable concrete practice because sustainability itself is still an unclear concept with a wide variety of interpretations and implications. The responses to the barriers for sustainable practice support this theory, as the primary barrier identified was the lack of a standardized code. If such a standardized code existed, then each social group would have a clear, defined idea of its role, responsibilities, and the boundary conditions within which it should operate. However, since sustainable concrete practice is just as vague as sustainability as a whole, the lack of a clear difference between social groups would seem to indicate that they require concrete action to establish their roles in an industry which practices sustainability and means to evaluate their actions.

5. FORMING SUSTAINABLE CONCRETE

5.1 Resolving conflicts between social groups

Following SCOT philosophy, the development of a technology is not a linear process, but occurs through the complex interactions and negotiations between the relevant social groups. The form of the artifact is "closed" when the relevant groups agree on a form, which establishes the paradigm for that technology (Pinch and Bijker, 1987).

In the case of this social investigation on sustainable concrete, however, no major conflict between the perspectives of the social groups was observed. This may seem to indicate that the form of sustainable concrete has been decided and closed, but this is not the case as concrete materials with sustainable characteristics (those characteristics indicated in the interview responses) have not seen wide application. There are several possible reasons for this.

First, although the relevant social groups were selected as those belonging to the concrete industry – that is, the groups involved with the manufacturing, production, construction, maintenance, demolition, and so forth of concrete materials and infrastructure – there may be other social groups with relevance which have not been included here. One example would be people who are opposed to the usage of concrete, such as the timber or steel industries. Another example would be people with no direct relationship to concrete but have a great amount of influence on how it is used, such as policy-makers who establish the construction bidding system. Institutional barriers such as those related to the bidding system are relevant in this case.

A second reason why there is no conflict between the evaluated perspectives may be because the interviewees were selected primarily for their knowledge or involvement with research, development, and/or sustainability. Therefore, the perspectives of people with no knowledge of sustainability, or those who are actively opposed to it, are not represented here. This obstacle is identified in many of the barriers to sustainable practice – primarily those related to social issues.

However, although the above-mentioned perspectives were not investigated here, the potential form of sustainable concrete may still be constructed based upon the input of those interviewed. This represents one possible form which sustainable concrete may take – but again, negotiation with other relevant social groups will be necessary in order to overcome the barriers to practical application.

5.2 Formation of sustainable concrete

The formation of sustainable concrete can be visualized by applying the relevant knowledge from the conceptual model of sustainable concrete practice to the developmental framework. Based upon the interview responses and as shown in Figure 14, engineering knowledge should include durability and LCC and sustainability knowledge should include $LCCO_2$ and resource usage. No specific traditional materials were specified, but waste and recycled materials should be used to satisfy the need to reduce resource consumption and improve recycling within the concrete industry. The design information for sustainable concrete should therefore be developed considering this combination of engineering and sustainability knowledge and media.

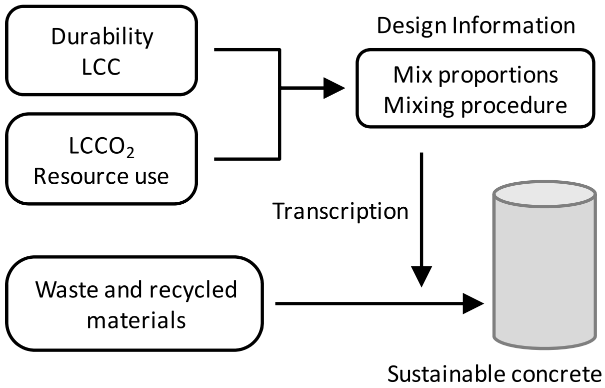

Figure 14 Formation of sustainable concrete based on social perspectives

Sustainable concrete formed with this knowledge and media represent the technological form which meets the problems and solutions held by the interviewees. Since the interviewees were selected for their involvement in research and development, as well as sustainable knowledge, this form of sustainable concrete best represents the potential form of sustainable concrete were it decided using only a top-down approach within the concrete industry – where top-down means that a select group of experts choose how to define sustainable concrete and establish that as the standardized definition. It is more likely, however, that the final form of sustainable concrete will be produced through a series of negotiations considering the perspectives of those who weren't evaluated in the interview process, although how these negotiations will affect the final form is not clear at this time.

6. CONCLUSION

In this paper, the formation of sustainable concrete was proposed in a two-step process: first by creating a developmental framework, based on social theory and management of technology, which proposed the social perspectives of the Japanese concrete industry as the input for the technological formation; and second by evaluating those social perspectives and applying them to the proposed framework.

From the evaluated social perspectives, a potential form of sustainable concrete was proposed which combines low LCC and durable performance with reduced $LCCO_2$ and utilizes waste and recycled materials. This form represents only one potential, however, because there are other social groups with relevance which were not considered in this social investigation. These perspectives will need to be integrated and negotiated in the future to establish closure for sustainable concrete.

The proposed methodology, however, may be widely applicable because it is based upon the assumption that the social situations change, so those social perspectives are used as input. Consideration of different social perspectives, both within Japan (as in the investigated case) or in other countries with different construction cultures, may produce sustainable concrete of a different form.

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