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PRODUCT AND PROCESS QUALITY ASPECTS OF READY-MIXED CONCRETE TECHNOLOGIES

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ABSTRACT
Market acceptance of new types of concrete and associated technologies that have emerged during the last decades varies. The purpose of this investigation is to identify which features of new technologies in concrete that determine adoption by construction contractors, designers and clients. For each technology, product qualities, process qualities and their mutual relations are studied. Results indicate that more widespread market acceptance of certain new technologies presupposes changes in the supply chain, implying a reallocation of tasks and risks between ready-mix concrete suppliers and construction contractors. The potential for a more responsive integration of construction design and site activities is also investigated in the light of features of individual technologies.

KEYWORDS
Ready-mixed Concrete, Innovation, Process Quality, Product Quality, Supply Chain

1. INTRODUCTION

Innovative technologies are not always easily introduced in construction, and market acceptance of new types of concrete that have emerged during the last decades varies. As examples, we choose innovations related to fiber-reinforced concrete, high-strength concrete, and self-compacting concrete. While the focus is on the role of suppliers of ready-mixed concrete in the supply chain, we believe that it is necessary to consider the entire length of the chain from the extraction of raw materials to demolition of constructed facilities if the pattern of market adoption is to be understood.

Therefore, the purpose of the present investigation is to identify which features of in situ concrete technologies that determine their adoption by construction contractors, designers and clients. The reasoning is based on the assumption that each stage of the supply chain can be characterized by both process and product qualities. Furthermore, it is assumed that the interaction between subsequent links of the supply chain as well as the relation between process and product qualities allows us to explain and predict the success or failure of technologies in this field.

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2. GENERIC FEATURES OF TECHNOLOGIES

Technologies used in construction can be classified in various ways. Summarizing a wide range of earlier research in that area, Tatum (1988) proposed a classification system of four components for construction technologies, which can be used as a base for predicting market success for innovations.

The first of the four components belonging to Tatum's classification is Materials and Permanent Equipment Resources, a component that includes materials and equipment permanently incorporated into the production of the constructed product. The second component is Construction-Applied Resources with eight elements: information, skills, equipment, tools, general conditions, space, energy and time. These eight elements describe the value that construction adds to the resources of the first component in producing the constructed product. The third component, Construction Processes, and the fourth, Project Requirements and Constraints, cover the methods and tasks the resources applied are using and the unique conditions influencing a particular project. Obviously, a market breakthrough for an innovative construction technology depends on many contextual factors, not just tangible features of the technology as materials and permanent equipment. Thus we have to consider intangible or process aspects, closely tied to the tangible or product aspects of a given technology used in construction.

Pries and Janszen (1995) have studied how innovation in the construction industry is subject to the dominant role of environment that includes intangible aspects. By referring to complementary assets such as service, special attention and education, Pries and Janzon explained why the sand-lime industry in the Netherlands had been more successful product innovators than the corresponding industries in the UK and Germany. Clearly, it is worth applying the distinction between product qualities and process qualities, a dichotomy that is found in mainstream literature on service management and marketing (Grönroos, 2000). A supply chain with a series of successive activities of transformation and assembly of intermediary products and a corresponding series of commercial transactions can be interpreted in these terms. For each stage, there will be both product and process qualities to be identified. Taking process as well as product qualities into account, our ability to understand innovation should be improved.

In Table 1 requirements of the elements of the first component of Tatum's classification system are ascribed to three types of high performance concrete technologies and compared with conventional concrete technologies.

Table 1: 'Construction-Applied Resources' Used on Site by Concrete Technologies

Resource element	Conventional concrete	High-strength concrete	Fiber reinforced concrete	Self-compacting concrete
Information	o	+	+ +	o
Skills	o	+	+ +	-
Equipment	o	o	+	o
Tools	o	o	o	-
General conditions	o	o	o	o
Space	o	o	o	o
Energy	o	+	+ +	-
Time	o	-	-	- -

+ + = highest requirement, + = higher requirement, o = usual requirement, - = lower requirement, - - = lowest requirement

Resource requirements on the construction site, associated with specific technologies, are listed in Table 1, using information from Okamura et al. (2000), Shinmoyama et al. (2001), and Zollo (1996). Depending on the relative weights that can be assigned to the eight resources elements in Table 1, we should expect the three innovative technologies to gain significant market shares. However, we may have to look beyond the pattern of resources required on the construction site in order to understand why technologies are accepted or rejected.

Table 1 can also be seen in the light of the nine selection factors suggested by Proverbs et al. (1997). In their investigation, planning engineers employed by UK contractors were asked about the choice of concrete supply methods, either site mixed or ready-mixed, for high-rise in situ concrete construction. The selection factors, identified through factor analysis, were (1) costs, (2) quality, (3) production speed, (4) quantity of concrete, (5) flexibility required, (6) safety, (7) plant and equipment availability, (8) operator and labor availability, and (9) company practice.

The effect of different proportions of construction-applied resources like the ratios of unskilled, semi-skilled and skilled workers on a typical high rise construction project with an in situ concrete framed structure has been studied by Proverbs et al. (1999a). In the UK the effects of a lower proportion of skilled site workers appears to be compensated by a greater intensity of supervision than in France and Germany. However, a high supervisor-to-operatives ratio also appears to be associated with greater project duration (Proverbs et al., 1999b). Otherwise, it is noteworthy that the nine selection factors do not highlight information and skills, two resource elements where alternative concrete technologies show clear differences in Table 1.

3. THE SUPPLY CHAIN OF READY-MIXED CONCRETE

In general, concrete is characterized as a composite system in two physical states: the liquid state, fresh (unhardened) concrete, and the solid state, i.e. hardened concrete. The ingredients are basically the pulverous binding material (cement), the solid filling materials (sand and stone), referred to as aggregates, and water, the liquid activator of the chemical reaction. Mixing these ingredients by manual or mechanical techniques starts the irreversible transformation process from fresh to hardened concrete. Because of this transformation Tommelein and Li (1999) identified ready-mixed concrete as a typical perishable commodity, and they saw the batching and delivery of ready-mixed concrete as a prototypical example of a just-in-time production system in construction, emphasizing the consequences of the irreversibility of the transformation process.

This irreversibility implies that concrete exerts an influence on the scheduling of site operations, far in excess of the cost of a load-carrying concrete structure in itself. Since concrete and concreting operations are crucial for the coordination of many construction sites, contractors could be expected to drive innovation in this field. Yet, the project nature of contracting is known to retard the development of management practices that merge technical expertise from contractors and their suppliers (Gann and Salter, 2000). These are thus several reasons for taking a broader view.

The nine selection factors given by Proverbs et al. (1997) can be compared to what was found by Idrus and Newman (2002), who conducted their research among both contractors and designers in the UK construction industry, studying construction related factors that influence the choice that influence between in situ, precast or hybrid construction concrete floor systems The twelve factors identified by frequency and severity index analysis are: (1) appropriateness of use, (2) cost, (3) constructability, (4) speed, (5) health and safety, (6) accommodation of services, (7) familiarity, (8) quality of finished concrete, (9) flexibility, (10) supply chain network, (11) labor dependencies, and (12) procurement method. By extending the analysis to designers and not only asking contractor staff, it seems that process quality factors emerge more strongly.

The longest stage, the operations and maintenance stage, or in other words the facilities management stage, for a constructed facility is preceded by a supply chain that links backwards through construction to the production of materials and components. Continuing backwards in the supply chain, we finally reach the extraction of raw materials such as activities in a limestone quarry. And the facilities management stage is followed by demolition. For each of these stages, there are processes and products.

In Table 2, examples of process qualities and product qualities are assigned to intermediate product stages for the supply chain of ready-mixed concrete.

Table 2: Features of in situ Concrete Technologies, by Intermediate Product Stage

Stage	Process quality	Product quality
Raw material extraction	Ecological impact	Variability
Cement production	Ecological impact	Refinement
Concrete production	Precision of mixing	Plasticity
Construction	Duration	Moisture content
Facility usage	Maintainability, tendency to carbonatization	Noise insulation, structural flexibility
Demolition	Emission of hazardous substances	Reusability

Table 2 indicates a complex reality of several processes and actors. There is an intricate linkage between process and product qualities that arise in successive stages of the supply chain. These qualities are associated with costs, benefits and risks for the companies that are involved. New technologies may face obstacles due to suboptimization in the total supply chain.

4. CONCRETE SUPPLIERS, DESIGNERS AND CONTRACTORS

Innovative concrete technologies raise the demands on information and skills on the construction site, as indicated in Table 1. This implies that we should recognize an opportunity for new patterns of knowledge management along the supply chain. In particular, it may be efficient to reallocate task and risks between ready-mix suppliers and construction contractors. However, the degree of integration with building design is crucial. Today, it still appears to be fundamentally true what Nam and Tatum (1988) stated, namely that the product design function in construction normally is separated from production in contrast to the manufacturing industry.

A pessimistic strategy for new concrete technologies can be based on a conscious decoupling of design and construction. Ozawa et al. (1992) give examples from Japan where the communication lack between the designer and the construction engineer has been described as one reason for the development of vibration free, self-compacting concrete. The advantage of self-compacting concrete is that its use reduces the need of design integration. Utilized in the construction of the anchorage of the Akashi-Kaikyo Bridge, self-compacting technology reduced the production duration by 20% from two and a half to two years, according to Okamura et al. (2000).

The more optimistic strategy emphasizes the potential for design integration, which also implies that issues of risk and liability have to be dealt with (Nam et al. 1991). That this is possible is illustrated by a construction project involving high-strength concrete in Seattle as early as in 1988 where designers, contractors and authorities worked closely together to use innovative new concrete technology. This close collaboration resulted in fewer load-bearing columns and thus greater freedom in interior and exterior design for the architects. And in the facilities management perspective there was more valuable space for use.

Design and construction appear to come closer together in current practice. Winch (2001) takes the view that one of the major issues in horizontal governance in the construction sector is the changing role of trade contractors. He notes the involvement of some of them in design but sees a rise of the level of uncertainty under which such trades procured.

Ideally, a wider concept of design should cover the entire supply chain and life cycle of constructed facilities, identifying optimal combinations of process and product qualities for each stage. A pragmatic first step would be to reallocate tasks and risks in the triangle formed by ready-mixed concrete suppliers, construction contractors and designers.

5. CONCLUSIONS

The analysis presented here indicates that an adoption of new concrete technologies by the actors in the construction market should be facilitated by design integration, taking into account process and product qualities in the entire supply chain for ready-mixed concrete that starts with the extraction of raw materials and ends with the demolition of the constructed facility.

The link between product qualities arising from the concrete production stage and on the other hand process qualities during the construction stage is one explanation for the relative success of self-compacting concrete, whereas the construction stage product qualities of high-strength and fiber-reinforced concrete technologies appear to be associated with more limited and specialized advantages in terms of process qualities during operations and maintenance of the constructed facility.

Integrating design in the total information flow and sharing it more efficiently among ready-mixed concrete suppliers, construction contractors and designers will probably raise market acceptance of new concrete technologies. A better understanding of how technology affects the long period of operations and maintenance of a constructed facility should be based on solid knowledge of the activities to be sheltered by the facility.

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