The context for transfer of CO_2 optimal materials technologies in construction

Tessa Goverse

Vrije Universiteit, Faculty of Science, Social Aspects of Science and Technology, De Boelelaan 1081, 1081 HV Amsterdam, the Netherlands
Tel/Fax: +31-20-4447981/+31-20-4447988
E-mail: goverse@nat.vu.nl

Paper prepared for the 7th International Conference of the Greening of Industry Network, November 15-18 Rome, Italy

The work reported here is part of a Ph.D. project that aims at improving the understanding of the organisational aspects of the construction context on developments in materials technologies. In order to identify barriers and incentives for implementing CO_2 optimal materials technologies, this paper focuses on the factors that influence the choice for materials use by actors in the construction sector. Purpose of the study is to describe this in sufficient detail in order to support public policy strategies for reducing CO_2 emissions by providing changes in the materials system.

Dutch scenario studies show that materials technology can play a positive role in reducing carbon-dioxide emissions (Gielen and Kram 1997). These technologies range from more efficient materials use to materials innovation and substitution of materials in products. This paper reports about a research project that is part of a large modelling effort to study MATerials Technologies for CO_2 Emission Reduction (MATTER). Using an optimisation model the potential of cost-effective materials technologies in the European materials system are investigated. The outcome is based on cost information, technologies and CO_2 emissions attributed to the function of materials use. On this basis a wide range of beneficial changes in materials production and materials use that reduce the CO_2 emissions are suggested. However, the options identified by the model are not necessarily in line with other arguments on which decisions on materials development and materials use by actors are based. An adequate understanding of the sources and dynamics of materials innovation is essential for the resolution of environmental problems, such as climate change. The conditions that shape and constrain change in materials use are of major concern for successful implementation of CO_2 reduction strategies within the materials system. One of the main points in our work is to understand the compatibility between CO_2 reduction options suggested by modelling efforts and the dynamics of technological production systems. Aim of this paper is to search for key factors in the institutional context of the construction sector in order to obtain improved understanding of barriers to or chances for the implementation of CO_2 optimal materials innovations. Results can serve as a tool for development of policy strategies to stimulate the implementation of CO_2 optimal materials technologies.

The study of materials innovation focuses on the construction industry, which is involved in large materials flows. After studying the theory of technical change, exploratory interviews were held to become acquainted with this sector. Then, the literature about innovation in the construction industry was studied. It appeared that relatively little organisational knowledge exists about innovation processes within the construction industry in general and the decision making on materials technology by actors in particular. The grounded theory approach was regarded as a useful tool for studying the influence of the institutional context on the choice for materials use by actors in the construction sector.

The paper starts with the outline of the methodological perspectives used. Then, materials use within the construction industry is briefly discussed. Special attention will be given to the interface between materials suppliers and the building process. After presenting materials application as a central process for the implementation of materials innovations, an overview is given of the empirically found data, which show the main factors that affect the decision of actors concerning materials use. The role of these factors will be further discussed in section four, in which an empirically based model for the context of the transfer of materials technologies is presented.

1. Methodology

Grounded theory, first presented by Glaser and Strauss (1967), is an approach where the researcher systematically seeks to develop a theory appropriate for the empirical phenomenon studied. The purpose of the approach is to build theory. This implies that data and theory are generated at the same time. The development of grounded theory includes a notion of independence; this means that hypotheses and concepts come from the data and are worked out in relation to the data in the course of the research. However, in this project also existing ideas about innovation in general were studied. This knowledge makes it impossible to derive interpretations only by generalisation of observable data. According to widely accepted insights 'there are and can be no sensations unimpregnated by expectations' (Lakatos 1982). Therefore the approach should be regarded as semi-grounded, since the studying of formal theories will have resulted in ungrounded assumptions by the researcher. Still, the methodology and techniques of grounded theory, further developed by Strauss and Corbin (1990), seemed appropriate in this study because the approach provides a powerful means to understand crucial elements in the institutional context of a poorly understood area, and it provides a basis for developing strategies that will allow for some measure of control over it (Strauss and Corbin 1990).

The basic methodological approach of the study was to interview actors from industry, policy and research institutions about their views on materials innovation in the construction industry. All respondents were asked to point out their opinion about the driving forces behind developments in materials use. During the collection of data, a view of materials innovation in the Dutch construction industry and its relation with factors in the socio-economic context emerged. After each interview a first analysis was done; where appropriate, new insights were included in the questionnaires.

After collecting all material, interview texts were thoroughly analysed by using a qualitative computer programme (QSR 1997). Materials application was chosen as the central process for studying the implementation of materials technologies. According to the grounded theory method, the analysis was conducted by coding texts from the interview reports. Codes were aggregated in categories that appeared relevant and built into a so-called conditional matrix. The matrix functions as a framework for placing the relevant factors in the institutional context of materials innovation grounded in the empirical data at different institutional levels. Mutual relations between factors were further explored resulting in the organisation and aggregation of factors in four clusters.

2. Innovation in construction

Useful theoretical concepts for the study discussed in this paper are derived from literature on technical change and technological systems (Lundvall 1992, Edquist 1997). A technological system can be defined as 'a network of agents interacting in a specific technology area under a particular institutional infrastructure for the purpose of generating, diffusing and utilising technology.' (Carlsson and Stankiewicz 1991) Although a technological system is technology specific, each system consists of a part that creates technology (production system) and a part that uses it (usage system). The transfer between these systems and the process of spreading a newly generated technology among users is called diffusion. Successful implementation of a technology is a function of the adoption and diffusion of this technology by firms in a sector.

A new technology can be regarded as a discontinuity within a technological system (Ehrnberg and Jacobsson 1997). The success of implementation depends on how the technology fits within the existing technological system. In addition, developments of competing technologies within the same technology area need to be taken into account. We therefore assume that the socio-economic context in which the implementation of materials innovations takes place plays an important role in the transfer and broader implementation of new materials technologies.

The materials supplying industries and construction industry meet at the building process. Actually, the core activity of the building process is the organisation of knowledge, labour and materials in order to integrate different material elements into one product: the building. Some of these material elements have a repetitive character whereas others are singular. Hence, because of the site-specific character of a building project most construction works are the result of a unique combination of processes and products. Slaughter (1998) concisely summarises the key characteristics of construction works as 'large, very complex, and long lasting, and they are created and built by temporary alliances of disparate organisations within an explicit social and political context'. The choice of application of specific materials in the construction industry is made by actors in the building process and occurs at the interface between materials supplying industries and the construction industry.

Figure 1 shows the interactions between the materials supplying industry and the building process. The materials supplying industry is represented as sub-system (A), whereas the construction sector is represented as sub-system (B), enclosing the different stages in the building process. Materials innovations can be developed in both the building and the materials sub-systems. However, an important part of the materials innovations are developed by or in co-operation with materials suppliers (Pries 1995). Transfer of (new) materials occurs during the realisation stage of the building process (thick arrow). This is the stage where the materials flow is linked to the building process. However, the decision process on materials use starts earlier in the building process and does have a major effect on materials use during the realisation stage. In particular, the requests of the client and the materials choices proposed by the designer are relevant. Actors within the materials system (the suppliers of construction materials) therefore try to influence the decision making by actors in the earlier stages of the building process. In figure 1, this is indicated with dashed arrows.

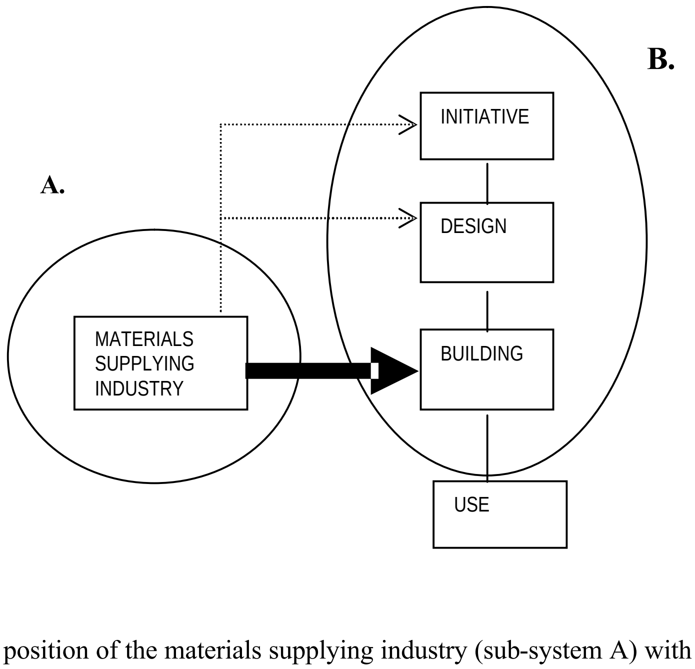

Figure 1: The position of the materials supplying industry (sub-system A) with regard to the construction industry (sub-system B); the thick arrows represent the flow of construction materials from materials suppliers into the building process; dashed arrow indicates strategic action of the supplying industry towards the construction industry.

In general terms, the materials supplying industry can be regarded as the production part of the technological system for materials technologies and the construction sector as the usage part. The precise constitution of a technological system depends on the technology involved (section 1). CO_2 optimal technologies for the construction sector largely vary (e.g. new materials, substitution of materials in products, more efficient materials use). This paper does not seem to be the right place to discuss all the individual characteristics of the materials options identified by the computer model, and their positioning within the institutional context. However, successful implementations of these options all have in common a change in materials use (thick arrow in figure 1). Whereas an important part of the materials technologies is developed at the materials sub-system A (e.g. development of new materials) but also in the construction sub-system B (e.g. substitution of materials in buildings), the success of implementation largely depends on the adoption and diffusion by actors in construction sub-system B.

3. Context for transfer and implementation of materials technologies

The implementation of materials technologies depends on the decisions made by actors in the building process. Other actors, such as actors involved in the supply of construction materials, develop strategies to influence the decisions of actors in the building process. Factors such as the position of the materials suppliers and their involvement in the building process therefore need to be taken into account to explain the development of materials innovations in the construction sector.

An interplay of actors is responsible for decisions on materials use. Their actions result in patterns of the transfer of materials from suppliers towards construction. The application of materials in construction as indicated in figure 1 is therefore regarded as the central process for implementation of materials innovations.

The first step in the analysis is to investigate the factors in the institutional context of the building process that have an affect on the choice of materials by relevant actors. For this purpose methods and techniques of the grounded theory approach are used. A second step is the classification of the relevant factors in broader categories.

3.1 Factors for materials use

Relevant items distilled from the empirical data are placed in an analytical diagram showing at which institutional level factors are located, (developed by: Straus & Corbin 1990). The diagram (or conditional matrix as Straus and Corbin named it) is useful for considering the wide range of factors related to the application of materials in construction. Figure 2 is the final result of the coding process, showing the factors identified at different institutional levels. The status of the diagram is descriptive. The distance from a factor to the central core concept not necessarily shows the relative impact of factors on materials use; it only makes a distinction between the institutional levels to which the factors belong. For more information about the division of factors in the layers of the analytical diagram and the representation of the various institutional levels, I refer to Strauss & Corbin (1990) chapter 10: the conditional matrix.

The core concept of the analysis (materials application) is placed at the centre of the diagram. Factors identified as conditional for materials application are subsequently grouped and placed in concentric circles surrounding the core concept. All factors have an effect on materials use in construction. Factors are grouped according to the institutional level they belong to; the concentric circles represent various institutional levels. The first level is the interactional level. By interaction we mean actors doing things together with regard to one another in regards to materials use in construction works. The second level includes the knowledge, experience, and philosophies of various groups involved in materials use. Moving outward, we find subsequently the organisational level. Each will have its own structure, rules, problems, and histories. The fourth level may be regarded as the national level, including national politics, government regulation, culture, history, issues etc. The outermost level is the international level. Its feature includes international politics, international regulation and international issues.

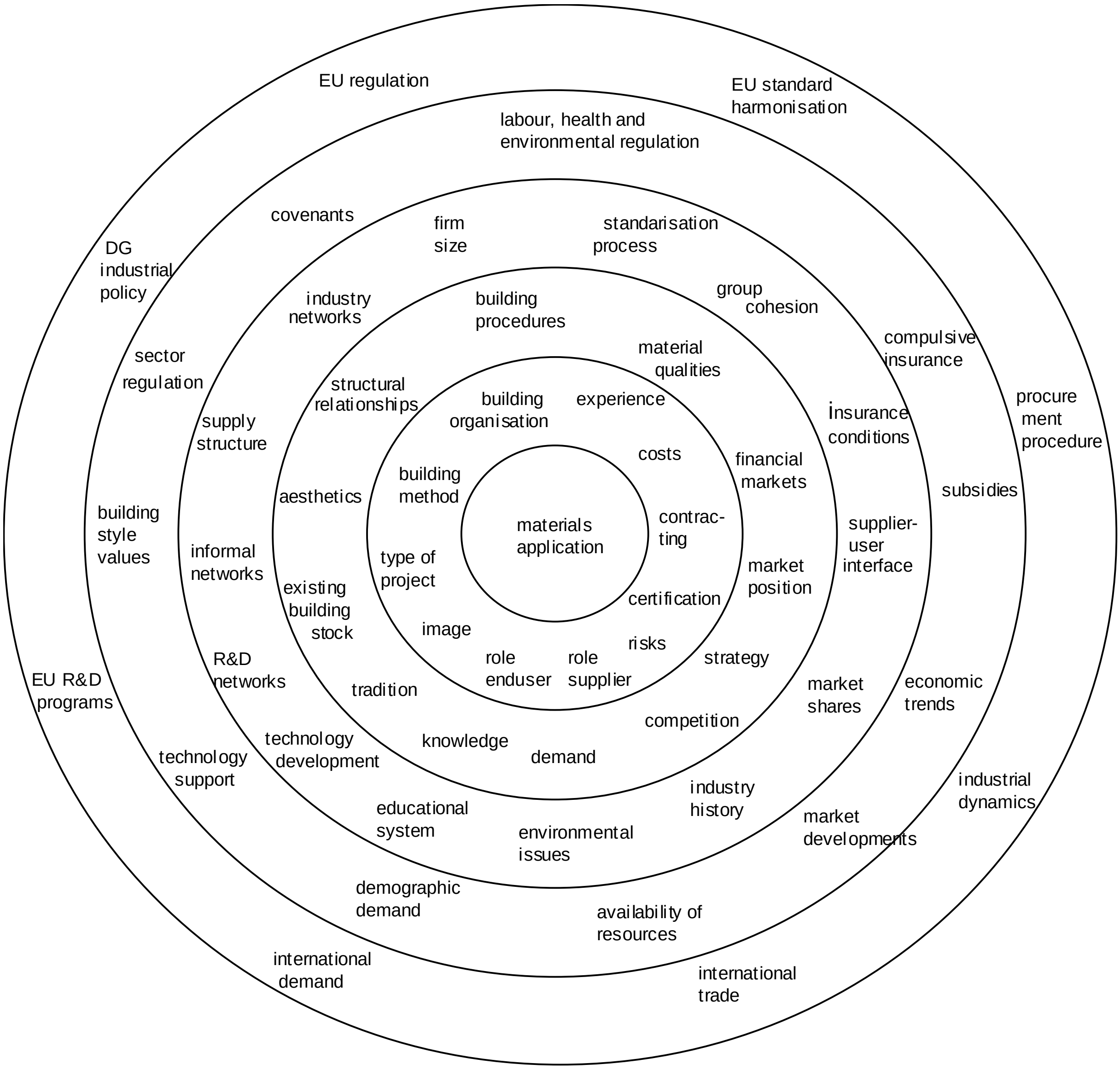

Figure 2: An overview of the specific conditional features for materials use at different levels of influence in the socio-economic context of the construction industry.

The circle closest to the centre includes the factors that directly interact with decisions on materials application. Materials choices are made within the building organisation, which consists of the client, the designer, the main contractor, and construction engineers and subcontractors such as sub-assembly suppliers. Important factors within the building organisation concerning materials use are amongst others costs, risks, the existence of contracts, certificates, and the building methods used. The role of actors, which are not directly involved in the building project, is important as well. Specific demands by the end user as well as attractive delivery conditions offered by the materials suppliers may affect materials use. Some of the factors are related to the building project itself; for instance, the purpose of the project and the image of a project. If the purpose of a project is speculative building, different considerations play a role for materials use than in case a building is intended for private housing of an office. Concerning the role of image, if a building project is part of a sustainable building program, or if the project team keeps up with the green image, materials decisions will be adjusted to that. For example, tropical hardwood, regularly used in some applications, will probably be replaced by sustainable timber.

The second layer represents the group level. Within this level group characteristics are placed that explain the behaviour of the actors involved in materials choice, e.g. the actors that are mentioned at the interactional level. We give an example of each group. An argument that is highly valued by professional clients that sell or rent buildings is the existing building stock; this is for them an indicator for the attractiveness of buildings towards the customers. In addition, the financial markets and structural relationships with main contractors are important. For designers, material quality and the aesthetics of materials are important arguments. Contractors often have their own specialisation, each strongly following their own traditions of working with materials and methods, and their knowledge of best practices. Their activities and choices are highly structured by building procedures. The market positioning and strategies of materials suppliers towards the construction industry are also conditional for materials use. The traditional materials have obtained a strong market position. These materials industries have the resources (money and time) to defend and increase their position in the construction industry. Supplying industries with a less dominant position use other strategies to affect materials use in the construction sector (e.g. good services, skilled people). The groups of materials suppliers largely vary concerning their strategies towards the construction industry.

At the organisational level a wide variety of factors are found. We highlight on the one hand the knowledge infrastructure (the existence of R&D networks, informal contacts between groups, the direction and subjects of technology development both in the area of construction and materials, the educational system and the developments of standards) and on the other hand, elements in the organisation of the industries (the networks of firms within and between sectors, the cohesion within a sector, the size of firms, particular issues that originally are posed upon an industry from outside the construction or materials system (environmental, insurance conditions), and the industry history).

The fourth layer represents the national level. Construction activity is strongly linked to demographics (national demand for houses), the need for infrastructure and urban development. The sector is therefore highly sensitive to developments on the construction market and economic trends. At the same time, the construction industry has to comply with all type of regulation that affect indirectly material application; for example, measures to protect the health of workers and users of buildings, regulations for investments in buildings and tax-systems. The regulations are developed at national and sector level, both by the government and sectors themselves. For some issues covenants between the government and the industries exist. In addition, stimulation programmes and measures such as subsidies and technology support affect materials use. A rather different type of factor is the geography within a country. The availability of resources, the geographical landscape as well as climate conditions have a large impact on the (historical) development of industries and on building styles.

The outermost layer, include factors at the international level that potentially affect materials application in construction. Within this level the regulation of the European Union is mentioned. The influence of the European Union operates in different policy areas: the industrial politics of DG XII, the procurement policy of the EU for construction works, the European R&D programmes, harmonisation of the member states' materials and building standards and other EU regulations, including labour conditions and the environment. Furthermore, the industry dynamics in Europe (vertical integration, specialisation, computerisation etc.) as well as international trade in construction materials and demand for construction projects are included.

3.2 Towards clustering the factors

The analysis shows that materials application is responding to many factors within the construction context. This result indicates that materials innovation in construction takes place in a highly complex environment. However, there are clear dependencies between factors. The coherence between factors that mainly belong to the same organisational subgroup are put forward in the conditional matrix. In order to handle with the complexity and to enhance further understanding of relations between factors, factors are mutually compared to break-up the data. This resulted in the identification of 4 clusters of factors:

1. organisational forms of the building process

2. structuring of the construction sector and the materials supplying industries
3. organisation of R&D and information-networks
4. national styles (cultural traditions, standardisation, and government regulations)

These clusters cut through the different institutional levels; within a cluster both the frame of reference of a professional group as well as sector regulation can be included. The coherence between the factors presented in figure 2 will be discussed along the lines of these four clusters. For each cluster an example of the Dutch construction industry will be given.

Organisation of the building process

The first cluster points at the organisation of materials use within the building process and includes the subgroup of actors directly involved in the building process. It includes the building organisation, the factors that influence organisation of materials use within the building process, and group characteristics of the partners that participate. This cluster is almost completely in line with the first and second layer within the diagram.

The coherence explored between actors is highly hierarchical. Materials decisions are made at different stages within the building process. The three main steps in this hierarchy are definition of the requirements, the specifications of these requirements into a design and the translation of the design into a materials product.

Materials application depends on the configuration of actors in the different stages of the building project. The building organisation and the responsibility of actors differ among projects. In the traditional model, the client and designer takes the major decisions in the definition and design stages, whereas more integrated forms such as the building team or the turnkey organisation include the skills of the contractor. These new forms of building organisations are better able to deal with complexity and change (SBR 1992).

> In the Netherlands, generally cooperation with a main contractor takes place. In most cases a traditional building organisation is used. Sometimes, a building team is used to strengthen the relationship between design and realisation. There is a trend towards new forms of process organisation with a tendency towards both horizontal integration (between contractors and sub-assembly suppliers) and vertical integration (between sub-assembly suppliers or contractors and materials suppliers).

The structure of supply and building

This cluster consists of factors that relate to the interaction between the materials industry and the construction industry. For each materials sector, these factors are different. Materials suppliers for instance differ in the way they (strategically) interact with the building system. Structural relationships between materials suppliers and the construction sector, a good market position on the construction market, and construction oriented strategies seem to add to the success of particular construction materials. Differences between materials industries can be explained from the large differences in industry organisation and industry strategy. The industry structure of the materials industries and the way they interact with the construction industry have a large effect on their potential power to control or influence (change in) materials use in the construction sector.

> The concrete industry is an important player on the Dutch construction market. The large cement company cooperates with the small concrete firms to promote the application of concrete in construction works. Some of the large contractors have a concrete producing division. The steel industry is less dominant on the construction market, but has a strong market position in single storey buildings (halls). Steel frames necessary for the use of steel in offices are not produced in the Netherlands. Compared to the cement industry the Dutch steel industry is loosely coupled to the construction industry.

Organisation of information

This cluster includes all factors related to the development and exchange of information on materials or materials use. Knowledge acquisition by Research & Development is regarded as a driving force for the development of industries. Developments in materials etchnology are, however, rather slow. This has to do with three aspects some of them again related to the structure of industries.

First, materials industries and the various construction segments differ in research capacity. For several reasons R&D expenditure is more difficult for small firms. For instance, the ready mixed industry consists of mainly small firms. Their competitor, the prefab concrete industry, produces concrete products in factories. Companies are larger, and moreover, the production process occurs under controlled conditions. This provides better opportunities to optimise the product and the process. Moreover, the value added of concrete products is higher than of ready mixed concrete. Therefore, the margins of the prefab concrete industry allow more room for R&D compared to the ready mixed concrete industries.

Second, the diffusion of knowledge between the materials and construction industries varies. The exchange of information takes place at the building site (interaction between material supplier and contractor), but also in the conceptual stage of a building process (interaction between the material suppliers and the client, designers or building team). If there is only exchange between supplier and contractor, it is often in a one way direction: from the material supplier towards the actors in the building process. This may suggest that the materials industries are not optimal informed about the needs and demands of the construction industry.

Third, the knowledge of suppliers utilised into the building process has significant effects on materials use. As discussed in section two, there is a special problem concerning the diffusion of knowledge in construction: building projects are often unique. However, there are innovative strategies to overcome this barrier. One of the possibilities is to develop repetitive elements that require similar ways of handling, which can be standardised; another possibility is offering assistance together with the material.

> Research in the Dutch construction industry is coordinated by four institutes (COPI's), which are partly financed by the Dutch government (Spekkink 1997) . One of the COPI's, CUR, is actively involved in the development of provision standards for materials use in construction. The possibilities for product development are rather small in the Netherlands. The private support is limited, because there are only a few large construction companies. As a result of the comparatively small domestic market (the Netherlands is one of the smallest european countries), also the public basis for product development is modest (Schellevis *et al*. 1995). Environmental information is becoming increasingly important for the construction industry. This is partially reflected within recent building specifications.

National styles

The fourth cluster consists of factors framing national styles. It includes the regulations within the construction and materials industry, which are evolved over years, as well as significant developments within the industry histories for the development of materials. It also includes the impact of the geographical distribution of natural resources, climate factors as well as local building preferences.

The fourth cluster is quite different from the former three; this cluster of factors does have an effect on the interplay of all factors mentioned in the clusters previously discussed. Cultural traditions, standardisation practices and government regulations make that the borders of countries shape national innovation systems for the construction industry

> The Dutch construction industry has obtained an international reputation in dredging and hydraulic engineering. Stony materials dominate the pattern of materials use in construction works. In the list of top 10 contractors in Europe the Dutch construction firms are not included; this list is dominated by the French and British firms. According to an international comparison the Dutch construction firms can be classified as 'constructing specialists'. The French in contrast are more focused on the total product. Typical features of the Dutch construction industry are the strong regulation of the building process and the high share of public spending in construction research.

3.3 Materials use in the Netherlands

The results show that materials use is influenced by different categories of factors. The ways in which these factors impact give shape to the pattern of materials use within a country. However, is it possible to find an explanation for materials use within a country based on these factors? In the previous section the Dutch construction situation illustrated the four sets of factors. In this section we slightly digress onto a discussion how elements in these four categories can be linked to materials use in the Dutch construction industry. Further investigation of these factors gave rise to the following explanatory outlook for the present pattern of materials use in the Netherlands. The focus is on the well-developed position of concrete use.

As mentioned earlier in this paper, the Netherlands is leading in dredging works and hydraulic engineering. The development of this particular part of the construction industry should be regarded in the historical perspective in which the Dutch society has been involved in the continious struggle against river and sea water over ages. The largest Dutch construction companies are all active in this segment of construction. A lot of knowledge is created by the conductance of large hydraulic works on the domestic market. A large professional client as Rijkswaterstaat (Department of Public Works) definitely played here an important role. The fact that the Dutch construction industry has a strong profile in dredging and hydraulic engineering is possibly related to the pattern of materials uses in construction, in particular the dominant the position of concrete.

First, concrete is often used for the realisation of works in this field. The attention paid towards this material is therefore large. Successful areas of application of materials stimulate research related to these materials. The research results in turn provide opportunities for improved material qualities and materials handling. If the Netherlands wants to keep its prominent position, R&D is of major importance. As a consequence, the success of a material and R&D are mutually reinforcing. This is also supported by finding of the Dutch Economic Institute for the Construction Industry, which demonstrate that relatively much research and development in the Netherlands is conducted in the areas in which the Netherlands are relatively strong (Schellevis *et al.* 1995). Dredging, hydraulic engineering, concrete construction and environmental engineering are mentioned.

Second, particularly the large construction companies are involved in this segment. Larger companies are in general better able to finance and to coordinate the research and development in the application of materials.

A third indication is the central position of CUR within the construction industry. This is an institute that is heavily involved in innovative civil engineering projects and therefore has built a lot of knowledge within the segments of the industry in which concrete is an important construction material. Part of the research eventually results in the development of (pre)standards. Moreover, strong historical links exist between CUR and the concrete world. In fact, the organisation has its roots within the concrete industry; originally it was founded as a special research and testing group of the Concrete Association (Betonvereniging).

Fourth, the geographical and geophysical situation has been favourable for the development of the concrete industry in the Netherlands. Natural resources (sand, lime, gravel) and water were sufficient available. Cement production was started-up in the Netherlands self. Cement companies are large firms with in-house possibilities for research and development, which entirely focuses on the construction market. At present, the Netherlands has 3 cement factories belonging to the same company.

Fifth, the structure of the concrete and construction industry is favourable for concrete use. Some large construction agglomerates include concrete producing units. Historically, concrete was made on-site by the contractors themselves. Now ready mixed concrete or prefabricated concrete elements are deliver at the building site. Increasingly contractors start to cooperate or quasi-integrate concrete supplying firms. The link between concrete production and the construction industry becomes therefore rather short.

Sixth, the (former) practice of mixing concrete on-site results in good knowledge of contractors about concrete application (tradition, skills). If a main contractor is involved in the design stage (building teams, internal design departments of contractors) the concrete industry is to some extend represented by the contractors in the organisation of the building project. The steel and wood fabricating industry hardly act as main contractors in the building process. The position for concrete within the building process is therefore more advantageous for concrete compared to steel or wood.

Lastly, the large construction companies working in dredging or hydraulic engineering are the leading construction companies in the Netherlands. Their activities are not limited to these segments of the construction industry; they also have an important stake in other construction segments like housing or office building. Possibly, this has been creating favourable conditions for the diffusion of concrete technology towards other segments in the construction industry.

4. Model for the context of materials innovation

Adoption and diffusion of materials technologies are reflected by materials use in the construction sector. However, materials use is only one of the issues in the construction industry. Physically it plays a central role, as demonstrated by figure 1, but the choice for materials by actors in the organisation of the building process is based on a combination of factors, as presented in figure 2. In this paper arguments for using materials technologies are investigated by studying the conditions that affect materials use by actors in the building process. This provides a general view of the potentially relevant factors for implementation of materials innovations, which take place in this context.

The results of the exploratory research within the Dutch construction industry shows that many factors are involved in materials application. These factors vary in character and act at different institutional levels. However, they also show mutual dependency, which reduces the heterogeneity and the number of factors to some extent. The explored dependency of factors resulted in the identification of four clusters:

1. organisational forms of the building process
2. structuring of the construction sector and the materials supplying industries
3. organisation of R&D and information-networks
4. national styles

Another finding concerning the character of the factors for materials use is that some factors are stable over time, whereas others change. For a long time, the availability of raw materials has been a particular stable factor. In contrast, design trends are an example of a rapid changing factor that affects materials use. As a result, time is a factor for materials use in itself and patterns of materials application are changing over time.

In addition, there appears to be an order in sequence of influence. The order of effect can be read from the diagram in figure 2. R&D at the materials supply side are not immediately implemented in the construction industry. It first has to fulfil the requirements within a construction work (e.g. a building) as a whole. This means that although a new technology involves only minor changes in the production system, the implementation may impact largely on elements in the construction system.

The empirical evidence further suggests that the context consist of both ‘hardware’ and ‘software’ factors. Those frame materials applications and therefore the transfer of new technologies. Figure 3 shows a model for materials application, which combines the three of the four clusters, the order of sequence in influence of factors and the distinction between the ‘hardware’ (structural) factors and the ‘software’ (institutional) factors. Materials application is placed in the centre as the result of interaction between materials supply and construction. Both materials supply and construction are influenced by different factors. The ‘hardware’ factors are placed on the right side and the ‘software’ factors are place on the left side. The distance in the figures of the factors to materials application is according to the order of influence on materials application. On the right side the literal structure of supply and building (cluster 2) is reflected. On the left side, the institutional organisation of the sector, including the organisation of information (cluster 3) is reflected. The organisational form of the building process (cluster 1) is shown as one of the factors in the structure of construction, close to the process of materials application (the project organisation). The project organisation can be regarded as gate keeping for (change in) materials use. National styles (cluster 4) influence the picture as a whole and therefore cannot explicitly be included in figure 3.

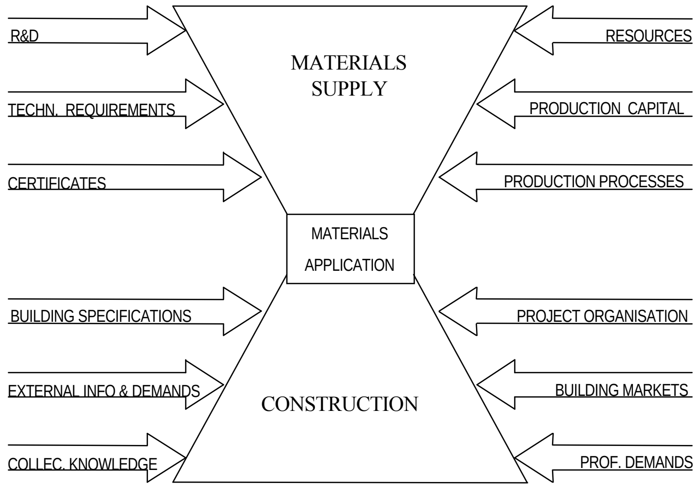

Figure 3: A model for materials innovation as the outcome of the interaction between the materials supplying industry and the construction industry.

Materials supply is on the one hand framed by the availability of resources, existing capital (industry structures), and accompanying production processes, and on the other hand by rules and institutions such as the knowledge infrastructure (R&D), the ways of (technically) handling materials and certification.

In the construction industry, materials application is structured by the specific requirements of a building project, the possibilities within a construction segment and the building organisation of a project. The distribution of responsibilities over the different stages in the building process, and thereby the input of knowledge, depends on the organisational form. Each actor has its own frame of reference, which can be regarded as the collective knowledge of a professional group. In order to establish a building, the information of the different actors need to be combined with external influences, such as regulation and environmental pressure. At the operational level, procedures and common ideas and practices about materials application are standardised, and formally institutionalised in building specifications and standards set by representatives of the construction sector, the materials suppliers and the government.

Materials technologies may be developed by R&D of the supplying industry or within professional groups in the construction industry. However, both R&D and the specific ideas of collective groups do not dominate the building process; the two structures, materials supply and construction, need to integrate and associate information from inside (e.g. construction methods) and outside the sector (e.g. environmental demands) for the creation of technology (Foray 1991) in order to render them specific at the construction site. Materials innovations need to be integrated within the existing production structures and need to be combined with other needs and demands which are essential for the building process. Therefore, figure 3 can be regarded as a model for materials innovation in which materials innovation is represented as the outcome of choices made by actors in the interactions within and between the supplying industry and the construction industry.

Successful transfer of materials innovations often fail because of barriers to implementation, such as a lack of knowledge and skills within the construction industry, incompatibility with existing construction methods or building styles, or difficulties concerning the building organisation or supply. Strategies for the transfer of materials options for CO_2 reduction need to take into account the complexity caused by the number and variety of relevant factors for materials use, the order of effect in which these factors impact upon materials use and the way relevant factors in the institutional context change over time. The influence of these factors will differ per country as well as per materials option studied. The relevant set of factors for successful implementation depends on both the type of technology and the type of materials. For instance, the organisation related to the use of a technology differs between technologies; construction materials suppliers interact with the construction industry in various ways; and, materials industries differ in sector organisation. Concerning CO_2 reduction options in materials use, firstly, a distinction need to be made between materials technologies which are in line with the dynamics in materials applications and those that are not. Strategies for the first would be based on addressing or facilitating the underlying patterns, whereas the others require a much more differentiated strategy. Secondly, policy efforts for implementing particular materials innovations need to address different institutional levels, depending of the type of technology and its compatibility with the organisation and developments within the construction context.

Materials application in the construction sector is a dynamic process. This process is driven by a factors with a physical, economical and organisational or institutional character, which determine the national profile of materials use and materials innovation in a country. Change in materials use is both structured and facilitated or hampered by these patterns. A pre-evaluation of the impact of specific (families of) CO_2 optimal materials technologies seems to be desirable in order to assess the crucial for successful implementation. This requires, however, good insight in the dynamics of the organisation of materials use within the construction sector, the industry structure, information-networks and national styles in materials use and technology development. The results presented in this paper contributed to this by showing in a structured way a general picture of the relevant factors in the context in which implementation of materials technologies takes place.

Acknowledgement

The author would like to thank the Dutch Research Foundation (NWO) and the National Research Program for Climate Change and Air Pollution (NOP) for funding the research project.

References

Carlsson, B. and Stankiewicz (1991). “On the nature, function, and composition of technological systems.” *Journal of Evolutionary Economics* 2(1): 93-118.

Edquist, C., Ed. (1997). *Systems of Innovation. Technologies, Institutions and Organizations.* London, Pinter.

Ehrnberg, E. and S. Jacobsson (1997). Technological discontinuities and incumbents' performance: an analytical framework. *Systems of Innovation. Technologies, Institutions and Organizations.* C. Edquist. London, Pinter**:** 318-341.

Foray, D. (1991). “Industrial cooperation and the organizational dynamics of the innovative firm.” *Research Policy* (20): 393-405.

Gielen, D. J. and T. Kram (1997). *The MARKAL Model for environmental accounting in energy and materials systems.* ConAccount workshop: Regional and national material flow accounting "From paradigm to practice of sustainability", Leiden.

Glaser, B. G. and A. L. Strauss (1967). *The discovery of grounded theory: strategies for qualitative research.* New York, Aldine Publishing Company.

Lakatos, I. (1982) *The methodology of scientific research programmes*. Philosophical Papers. Cambridge, Cambridge University Press

Lundvall, B.-A. (1992). *National systems of innovation*. London, Pinter.

Pries, F. (1995). Innovatie in de bouwnijverheid. Faculteit Bedrijfskunde. Rotterdam, Erasmus University**:** 222.

QSR, Q. S. a. R. P. L. (1997). QSR NUD*IST. London, SCOLARI Sage Publication Inc.

SBR (1992). Bouworganisatievormen in Nederland. Rotterdam, SBR.

Schellevis, J., A. L. J. Veraart, E.D.N. Verweij and O.M. Vries (1995). De Nederlandse bouw internationaal vergeleken. Amsterdam, Economisch Instituut voor de Bouwnijverheid.

Slaughter, E. S. (1998). "Models of Construction Innovation." *Journal of Construction engineering and Management* 124(3): 226-231.

Spekkink, D. (1997). Sturing van wetenschappelijk onderzoek door branches: voorbeelden uit de bouw. *Sturing van wetenschappelijk onderzoek*. F. J. M. Zwetsloot. The Hague, DELWEL Uitgeverij B.V.**:** 68-75.

Strauss, A. and J. Corbin (1990*). Basics of qualitative research: grounded theory procedures and techniques.* California, Sage Publications, Inc.