STRETCHING THE TROUSERS TOO FAR?

Convening societal and ICT development in the architectural and engineering practice

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Abstract. The publicly and privately funded national R&D program 'Digital Construction' was initiated in 2003 in order to establish a common platform for interchanging digital information and to stimulate digital integration in the Danish building industry. This paper explores the relation between visions, strategies and tools formulated in the 'Digital Construction' program, and the first experiences made from implementing the 3D work method part of the program in an ongoing building project. The discussions in the paper are placed in the complex field between choosing strategies for integrating information and communication technologies on national level, and the effects of these strategies on real life building projects.

1. Introduction

Information and communication technologies (ICT) are for good reason heavily linked to future prosperity and growth in a range of European countries. However, the Architecture-Engineering-Construction (AEC) industry has been slow in turning the potential of ICT and CAD into increased efficiency and quality (Gann 2000; Wikforss 2003), and the productivity status in the AEC-industry described in the Latham report in 1994 (Latham 1994), still gives raise to concerns. Based on this context, several international and national initiatives for integrating ICT in the AEC-industry have emerged. In Denmark the national research and development (R&D) program "Det Digitale Byggeri" (Digital Construction), co-funded by public and private sources, was initiated in 2003, in order to establish a

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common platform for interchanging digital information and to stimulate digital integration in the Danish AEC-industry (EBST 2005). The R&D program ended in March 2007.

This paper explores the relationship between the expectations, strategies and tools formulated in the 'Digital Construction' program and the benefits and challenges experienced from implementing and using 3D object models in practice. Are the trousers stretched too far regarding the convening of societal and ICT development in the architectural and engineering practice? The analysis will be based on an ongoing evaluation of this R&D program and the first experiences made from implementing a part of the program in the building design process of the new Icelandic National Concert and Conference Centre in Reykjavik (CCC-project). The discussion points on the challenges from convening societal and ICT development in the architectural and engineering practice.

2. Method

The discussions and analysis regarding the 'Digital Construction' program are based on the results from a qualitative process evaluation. Initiated by EBST (The National Agency for Enterprise and Construction, a Danish public body within the resort of the ministry of Economy and Business), the evaluation started in the winter of 2004. Seeing the Danish 'Digital Construction' program from a process evaluation point of view gives the possibility to evaluate the dynamic development of the program (Van de Ven 1999; Patton 1990, 1998). The process evaluation has been documented in four intervention and status notes of the program's progress (Koch and Haugen 2006). The process evaluation is based on an array of methods: interviews, participant observation and desk research. Just above forty interviews have been carried out, comprising biannual interviews with project managers from EBST and project managers representing the various active development consortia within the program, the surrounding learning network etc. The exploration of the experiences made from implementing 'Digital Construction' in the CCC-project build on the first findings from a qualitative case study of the project (Yin 2003). Around 12 semi-structured interviews (Kvale 1997) have been carried out in 2006 with architects and engineers involved in building design and management. Documentary analysis and observation of design meetings are further sources of the empirical data. The brief glimpses into other national and international initiatives for integrating ICT in the AEC-industry are based on interviews with key actors involved.

A research framework has been developed and applied for supporting the exploration of the ICT impact on the architectural design process (Moum 2006). The framework is based on the suggestion of three levels; a macro-level (AEC-industry), a meso-level (the design team in the CCC-project) and a micro-level (the individual architect/ engineer). The discussion part of the paper is placed in the dynamic relation between these levels: between initiatives and strategies emerging on a national level (macro-level), the processes within the project team (meso-level) and the individual experiences from ICT usage (micro-level). The framework focuses furthermore on four central design process aspects: generation of design solutions, communication, evaluation of design solutions and decision-making.

The authors recognize that through using an Icelandic building project as a case of the implementation of the Danish national program, the exploration is limited to the internal part of the design process. A full evaluation would encompass the interactions also with external actors, such as the Danish state acting as client. Nevertheless, the CCC-project's organizational structure, complexity, architectural ambitions and economical and management related aspects, makes it an exceptional project. Thus, the authors consider the project to be an interesting case for exploring not only technological, but also some non- technological challenges and benefits from of 'Digital Construction' in architectural and engineering practice.

3. R&D Efforts Integrating ICT and 3D CAD

The International Alliance of Interoperability (IAI) was founded with the aim of promulgating interoperability and efficient information exchange between different ICT systems (International Alliance of Interoperability 2006). IAI is the key actor behind the development of the file exchange format IFC (Industry Foundation Classes) to ensure a system-independent exchange of information between all actors in the whole life cycle of the building. The program of the international IAI conferences from the last two years indicates a focus change from being technology development oriented to becoming implementation oriented. Consequently, IAI introduced the new brand "BuildingSMART" in June 2005.

The Finnish Vera Technology Programme became a central player in IAI's efforts regarding the development of IFC as an international product model standard (VERA 2006). The program made Finland one of the leading countries developing ICT for the AEC/FM industry. Five years later, after this program came to an end, the Confederation of the Finnish Construction industries initiated the ProIT-project Product Model Data in the Construction Process (ProIT 2006), which focused on developing strategies for implementing 3D product models. The program was based on a joint effort between research and the building industry. Guidelines for architectural and engineering design were developed, and 3D product modeling was trialled in several pilot-projects.

Powerful players in the Norwegian AEC-industry have recognized the potential of introducing information exchange with IFC-based 3D object models throughout the value chain of the building process. The Norwegian BuildingSMART project is a joint venture of actors from both industry and research, and comprises several research and development projects. They include international projects (BuildingSMART - Nordic Chapter 2006) such as the IFD-project (Information Framework for Dictionaries), the IDM-project (Information Delivery Manuals), and electronic submissions to planning authorities. This last project is based on the experiences from Singapore, where they issued the CORENET in 2002 as a public e-submission system (CORENET e-Information System 2006). One of the implementation arenas for the BuildingSmart technology is the ongoing Norwegian pilot building project Tromsø University College, also called the HITOS-project (Statsbygg 2006). The public client Statsbygg (The Directorate of Public Construction and Property) requires and supports the implementation of IFC-based 3D object modeling by connecting a R&D project to the building project, based on a close collaboration between the design team, the software vendors and the Norwegian BuildingSMART.

Finnish promoters of the ProIT project, emphasized that Finland can harvest from the benefit of being a small country (ProIT information DVD "Product modeling as the basis for construction process", released 2005). Compared to many other larger countries, it is easier to gather the driving forces and to work together in implementing new technology. This situation has probably been a good starting point also for the R&D initiatives in Norway, and as we shall se later, for the Danish 'Digital Construction' program. In contrast, combining forces in the German AEC-industry is understood as far more challenging by its German promoters (interview with leader of the German BuildingSMART chapter). Some of the reasons for this situation are probably the complex and fragmented societal, political and business related structures of the country and the "bad times" in the German AEC-industry since the mid nineties. Generally, an essential target of the international BuildingSMART's and the German chapter's efforts are the players in the AEC-industry with the power and ability to implement the standards and technologies developed.

These are only selected examples from some European countries, not representing a complete picture of all worth mentioning international or national initiatives. The intention is to give the reader a brief glimpse into some trends as a "backdrop" for the further exploration of the Danish R&D program. Nevertheless, the authors interpret the Danish R&D program as strongly embedded in and characterized by the Danish institutional set up. A limitation of the present contribution is that the characteristics of this embedding and how it impacts on the program is not (yet) further developed.

A possible reference for investigating these aspects is Bang et al. (2001) in Manseau and Seaden (2001).

4. 'Digital Construction': A Public R&D Program in Denmark

A central feature of the 'Digital Construction' program is the belief in the client-power of the state. It is hoped that through a targeted development program the Danish state can set a standard for digitalized tendering, design, classification of building data, project webs and managing facilities. Three major professional state clients were envisioned to be central drivers in the program process. These three state clients of buildings cooperated with the consortia established in the program. The assumption was that the construction sector actors will engage in developing a basis for a future legislated digital interaction with the public clients. Another main idea of the program has been to adopt existing and developed generic software packages and configure those to support the developed guidelines and standards. The program has been taking a consensual approach in combining forces and mobilizing AEC-industry players, who were believed to be best able to drive and develop new methods and procedures to be used by the industry in the future. The establishment of proper and consensus based strategies for implementing the solutions agreed upon in practice, was an essential issue in the program. Based on this background, three main strategies have been defined (EBST 2005):

1. To provide a **digital foundation** for standards and methods to assure that all players in the construction business are "speaking the same digital language"
2. To establish a set of law-regulating **client demands,** which were issued by 01.01.2007 in public building projects
3. To build up a "**Best Practice**" base - a compilation of experiences of real life projects demonstrating how the integration of digital solutions in real life projects can enhance efficiency in the working process

In support of area "3," the program encompassed an effort to evaluate and communicate best practice experiences for implementing and operating ICT in construction. The consortium responsible for this part of the program featured a handful of the largest players amongst contractors and consulting engineers. The project ran into a number of problems; importantly it turned out to be very difficult to find best practice examples. In December 2006, the "best-practice" base of 'Digital Construction' included 17 cases, whereof 5 deal with 3D-issues, 4 with project web, and the rest with e-learning, commissioning, e-mail standard and other smaller ICT-issues. This base represents mainly cases with a limited scope, focusing on smaller parts of the building process. The cases are derived from the developmental work within Digital Construction of experimental character rather than well-documented “best practice”, as also noted by the program itself ('Digital Construction' public website 2006).

4.1. THE DIGITAL FOUNDATION

Over the spring of 2004, the digital foundation part of “Digital Construction” was divided into four project proposals:

- Classification
- 3D work methods
- Logistics and Process
- Building Items Chart (not followed up)

This collection of projects reflects a delicate balance of interests. Object orientation has been “secured” space through the 3D work method project. Whereas positions of more pragmatic type as well as interests in favor of a “document-view” are secured space within classification. Moreover, logistics and process represents an area that contractors are interested in. Broad participation was assured at workshops and was obtained in the sense that more representatives from contractors than initially was mobilized. The design was challenged both internally and externally by website debate and in the program council. In May and June 2004 several elements were taken out in order to meet the overall budget. The remaining three projects (the first three bullet points) stabilized and all commenced before September 2004. As of 2007, the new classification has been developed and is now under scrutiny by external experts. The 3D work methods was finalized by summer 2006, with extensive material available on the public website and used in the case below. The results of the logistics and process- project was a proposal for the use of so-called “production-cards” a tool for detailed scheduling at the building site, inspired by last planner /lean construction ideas.

4.2. THE 3D WORK METHOD PROJECT

The 3D work method project is intended to match the building processes and technologies known today, and mirrors the general visions of the ‘Digital Construction’ program. An important issue in the development of the 3D work method was to ensure that the established manuals allow new and innovative collaboration scenarios and the implementation of future CAD technology. Around 35 companies representing different interests in the industry have participated. The joint efforts in the 3D work method project have resulted in a 3D CAD manual built upon four parts: (http://www.detdigitalebyggeri.dk):

- 3D work method (description of concept)
- 3D CAD manual (practical guidelines for building up the 3D model)

- Layer and Object structures
- 3D CAD project agreement.

The four manuals aim to specify a common working method for all parties in planning and construction to support the building-up, exchange, and re-use of the 3D models throughout all phases of the process (bips 2006). Further aims formulated in the concept are (examples): work process optimization and improved collaboration, improved quality and consistency of project material, clear definition of responsibility through common work method principles, improved communication through visually understandable 3D models, and automation of sub-processes.

The key idea of the 3D work method project is that each discipline shall build up, maintain and importantly, be responsible for their 3D discipline-specific object model. All necessary changes/editing shall be undertaken in these discipline models. The discipline-specific model is also the basis for generating 2D drawings and quantity take-offs. The exchange of the models between the disciplines is to be based on IFC or another appropriate file exchange format. The 3D work method manual furthermore suggests building up the 3D models according to seven information levels according to the increasing need for concretization. The 3D work method proposes in the next step to gather these discipline models into a common project model. The decision to which extent a common model shall be integrated and used in a building project depends on the project specific technical and financial possibilities to be clarified in the CAD agreement. From January 2007, the 3D work method project has been implemented as guidelines together with the client demands, requiring the compulsory use of 3D object models in public building projects with building costs exceeding 40 millions Danish kroner (5,3 mill. Euro). (EBST 2005)

5. The National Icelandic Concert and Conference Centre in Reykjavik

Figure 1. Left: The CCC-project. Right: 3D visualization of quasi-brick-façade. (Courtesy: Henning Larsen Architects)

The National Icelandic Concert and Conference Centre (CCC), Figure 1, located in the harbor of Reykjavik, is a prestigious public-partnership project aiming to make Reykjavik visible in the international landscape of architectural and cultural high-lights.

5.1. THE ROLE OF THE 3D OBJECT MODEL IN THE CCC-PROJECT

The CCC-project is one of the first ongoing large-scale building projects in Denmark attempting to work with and exchange 3D object models. The interdisciplinary use of 3D object models is expected to play an important role in supporting the development of the complex design solutions and in the smoothing of interactions between the actors and the processes. Following the 3D work method manuals, each discipline has been building up their own discipline model using the software most appropriate for their specific needs (Figure 2). Each discipline can directly upload the model files from other disciplines as external references. A CAD operator gathers the different discipline models into a common model, which they use for making clash-detections for generating visualization files (Figure 3, left).

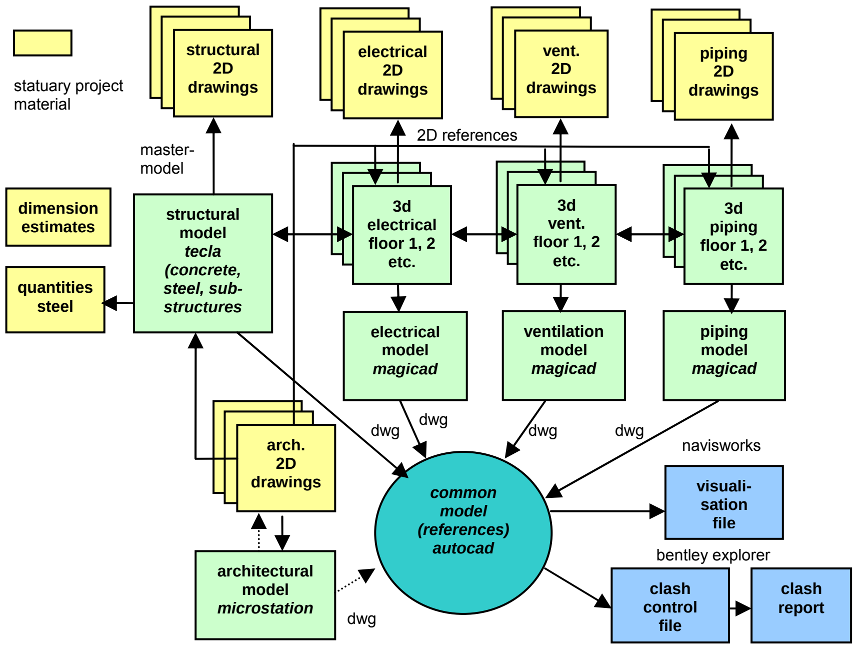

Figure 2. Overview ICT system CCC-project

An important issue which influences the interdisciplinary use of the 3D object model and the data-exchange between the architects and the engineers is that the architects are still mainly working with 2D CAD. 3D object models are only used in limited parts of the project, for instance in developing the complex building envelops and the quasi-brick façade. According to the architects' project manager, the risks connected to the implementation of a totally new CAD-technology into such a large and complex building project were considered as too high. However, the architectural company agreed to build up a "test" 3D object model as an "add-on" to the actual 2D project material in order to collect experiences and test out the potential. The first upload of the architectural 3D object model into the common model was possible summer 2006, toward the end of the design proposal phase. Generally, the importance of the 3D object model for the architectural design team has increased since the start of the project. In Autumn 2006, the architectural company was considering to generate parts of the 2D project material directly from the 3D object model in the detailed design phase.

To work with 3D object models is not yet an issue for the contractor partly because the contractor is an Icelandic company and thus not directly part of the target group of 'Digital Construction.' This also mirrors the situation in the program generally, where the architects and engineers were the most active players. Thus, the implementation and use of the 3D working method of 'Digital Construction' in this project is limited to the design group. The statuary documents of the project are traditional 2D drawings (partly generated from the discipline models).

5.2. EXPERIENCES FROM IMPLEMENTATION AND USE: EXAMPLES

Until a kick-off meeting where the 3D work method concept was presented within the engineering company, the project participants were overwhelmed and skeptical as they were confronted with the decision to implement interdisciplinary use of 3D object models in the project. According to the project manager of the engineering disciplines, the clarity of the concept regarding responsibilities and discipline models increased the acceptance among the project group actors.

The 3D object model has until autumn 2006 been playing its main role in supporting geometrical development, coordination and space management internally in the design team. Several interview respondents in the engineering company pointed out the improved understanding and control of the building geometry and geometrical relations between the different disciplines as substantial benefits. Clashes and failures could be recognized and solved earlier. The 3D visualizations have also been helpful in order to achieve a shared understanding regarding the needs and the intentions of each discipline. An interview respondent involved in the architectural façade group pointed out that developing and communicating the complex building envelope would have been nearly impossible without using a 3D model for solution generation, communication and evaluation (Figure 1, right). The 3D model has also contributed to improved communication of project intentions to actors outside the design team. In Autumn 2006, the engineering company presented and demonstrated their visualization file of the common model and the possibilities for easy 3D navigation. According to the project manager from the engineering company, this was a success and a breakthrough in communicating the very complex interplay between the different contributions in a visual and easy understandable way to project participants who had difficulties in interpreting traditional 2D drawings. Still, in most cases, the 3D object model has not been used directly or real-time in meeting situations.

Regarding other possible 3D model related aims and activities defined in the 3D work method concept, simulations based on the 3D model have not yet been carried out. Neither have quantity-take offs been automatically generated. An exception is the engineering group developing the steel constructions. They seem to utilize more fully the possibilities of their discipline 3D model. According to one of the interview respondents involved in the international IAI, the domain of steel construction is generally in a leading position regarding software development and use.

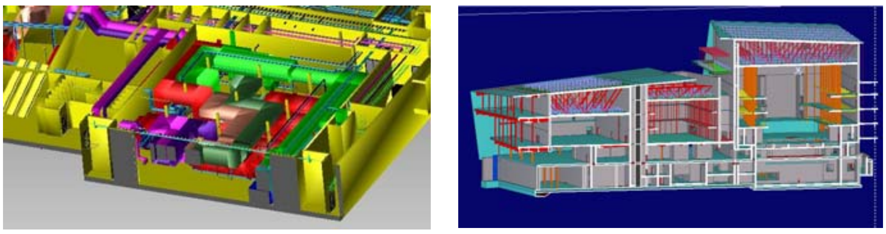

Figure 3. Left: view of the common model. Right: Visualization of structural systems, with the façade “reference shells”. (Courtesy: Rambøll Danmark A/S).

It soon also became clear that the seven information levels defined in the 3D work method project were difficult to handle in practice. Generally, the level of detail in the different 3D discipline models seems to depend on, for instance, the starting point of modeling, the software capacity, the skills of the user and not at least that the delivery to the contractor should mainly be based on traditional 2D drawings and details. The architects developing the building envelope soon realized that modeling the complete façades into detail would not only exceed the capacity of both the software and the user, but it would also be inefficient due to data exchange with the engineers. Thus, the architects established simplified “reference shells” of the façade, which are implemented in the discipline models and in the common model (Figure 3, right).

Several technical problems have emerged throughout the planning. The different software programs do not in all areas address the needs of the disciplines or the actual complexity of the processes. Through a narrow collaboration between the software vendors and the users of the software in the project, some of the most crucial problems are solved one by one. The main non-technical challenge in the project seems to be the different ambitions and possibilities of the architectural and the engineering company due to the use of the 3D object model. This situation has made the interdisciplinary coordination and the exchange of data between the architect and the engineer a challenging issue. An example from the exchange of data between the architects and the structural engineers in the summer of 2006 illustrates the challenges. The basis for the structural model would normally be the geometrical 3D "master-model" of the architect. In this case, the structural engineers had to build up a geometric model based on the architectural 2D drawings (Figure 2). Complete digital 2D drawings from the structural 3D model were not generated until the end of the design proposal, since the generation of 2D drawings from the structural model is a time consuming issue. The architects had to "transform" hand-sketches from the structural engineers into their architectural 2D drawings. Hence, both the architects and the structural engineers felt they had to do more work than necessary due to insufficient information delivery from "the other side."

Here an organizational aspect is additionally intensifying this challenge. Within the engineering company, the engineers normally have no CAD skills. They develop the concepts and systems based on hand drawings. Skilled CAD operators build up the 3D model. Although some few of the younger engineers are skilled within 3D CAD, indicating a generation shift, to change this situation will, according to the manager of the engineering disciplines, take time. In addition, building up CAD skills and competences is also a question of educational and organizational policies and strategies, both inside and outside the company. Within the architectural company, all architects are mastering 2D CAD. According to the manager of the architectural group, this is clearly the aim regarding 3D object modeling. However, until autumn 2006, there were few architects with such skills. Lastly, it seems to be a general challenge to implement new technology within the limited time and financial frames of this ongoing and very complex building project. Nevertheless, there is awareness among the actors that not all the aims defined in the 3D work method concept can be fulfilled in the CCC-project.

6. Stretching the Trousers Too Far?

During the development of the 'Digital Construction' implementation strategies, it has been criticized that implementing existing ICT-systems in the AEC-industry is a conservative rather than forward looking approach. There have been efforts within the 3D part of the program to develop and implement ICT concepts based on more advanced technology, where all participants work with "common core data" throughout all stages of the building project. This project stagnated due to several issues such as implementation problems in practice and coordination issues within the program. However, there is much activity and effort within research at architectural schools, universities and applied science units to develop more innovative concepts and technologies. A weighty argument for the chosen level of ambition was that only aiming for the "low hanging fruits" could be a proper match to the actual status of the industry. The first experiences from implementing the 3D work method concept into the CCC-project indicate powerful benefits of the technology, but there are still many challenges to be handled before all aims and visions can be turned into reality. There are several points to be mentioned, which impact the situation.

First, the initiative for introducing and testing out the 3D work method concept and 3D object models in the CCC-project came form the engineering company. It was not a client demand, not to mention that the client is not a representative of the Danish state as the program envisions. Thus, the 3D work method until now only has been implemented in the design team. In addition, neither extra time nor financial means have been made available for the implementation. The engineers and architects have to carry the risk of negative consequences. Moreover, the shortcomings of the technology are make the handling of the 3D object models complicated and time-consuming. Finally, most of the actors in the design team do not have previous experiences and skills working with 3D object models.

When transplanting the 3D work methods to Danish AEC-industry as part of 'Digital Construction' a number of training and support measures are set up in the socalled Implementation network (Implementeringsnetværket 2007). It is interesting to compare the situation in this project with the Norwegian pilot-project mentioned earlier in the paper. In the HITOS project the client demanded and supported the testing of new technology. Implementing the new technology was a part of the contract. The design team was already trained in building up information rich 3D object models although not in exchanging information or merging them into a common model.

The question how far the trousers can be stretched regarding the implementation of a national based ICT platform into real life projects seems to depend on an array of issues placed on different levels. Based on the analyses in this paper, at least three issues can be mentioned: the impact power of the initiator for integrating 3D CAD in the whole life cycle of the building project; the potential of the technology to address the actual needs inherited in the project processes; and the readiness and skills of the project participants, both regarding the use of the technology and in adapting new working methods and processes.

7. Conclusions

The explorations and discussions in this paper are placed in the complex and iterative field between strategies for integrating ICT on national level. R&D programs on macro-level, such as the 'Digital Construction', could contribute to bridging the gap between research and practice through convening societal and ICT development in the building practice and the focus on implementation. The experiences in Denmark indicate that the involvement of public clients is a possible strategy for integrating ICT in the AEC-industry. However, the tightrope act between developing proper strategies and deciding an appropriate level of ambition on the one hand, and the actual readiness of the industry for ICT integration on the other, is challenging. The balance requires a broad understanding of the mechanisms and relations on many levels in practice. Process evaluations and multi-level explorations of practice could contribute to such an understanding.

From January 2007, the Danish state provides a stronger push toward the integration of ICT and 3D object modeling in the Danish AEC-industry. Thus, in Denmark as also for instance in Norway and Finland, powerful players have brought the snowball to roll. The first experiences made in Denmark could be an important contribution to the crucial discussions about strategies and aims for a pro-active ICT integration within the trinity of architectural and engineering design: research, practice and education.

This paper has explored only a limited part of this large scale and complex R&D program. As this paper is written, the first Danish public clients are now providing projects where the Digital Construction program results are used in full scale. More than 50 projects are underway. The Danish 'Implementation Network' (Implementeringsnetværket 2007) shall ensure and support the further implementation of the program and its solutions after the R&D program ended in March 2007. The trousers might be stretched, but reinforcements are on their way.

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